COMPOSITE SHAPE MEMORY ALLOYS FOR METALLIC STRUCTURES

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Abstract: Shape memory alloys exhibit nice and interesting properties based on them internal solid state transformation from martensite to austenite under temperature modifications. Damping capacity represent one of the latest attraction of shape memory alloys based on them big internal friction values having applications in many domains as dissipaters, dampers or structural elements for noise and vibrations attenuation. Composite with metal matrix materials represent interesting materials that use both materials properties. In this study a shape memory alloy composite material is analyzed by his interface between SMA matrix material and a steel reinforcement element point of view. Using scanning electrons microscopy and EDAX analysis few results were obtains and comment to establish the interface nature.

Keywords: *shape memory alloy, composite, diffusion*

1. Introduction

Among the various types of composites, the family of discontinuous metal matrix composites (MMCs) containing particulates, whiskers, wires, precipitates, fibers, nodules and platelets, are favoured because they offer improvements to the mechanical properties of the monolithic alloys while remaining relatively easily deformable. Metal matrix composites are compound materials whose microstructure consists of a metallic alloy into which a particular reinforcing component is introduced. MMCs offer advantages in applications where low density, high strength and high stiffness are a primary concern. The availability of various types of reinforcements at competitive costs, the feasibility of mass production and high damping capacity [1,2] make this type of MMC, metallic matrix and wires as reinforcement elements, more attractive. However, these materials may suffer from inhomogeneous distribution, size or shape of wires, low ductility, inadequate fracture toughness and inferior fatigue crack growth performance compared to that of the matrix [3,4].

To optimize the mechanical and physical properties, in particular the damping conditions and damage tolerance of such materials one can utilize shape memory alloys as reinforcement. Shape memory alloys (SMAs) have received great attention because of their shape memory effect (SME) and many investigations are conducted on their basic performance and applications.

The transformation under compression can result in stress in the matrix, which in turn enhances mechanical properties such as yield stress [5–10], fracture resistance [11,12], an capacity of suppression of crack growth [20] and thermo-mechanical fatigue [9,13]. Two SMAs which generate large amounts of strain and are capable of generating a large force upon transformation back to the austenitic phase are NiTi alloys and Cu-based alloys. Copper-based SMAs are particularly interesting because of their low-cost and relative ease of processing. On the other hand, NiTi alloys tend to be more thermally stable and to have a lower density, higher yield and ultimate tensile strength; they are also more resistant to corrosion than Cu-based alloys [14].

Traditional restoration techniques often do not give structures sufficient resistance against maximum expected earthquakes and/or might be too invasive. Therefore, there is an ongoing effort to find techniques that can guarantee structural stability and at the same time respect the integrity of the structure. Special devices that exploit the superb damping properties of Shape Memory Alloys (SMA) are under development. SMAs have found applications in many areas due to their high power density, solid state actuation, high damping capacity, durability and fatigue resistance. When integrated with civil structures,

SMAs can be passive, semi-active, or active components to reduce damage caused by environmental impacts or earthquakes.

Though most of the research activities of SMAs' applications in civil structures are still in laboratory stage, a few have been implemented for field applications and found effective [15-19].

Having a composite material with a metallic matrix of a copper based shape memory alloy in this study were analyzed some concerning about the metallic interface nature. The results present a highly well form interface between the matrix and reinforcement element, both metallic materials that improve the mechanical behavior of the material.

2. Experimental details

To obtain the shape memory alloy based on copper for the composite matrix was used a laboratory furnace with graphite crucible using copper, zinc and aluminum high purity materials with reduce percentage of iron [21].

After the matrix were melted, the liquid alloy, was poured in a special semi-form prepared for arch material reinforcement element stabilization with the geometrics and main elements presented in figure 1.
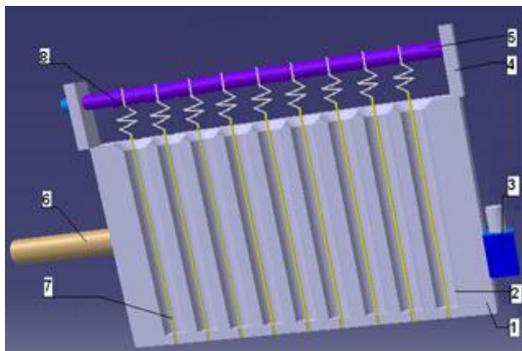

Figure 1: *Composite realization semiform having the elements: 1-metallic body form; 2-cylindric cavity for reinforcement element fixation and matrix body form; 3-articulation; 4-rod suport for arch fixation at extension; 5- rod used for supporting the extension arches for wires; 6- hand support, 7-reinforcement fiber; 8-arch used for metallic fiber extension*

Each melting provide material for nine samples with different materials as reinforcement element if is necessary or similar like in this case.

In figure 2 is presented the geometrical shape of the composite samples obtained and further analyzed.

Figure 2: *Catia software design of the shape memory based composite*

Chemical composition was determined through spark spectrometry analysis using Foundry Master equipment (for matrix and reinforcement elements chemical analysis) and EDAX analysis as well for interface study. In this study different EDAX software applications were used to determine the chemical variation of the elements on Line, Mapping or Point mode with automatic or element list considerations.

Microstructures of the composite in different heat treated states of material were obtained with a scanning electron microscope (SEM) LMH II by Vega Tescan brand using a secondary electrons (SE) detector at a 30 kV lamp power supply.

3. Experimental results

A composite material made by CuZnAl shape memory alloy as matrix and arch wire steel as reinforcement element was obtain by classical melting method.

Composite material surface was analyzed using a scanning electrons microscope to observe especially the interface between those two metallic materials that form the composite. From microstructure images, figure 3 a) and b), can be observe that a thick interface is formed in composite after the material suffer a 30 minutes homogeneous thermal treatment.

A proper chemical attack of CuZnAl and Fe-C alloys to evidence both microstructures is difficult, as can be seeing from figure 3 were only the interface is marked better, interface based on aluminum compounds. On the matrix some formation of martensite variants can be seeing and on reinforcement element no microstructure is evidenced.

Microstructural analyses represented in figure 3 evidence an interface formed between the shape memory matrix and the elastic element with different dimensional areas and relatively straight.
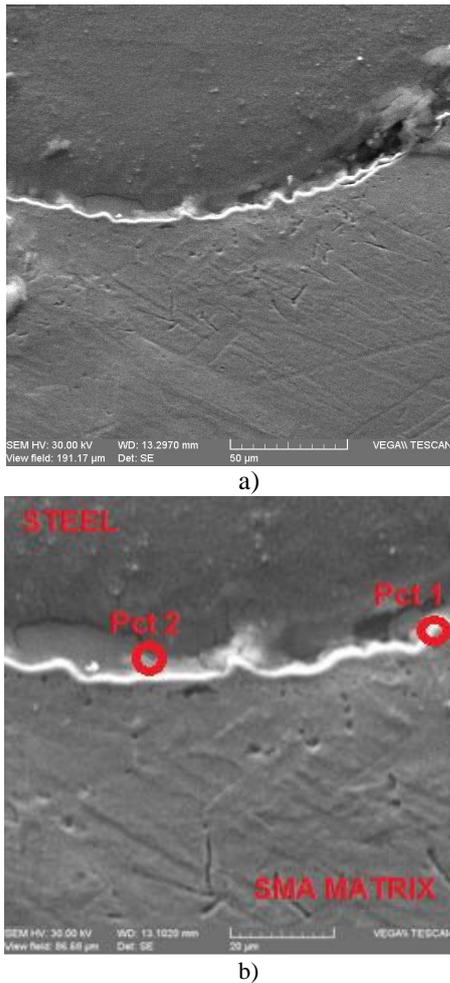
a)

b)

Figure 3: *SEM microstructure of the composite material a) 1000 x power and detail b) at 2500x*

The interface dimension is around 1-2 µm with areas modify as inhomogeneous.

In figure 4, on a selected line presented in a), is represented the chemical elements copper, zinc, aluminum, iron, manganese and silicon distributions. The selected line represents the elements distributions on matrix, the reinforcement element and interface as well in the same time. The line selected is of 20 µm perpendicular on the border area and evidencing the mass transfer type at the interface.

In figure 4 b) is presented a complete chemical analysis of the elements variation between matrix and reinforcement element with accent on the interface. Can be observed a diffusion type material transfer between those two metallic alloys. On the interface area formation of some new chemical compounds are observed as $FeAl_3$ and a migration of elements characterize the interface find a higher aluminum percentage on the steel part than the shape memory alloy material were a loss of aluminum is observed.

In figure 4 b) the interface areas is analyzed through mapping elements technique as well marking the aluminum conglomeration on the interface, a separation layer on the interface and the loss of Al element from the matrix. Silicon element is also presented on the border forming different stabilization compounds like $AlSi_2$.

a)

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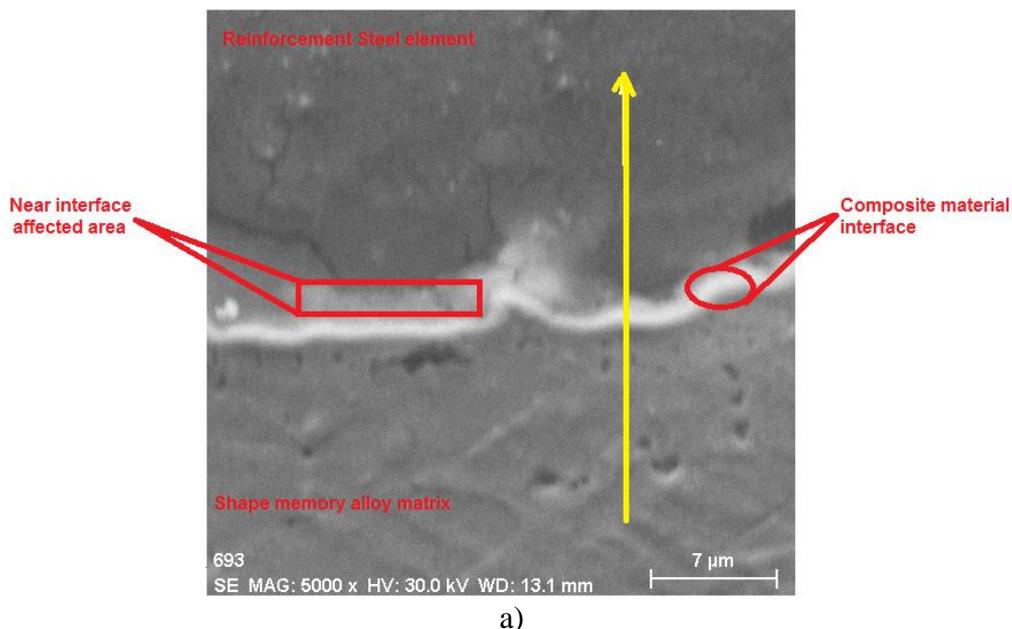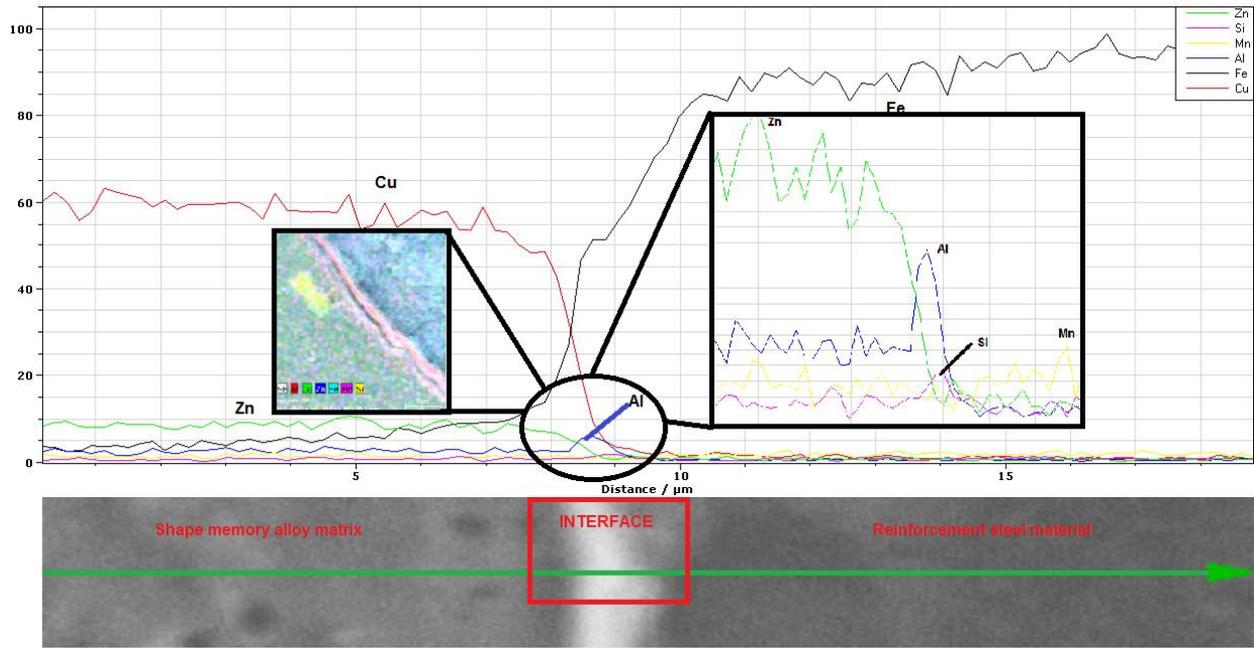
b)

Figure 4: *Composite material interface area analysis a) selected area for analysis and b) distribution of elements on the interface area*

In figure 3 b) two points were selected for chemical composition investigations the results being presented in table 1 and table 2 for Pct 1 and Pct 2. First point is selected on the interface and the second one near the border on the reinforcement element part. Even the first point is situated more to the matrix part the iron element has a very high percentage presence based on diffusion process movement of the elements. Aluminum is also present having a FeAl based interface. The other elements participate at the interface formation in smaller percentages and loosing in front of the iron aluminum compounds as X-ray signal and quantitative percentages.

Table 1: *Chemical composition of the interface in point 1 selected in figure 1 b)*

Element	AN	series	Net	[wt.%]	[norm. wt.%]	[norm. at.%]	Error in %
Iron	26	K-series	99081	71,50894	81,84484	75,4816	1,844726
Aluminium	13	K-series	8076	6,7355	7,709049	14,71579	0,381417
Copper	29	K-series	5054	5,971241	6,834324	5,539327	0,197696
Zinc	30	K-series	1144	1,479678	1,69355	1,333941	0,084248
Silicon	14	K-series	1761	1,102398	1,261739	2,31386	0,086212
Manganese	25	K-series	921	0,573593	0,6565	0,615477	0,084937
			Sum:	87,37135	100	100	

Table 2: *Chemical composition of the interface in point 2 selected in figure 1 b)*

Element	AN	series	Net	[wt.%]	[norm. wt.%]	[norm. at.%]	Error in %
Iron	26	K-series	120555	80,01884	91,8602	89,77184	2,05754
Copper	29	K-series	3090	3,256238	3,738104	3,210522	0,127146
Aluminium	13	K-series	1858	1,924301	2,209063	4,46842	0,141725
Zinc	30	K-series	701	0,820734	0,942188	0,786391	0,063644
Manganese	25	K-series	1126	0,611817	0,702355	0,697745	0,088394
Silicon	14	K-series	655	0,477439	0,548092	1,065084	0,057611
			Sum:	87,10937	100	100	

On the other part of the interface, at the reinforcement element side, copper is diffused in a reduce percentage of 3.738 % wt but higher than the copper presence in the arch-wire steel material.

Silicon element decrease as well in percentage comparing to the other side of the interface fact that represent a smaller formation of silicon based compounds. Mechanical tests of the composite material with present the material behavior, interface modifications and material properties as damping element.

4. Conclusions

A composite based on a shape memory alloy matrix were obtain and analyze by the interface formation point of view. The reinforcement element proposes was a steel archwire with 1 mm diameter. The interface between those two metallic materials was between 1 and 2 µm thick especially based on FeAl compounds. In formation of the interface diffusion process interfere with accent on aluminum and silicon elements decreasing the copper and zinc percentages. Interesting variations of chemical elements distribution can be observe on the border between materials anyway a nice bond between the metallic materials was created.

Acknowledgement

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