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THE CHEMICAL AND METALLURGICAL ANALYSIS OF COOPER-BASED SHAPE MEMORY ALLOYS

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ABSTRACT

The paper presents some aspects on the thermo-mechanical fatigue of shape memory alloy, a documentary synthesis of their industrial applications and chemical aspects concerning the use of these alloys in biomedical applications.

KEYWORDS: shape memory alloys; biomaterials; thermal fatigue; corrosion

1. Introduction

The fatigue of metals is the phenomenon which provides the cracks in different applications, in the conditions of temperature and work parameters variations. The thermal tensions are induced when the dimensions vary for a part due to the temperature change [1, 2].

In the case of equipments which work at high temperatures, the conditions to appear the cracks due to thermal fatigue are created. The behaviour of materials at thermal fatigue is influenced by the structural transformation effects and the mechanical properties.

The mechanism of defects accumulation in the crystalline network and inside the grain, due to thermal fatigue lead to creating the tension local zone, where a crack may appear. The cracks due to thermal cycles is sometimes associated to network tension by blocking the dislocation, which are moving inside the grain matrix, specially, due to mechanical or thermo-mechanical tensions which appear. The cracks by thermal fatigue are initiated along the surface. Because the cracks are initiated from the exterior, the corrosion process and oxidation along the surface of thermal fatigue cracks, it is inversely proportional with the crack depth [3, 4].

For producing a crack by fatigue three base factors are necessary:

- A maximum normal tension with a high value;
- A large enough variation of applied tensions;
- A large number of cycles for applied tension.

The cracking process develops slowly; the cracks propagation speed is progressively increased, reaching the moment of crack. The process takes place so fast, like in the case of static cracks for fragile materials, without producing a visible plastic deformation.

The cracked surface presents two zones: the old crack and the new crack. The old crack has a smooth and sometime shiny aspect. The new crack is characterized by irregular aspects, with high granulation, that proves a breakable character of cracks.

2. Results
Thermo-mechanical fatigue of shape memory alloys

In the case of metallic parts made of shape memory alloys, the possibility for the thermal or thermo-mechanical fatigue to appear does exist.

The mechanical fatigue involves the crack production in four stages: the accumulation of defects, the crack formation, crack propagation in stationary and un-stationary regime and respectively final break.

The main method to increase the resistance of mechanical fatigue for shape memory alloys is the granulation finishing, which may be realized by alloying, energy quenching and powder metallurgy.

The thermal fatigue is related to the irreversible formation of defects, which lead to a considerable hardening, in the case of binary bi-phase brasses, like (Cu-40%Zn).

In the case of shape memory alloys, Cu-Zn-Al type, should be noted that the mechanical cycling affects the critical temperatures of transformation, but much more reduced than thermal cycling.

Figure 1 presents the surface of Cu-Zn-Al alloys, with fatigue cracks.

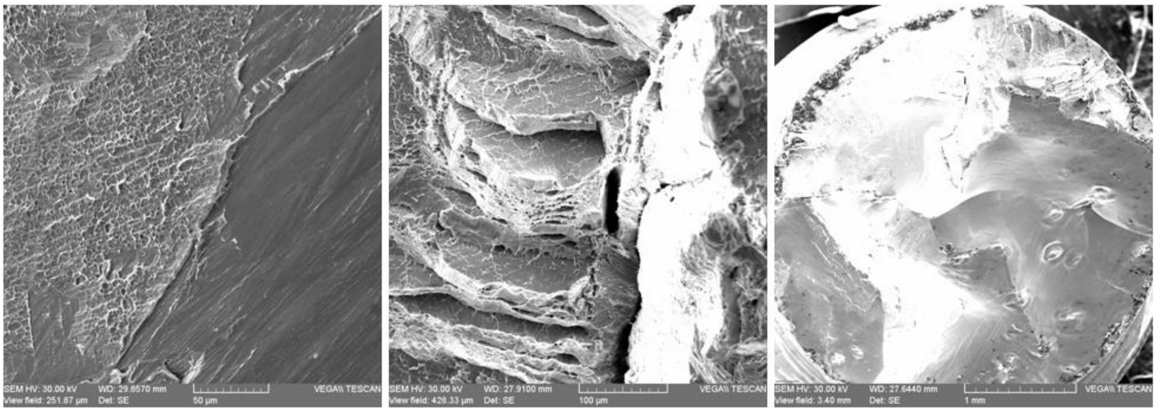

Fig. 1. *The aspects of cracks for a shape memory alloy, Cu-Zn-Al type, by thermo – mechanical fatigue on different magnifications 1000X, 500X and 100X*

The cracking by fatigue is the phenomenon which leads to break under repetitive tension or fluctuating, which are lower than the elastic tension of material.

The cracks at fatigue are progressive, with little cracks at the beginning, which increase under the action of fluctuating tension. The shape memory alloys are sensitive at fatigue.

Much more than that, the phenomenon for the classic crystalline materials, the shape memory alloys have some additional mechanism of linking at the change of phase which characterizes them.

It is found that the observed type of crack depends on the applying mode for mechanical fatigue.

The improving of life duration for these materials imposed the decrease of level for internal tension at grains limits and the increase of cracking resistance.

For obtaining these results, we can realize:

- the increase of grains measurements, decrease the measurements for martensite plates;
- the generation of laminated texture, which can reduce the differences of orientation between the grains, for reduction of the incompatibility for deformation;
- the possibility to obtain the plastic deformation at the level of grains limits appropriate also by the deformation efficiency.

Medical applications for shape memory alloys

Many types of shape memory alloys are known, but most of them are expansive due to the noble and rare metals use, also due to the complex obtaining technologies. The most interest is represented by the alloys like: Ni-Ti, Cu-Zn-Al and Cu-Al-Ni, which may be used in medical practice applications [4-9].

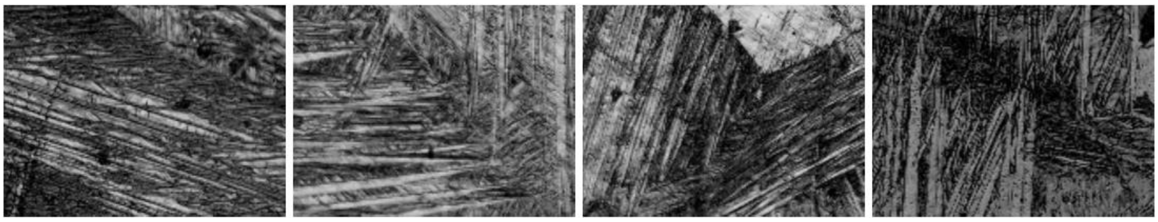

Fig. 2. *Optical microstructures for Cu-Zn-Al shape memory alloy; martensite structure (200X)*

The study of shape memory alloys has determined a development of the research in different activity domains, in the order to find the corresponding applications. At present, these alloys are used in the industry of aeronautics, aerospace, mechanical, electronic and medical technique. These materials are obtained in laboratory conditions, in order to certify the characteristics necessary in exploitation. In each of these cases, the parts made of shape memory alloys should be thermally treated (heating and cooling), to realize the proposed objective. Between the heat shape and cold shape an energy difference exists. The reversibility of the changes for the two shapes is the base for multiple applications. In this case, of great importance is the exact reproductivity of the two shapes. After some cycles of function, this is affected and so are affected the properties of shape memory.

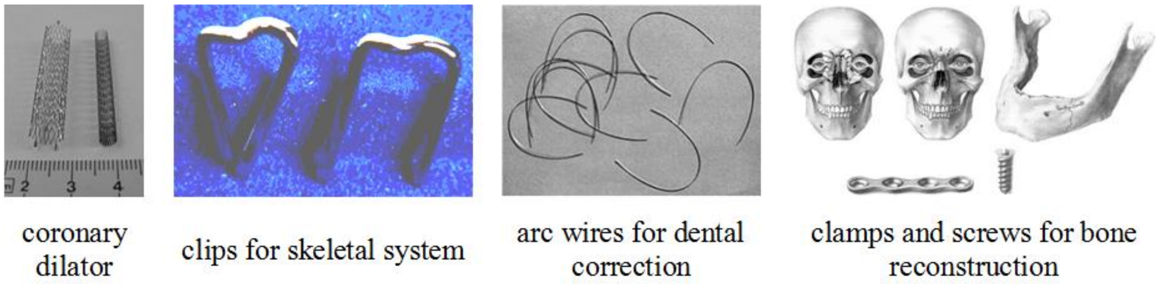

Fig. 3. *The medical applications for the shape memory alloys* [14]

Porous materials made from shape memory alloys, are also important, and they are used in various medical fields to replace some bone parts.

In time, these parts will be embedded by the human body, by the development inside the pores of the organic cells characteristics to bone system. In this way, the micro-prostheses make common body with the body cells and it is integrated in bone system, where adverse reactions should be limited.

The porous materials used in the medical field for prostheses present a good biocompatibility and elasticity, imitating the behavior of the bone part which is substituted.

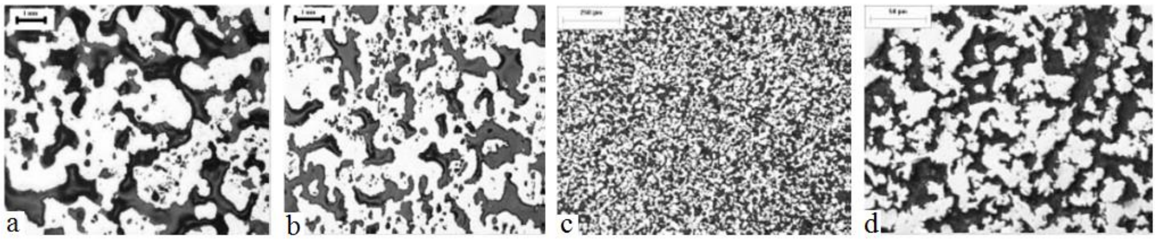

Fig. 4*. Optical micrographs on porosity of materials: a and b - large pores: porosity 42% (250X); c and d - big pores: porosity 50% (100X, 500X)* [15]

For the dental materials used to fabricate the prosthetics devices, a high diversity of metallic alloys is distinguished. The diversity was made in the direction of developing new materials with superior properties, but with lower obtaining costs. The cooper based alloys, were promoted like dental materials, for economic reasons, due to the increase of noble metals costs. In some countries of Europe, the alloys based on cooper are consider incompatible with the qualities of biomaterials used in prosthetics and are presented as materials with allergic risks and low resistance at corrosion [10-11].

Cooper and its alloys are recognized like materials with a good corrosion resistance and are used in many activity domains.

The good resistance of these materials is related to the formation of a uniform and adherent film on surface, which protect the substrate to the environment.

The appearance of the corrosion phenomenon is related to the formation and stability of this film; if the film is not formed or it is destroyed, the metal is corroded, either the entire surface, either locally.

The copper is an essential metal for living organisms, but too much cooper may be harmful. From this reason, the toxic effects of cooper alloys may be confirmed when these alloys were implanted subcutaneously or intramuscularly.

The date analysis shows clearly that these materials lead to modifications of tissues, like necrosis and inflammation. The cooper may have a chemically modifying role, inducing the carcinogen activity much more than nickel.

Chronic poisoning with cooper is a controversial problem and it frequently is related to muscle pain, hypertension, various neuro-psychological phenomena or hair loss. However, the World Health Organization considers the cooper to be a non-toxic metal.

3. Conclusions

The approach presents the correlation between the technological parameters which influenced the appearance of thermal fatigue phenomenon and the properties specific to metallic material with shape memory.

The copper-based shape memory alloys, may be used like biocompatible materials for the human body, just after the corrosion tests in different mediums which simulated the liquids from the human body.

Also the manufacturing of parts from the shape memory alloys must take into account the fact that the fatigue phenomenon may appear in the exploitation time, concretized by the degradation of shape memory effect.

These characteristics for shape memory alloys permit their use in smart structures, micro-actuators, some advanced composites, medical components and dental implants.

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