Behavior simulation of a copper based shape memory alloy under an external solicitation

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Damping capacity of metallic materials represents an attractive property for many kinds of applications. Shape memory alloys present besides memory effect and super elasticity a high value of internal friction especially on martensitic transformation temperatures domain. Paying respect for material properties using simulation software nodal von Misses tensions were appreciate at external loadings. Input data used in this study were experimentally determinate using a dynamic mechanical analyzer. The results exhibit differences of behavior, especially values of internal nodal tensions, between metallic materials and in shape memory alloys case between material states given by temperature variation concerning the martensitic transformation range.

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1. Introduction

The vibration problem represent a serious concern in the modern practical applications and relaxation type IF (internal friction) at metallic materials becomes interesting for applications in the aerospace, transportation, and manufacturing industry. Internal friction at metals appear because of a big number of phenomena's which take place at microscopic scale and one or on other interfere more or less function of material nature.

Paying attention to the internal friction causes is impose to give up to internal friction name and replace with amortization like in English or German languages (damping, respectively dampfung). Among many damping mechanisms, the one utilizing the rapidly when the temperature is held at a constant martensitic/displace transformation in shape memory as Delorme's theory [1] predicts. During the past century physicians reach to establish equations from what to result the real behavior of metallic bodies at variable solicitations in time and especially about the relaxation phenomena's [2].

In recent years, shape memory alloys (SMAs) have started to attract increasing attention due to some of their dynamic properties. The hysteretic phase transformation between austenite and martensite at high temperature and between different twins of the martensite phase at low temperature constitutes an intrinsic dissipation mechanism, which results in a considerable damping capacity.

Graesser and Cozarelli [3] first suggested the use of SMAs as novel damping materials and Clark et al. [4] demonstrated the feasibility of the concept for a nitinol wire device. Potential applications are seen amongst others in civil structures like buildings and bridges where SMAs can provide an efficient seismic base isolation; see [5]. Using a design and simulation software was realize, based on experimental results, analyze of some metallic materials behavior under external constrains based on finite elements method. The results express the internal tensions comportment especially in network nodes under an external solicitation of the material.

2. Experimental details

The simulation was made based on results from technical literature and from experimental processes especially dynamical mechanical analysis.

The storage modulus E' represent the stiffness of a viscous-elastic material and is proportional to the energy stored during a loading cycle. It is roughly equal to the elastic modulus for a single, rapid stress at low load and reversible deformation [6].

The loss modulus E" is defined as being proportional to the energy dissipated during one loading cycle. It represents, for example, energy lost as heat, and is a measure of vibration energy that has been converted during vibration and that cannot be recovered. According to [7], modulus values are expressed in MPa, but N/mm^2 is sometimes used. The real part of the modulus may be used for assessing the elastic properties, and the imaginary part for the viscous properties [7].

Value E" named "loss modulus" represent an amortization term describing the energy dissipation capacity in heat when a material is deform and appear named imaginary modulus as a part of complex elasticity modulus, E=E'+E". Discovering metallic materials with damping properties improve all the resistance properties of the materials all ready in use like polymers. Among the prevalent high damping metallic materials, shape memory alloys (SMAs) could be one of the most promising candidates due to their high damping capacity arising from the reversible martensitic phase transition (MT) and the stress induced reorientation of martensite variants [8].

The analysis made through FEM is, today, indispensable in all engineer activities of high performance, assisted projection being a creative activity with many implications in other disciplines. To solve complex problems of samples and assemblies analysis the project engineer must have all information's which have to permit him wording the problem numerical way.

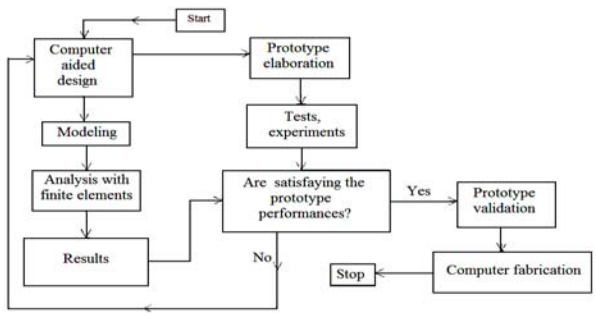

Fig. 1. Main components of an integrate system CAD-CAM.

Must be remark that in order CAD – FEM – CAM exist an iterative process for projection - calculus – execution. In this process are realized successively synthesis operations and analysis of prototype and o the model for finite elements calculus (Fig. 1) [9].

3. Experimental results

For simulation were use Catia drawing and analysis software used in automotive industry or other complex applications. Finite elements method represents one of the best existent methods for different calculations realization and simulations in engineering domain. This method and, of course the programs that are incorporate became base components of modern systems for projection assisted by computer.

One of the investigated materials is a shape memory alloy based on copper with chemical composition, determined with a spark spectrometer type Foundry Master, presented in Table 1.

Heating the material until 573 K the chemical composition does not modify so the properties of the material remain in big lines the same except the properties that modify in dynamic processes like internal friction.

The interesting differences of values for internal friction with temperature, for shape memory metallic alloys, variation are given by martensitic transformation characteristic for all shape memory alloys.

Table 1 Chemical Composition of shape memory alloy.

Cu %	Zn %	Al %	Pb %	Fe %	Sn %	Co %	Ni %
75.5	18.2	6,05	0.06	0.02	0.07	0.09	0.01

By transformation temperatures range point of view in figure 2 is represented the internal friction and storage modulus variations with temperature.

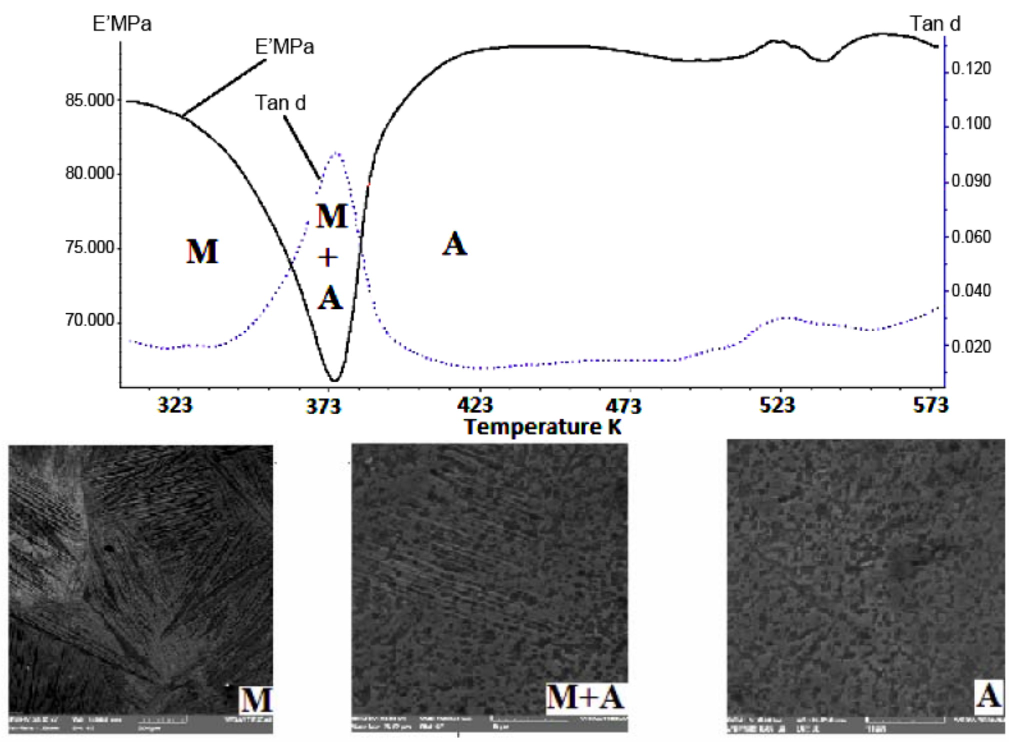

Fig. 2. Dynamic behavior of a copper based alloy with form memory with temperature variation evidencing the material microstructure in all three states martensite (M), martensite and austenite (M+A) and austenite (A).

Dynamic mechanical analyzer register the internal friction and elasticity modulus variation with temperature, all data – 700 values, information stored in a text file under table form or graphical expose like in Fig. 2.

In Fig. 2, in microscopes image, are presented the alloy microstructures in martensitic (M), martensite and austenite (M+A) and austenite (A) state observing in first picture (M) the martensitic plates, with different orientations based on grains orientation, a perceptual reduce of variant appearing and decreasing of them intensity is observe in (M+A) transition state and the total lack of martensite variants in austenite state (A).In figure 2 is observe a peak of internal friction in martensitic-austenitic field around 373 K temperatures. The storage modulus has a similar variation but inverse of internal friction decreasing from 85000 to 65000 MPa in martensitic transformation range. New variations observe in internal friction and storage modulus as well at 523 K is put on signal noise or different facts than solid phase modification type martensitic [10].

Simulations of material behavior pay respect for all experimental values and for plate shape as well. After this temperature range doesn't appear other peaks of internal friction or significant decreases of elasticity modulus.

For start, a usual material, an OLC35 steel, was investigated, based on material properties as Poisson rate of 0.30, storage modulus of 2.1 N/m^2, density 7800 kg/m^3, thermal conductivity 1.92 x 10^{-5} K^{-1} and maxim tension in elastically shape of 2.8 x 10^8 N.

Using the known properties and choosing a solicitation force, in all paper are presented cases with 5000 N force, simulation case were made on a plate as geometrical shape with precise dimensions of 100 millimeters long, 10 wide and 5 millimeters high presented in Fig. 3.

After the body shape was draw, using the dynamical module of the Catia software, can be analyzed the behavior of the material, in this case the force applied in fourth points, like in figure 3. In the same time the piece must be constrained, thinking at the dynamic process that is realize, the points can be choose freely or in different locations from case to case.

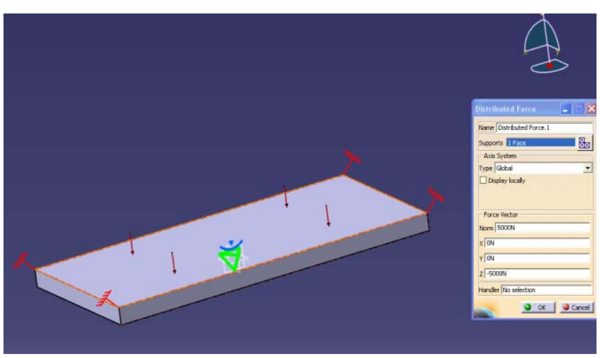

Fig. 3 Plate form with edges restrains and force applied.

Simulation result, the behavior of the plate under solicitation, is shown in figure 4, where the area was discretized under a mesh of nodes, according to von Misses stresses. The material exhibit minimum values of internal tensions within 9.8 x 10^7 and maximum 1.36 x 10^8 N/m^2. The electronically results present, for any point from the material surface considered node, the tension value. By this kind of analysis can be represent the dangerous areas like fracture supposed as well.

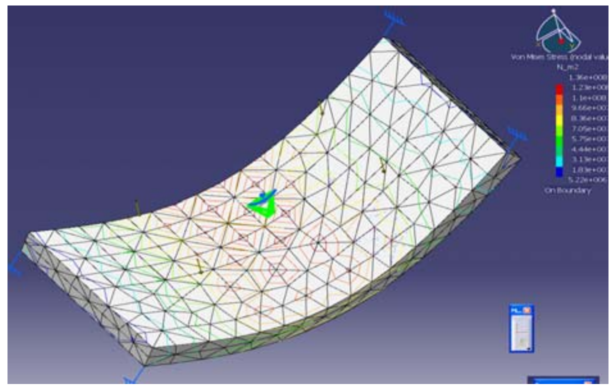

Fig. 4. Tensions Von Misses in nodal points for a metallic material, steel at a 5000 N load.

Trying to reach a correct simulation analyze of the shape memory alloys next was analyze an alloy based on copper, an ordinary brass having the main parameters with specific values of the material like in first metallic material case, Poisson's ratio value of 0.35, the storage module of 1.31 N/m^2, density 8216 kg/m^3, thermal conductivity 1.67 x10^{-5} K^{-1} and the maximum tension in the elastic state of 3.5 10^8 N. Using the same shape of the analyzed piece, usual conditions and same force to flush the request were obtained by finite element method of stress values, with lower von Misses values occurring internal mesh nodes with minimum values of 1.16 x10^7 and respective maximum 5.22 x10^8. Based on the results on a dynamic mechanical analyzer (DMA) particularly the storage modulus values, the virtual analysis were performed of a shape memory alloy type Cu-Zn-Al. The small amounts of other elements are elementary for good damping properties [11].

Analysis of this material was observed in storage modulus variation with temperature, achieving lower values in areas where the martensitic transformation increased internal friction. The results obtained are internal nodal von Misses stress values with minimum 1.16 × 10^8 and maximum 1.5x10^6, mesh distribution presented in Fig. 5, showing a decrease of minimum stress primarily due to lower value of storage module.

Further virtual experiments analyze the same Cu-Zn-Al shape memory material in the same conditions but introducing the storage modulus values for different temperatures respectively 362.73028 K and 348.23028 K while material achieve the value of storage modulus of 0.0598286 respectively 0.047556 N/m^2.

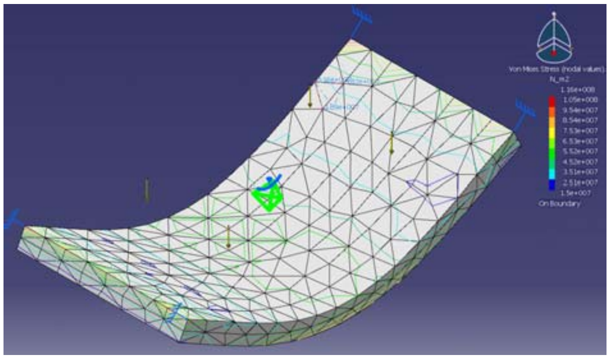

Fig. 5. Tensions von Misses in nodal points for a shape memory alloy from copper – zinc – aluminum system with chemical composition presented in Ttable 1.

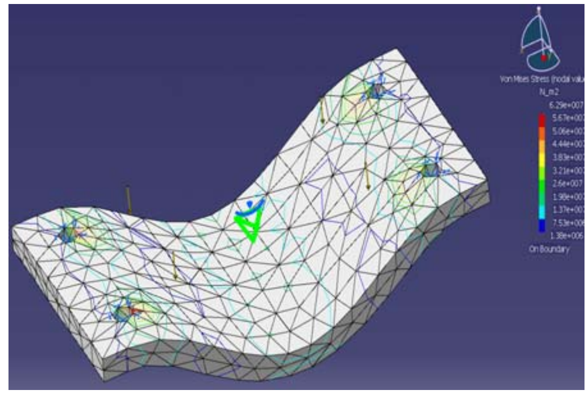

Fig. 6 Tensions Von Misses in nodal points for a shape memory alloy from Cu-Zn-Al with holes on the edges.

The conditions for applying a force of 5000 N have been minimal tension on the borders of the structural model of 1.05 x10^6 N/m^2 and respectively maximum of 7.5 x10^7 and 6.2 x 10^8 N/m^2, values lower than the von Misses stress in other cases mentioned above. The result present an actually achieving a shape memory alloy which in addition to this special property performs fifteen times better external demands in terms of internal stresses that occur due to changes in material part of the module storage temperature.

For practical applications in various frameworks and support systems have been investigated and several effective methods of trapping or connecting these materials, the first version of opting for a four screws fastening the ends located at distances of 5 mm from the head or to the edges, presented in figure 6. Result of simulation behavior of the material provided with four fixing holes and tried to an external force of 5000 N is shown in figure 6.

Designing a fixing system with four screws for attaching external plates change the behavior of the tried plate under external forces yielding nodal von Misses stress at minimum of 1.3 x10^6 and respectively maximum of 6.2 x 10^7 N/m^2. The band behavior simulation with fixing holes under the action of external forces requires further analysis in a general case it usually encountered in practical applications.

In this respect were analyzed three different situations where damping materials type steel, brass standardized or a Cu-Zn-Al shape memory alloy were analyzed. Immobilization of connections made on plates, all to be improved in terms of vibration damping, are achieved by using the proposed attachment and accomplished by fixing holes subsequently analyzed. Initially examined a set of steel tapes, item to be depreciated, the band heads and the element of shape memory alloys with high damping capacity in the middle. Determinations showed good behavior of the combination of low achieving internal nodal von Misses stress with minimum values of 1.02 x10^7 and maximum 9.17 x10^7 N/m^2 considering the shape memory alloy in martensitic state.

In the same test conditions, using the properties of the alloy registered during the martensitic transformation range, with the previous assembly and above properties were obtained minimum value of internal tension nodal von Misses minimum of 6.13 x10^6 and maximum 6.81 x10^7 N/m^2.

Besides the four screws fastening system is proposed and a mechanical grip on the long ends, the system shown in figure 7. Restrictions of movement and external forces applied are shown in Fig. 7. Experimental data was performed using a simulation model of the active element in the overall behavior of the alloy proposed exploratory Cu-Zn-Al in martensitic state, the storage modulus value recorded at room temperature.

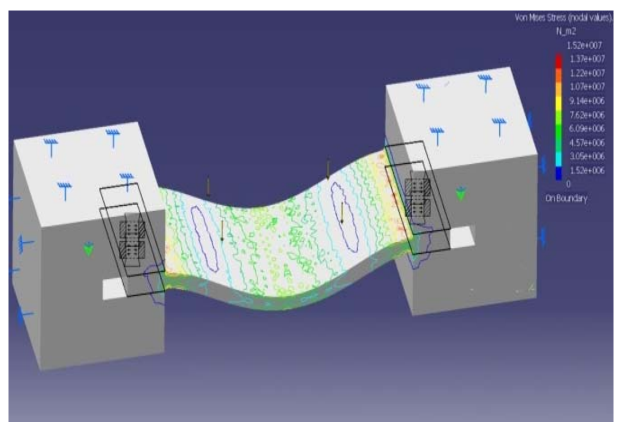

Fig. 7. Tensions Von Mises in nodal points for a shape memory alloy from Cu-Zn-Al mechanical connecting system on the plate edges

Experimental results present the minimum values of internal stress 4.73 x10^6 and maximum values of 5.95 x10^7 N/m^2 achieving a ten to fifteen times better behavior of these materials over conventional materials in the overall design.

Resulted nodal internal stresses that occur using the experimental material presented CuZnAl minimum value of 1.52 x10^6 and maximum 1.52 x10^7 N/m^2, low values comparing to those using conventional building materials.

4. Conclusions

Along with other metallic materials a shape memory alloy based on copper – zinc – aluminum was analyzed by internal friction point of view and experimental results were used to simulate, through finite element method, the material behavior at external forces solicitation. Internal tensions, von Misses type, on discretization network nodes were determinate for different metallic materials paying respect for them properties especially the complex elasticity modulus.

Low tensions obtained on martensitic temperature transformations range reveal the damping capacity modification, shown experimentally as well, comparing with martensite or austenite states of the shape memory material.

The shape memory alloy, based on copper analyzed in this paper, behaves, in martensitic transformation domain, fifteen times better than a usually metallic material like steel or ordinary brass at extern solicitations by internal von Misses tensions point of view.

Simulating the behavior of different alloys or materials in terms of external demands lead to the determination of a material that performs much better in foreign demand due to high internal friction property that holds the field alloy martensitic transformation.

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