OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 4, No. 12, December 2010, p. 2028 – 2031

Electrical behavior of a smart Nitinol spring under full time constrain

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Usage of shape memory alloys (SMAs) in mechanical work applications is influenced by electrical control system and parameters, material properties and environment factors. Determining the thermal behavior of a nitinol material (Nickel-Titan alloy) with a scanning differential calorimeter (DSC) and analyzing the mechanical and electrical responses on a testing laboratory equipment can be observe the spring behavior on different numbers of cycles. The control of material actuation is made through electrical parameters variation with nice results in different work regimes.

(Received November 1, 2010; accepted November 29, 2010)

Keywords: Shape memory alloy, Differential scanning calorimetry, Actuation

1. Introduction

Shape memory alloys are functional smart materials characterized by shape memory and superelastic effects (SME and SE). SMAs as actuators are well known as they are silent in operation, simple to operate, light in weight, and capable of developing large strains, to mention a few. SMA actuators possess high energy density, in the order of 107 J/m^3 [1], which is the highest among the presently known actuation principles. Among the many types of SMAs, the nickel–titanium and copper based alloys [2] has attracted many researchers due to its superior mechanical properties. It is characterized not only by good mechanical and thermal properties but also by excellent biocompatibility compared to other SMAs. Commonly, the nickel–titanium alloy is abbreviated to NiTi or nitinol. NiTi shows complex mechanical behavior that is dependent on the stress, strain, temperature, and production process. Thus, there have been many studies that have investigated the mechanical behavior of NiTi. They also have drawbacks such as hysteresis effects, high power requirements and control difficulties. In spite of all these limitations they are widely used in robotic arms, parallel mechanisms, endoscopic devices, heart valves, stents, orthodontic devices, surgical instruments etc. [3,4]. Mostly, SMA actuators have been integrated with a rigid or a compliant structure to exploit their shape memory and superelastic effects. Earlier researches had been focused on embedding the actuator inside the structure [5–7] so as to make a composite part.

The purpose of this study was to establish some electrical parameters of a shape memory alloy behavior under external forces action and to present the observations concerning the characteristics evolution under solicitation cycles.

2. Experimental setup

In order to conduct an electrical behavior analysis of a nitinol shape memory alloy wire, as 0.7 mm in diameter, were used few electronic equipments based on temperature and displacement analyze. The spring power supply was achieved using a current-controlled voltage source with two channels, having 30V/3A per branch and the electrical signal was controlled by a timer (based on a relay) to achieve different numbers of heating-cooling of the SMA active element. Temperature was recorded using a specialized device, class one of precision, having the thermal probe glued on spring to achieve correct registrations and experimental data recorded on a computer through serial connection port.

Action and reaction of shape memory element at changing temperature by Joule effect has been discussed in various working conditions using an external solicitation (a weight of 300g) to extend the spring when the material is in austenitic state resulting in movement and return by increasing the temperature in martensitic range. The element of shape memory alloy actuator (nitinol) has a length of 25 mm represented all four coils active and activated through a clamping system of electrical connectors, in the martensitic state of the material, and a length of 50 mm in the austenitic state of the material (room temperature) under the influence of gravity force applying under weight to shape memory element.

To highlight the martensitic transformation causing the memory effect of the actuator in the form of helical spring thermal analysis method was used by differential scanning calorimetry (DSC) [8]. Calorimeter used in the experiments is a calorimeter F430 MAYA with a maximum working temperature of 600 ºC and a maximum heating rate of 10 degrees Celsius per minute, which is endowed with SIM faculty. In this way we can investigate the starting point of transformation As (critical point when austenitic transformation began) and Af critical point (temperature at which the whole structure becomes martensitic).

Was analyzed the behavior of a shape memory alloy NiTi-based (nitinol) as marketed by the company arc educated Saes [9] to get an active element to use in practical applications such as gear type pieces.

3. Experimental results

The experiments were focused on some electrical parameters of the shape memory alloy behavior for applications to obtain the characteristics of their practical use primarily as a force capable of driving both austenitic and martensitic state of the material. A time evolution of the active element was also developed to highlight the influence of external factors on the evolution of the arc shape memory. Measurement of thermal behavior of the material were originally made by taking two pieces of thermo-mechanical loop coil spring, one in the middle of an active element, coil two on one from the end of shape memory element. The thermogram obtained as shown in Fig. 1) represent a characteristic endothermic peak on heating product of austenitic transformation. Looking more in detail the thermogram obtained, we note that the first derivative of heat flow against time (Fig. 1b) dashed curve reveals the existence of two very close peaks that can not be easily detected in Fig. 1a.

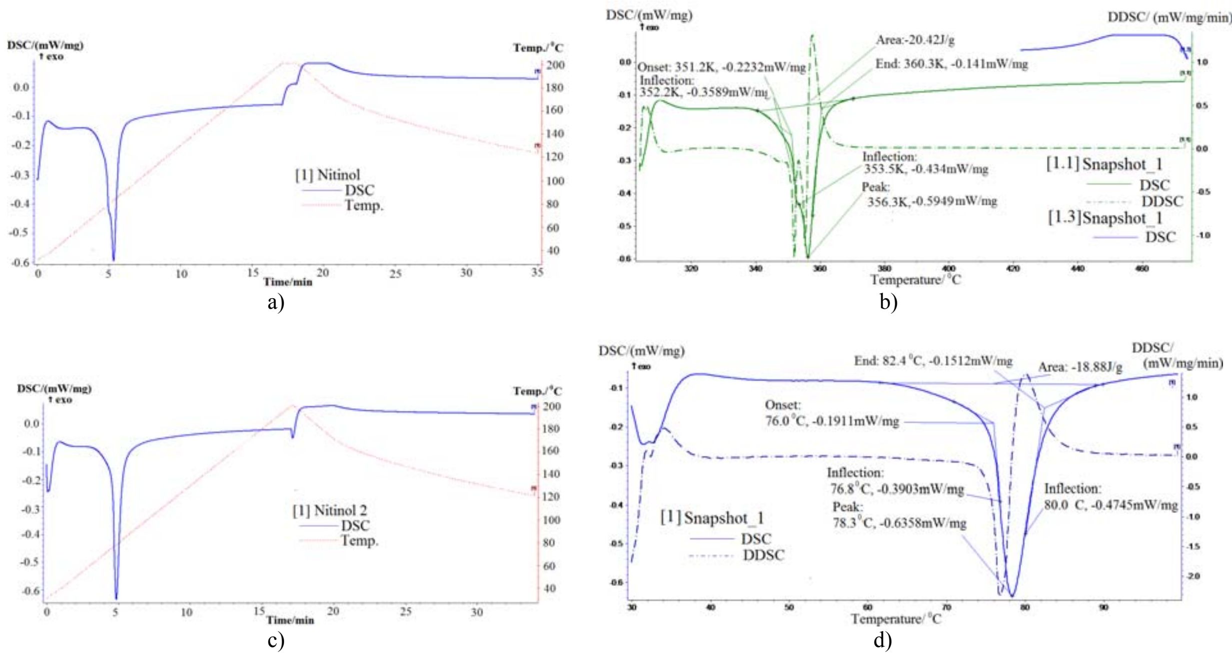

Fig. 1. Thermal behavior analyze of a shape memory alloy NiTi a) and b) the analyze took place on two materials parts from different sides of the spring having a 30 mg weight and in c) and d) the results are made on a single piece of material from the middle part of the spring.

Two hypotheses have been issued based on the results expressed in Fig. 1 a) and b), first on the fact that the alloy has a pre-martensitic transformation typical for alloys NiTiCu or the two peaks are caused by mechanical and thermal history of the two fragments of different subject analysis. To explain the phenomenon repeated test of calorimetric (DSC) were done using a single piece of shape memory alloy also collected from the second spiral of the actuator. As shown in Fig. 1c) the DSC-time variations and in Fig. 1d) modification of temperature DSC to obtain a single peak which confirmed the second hypotheses case the different thermal-mechanical solicitation according to the actuators requested item. Rating curve using the software specifically of DSC equipment is shown in Fig. 1d). The assessment shows that the values of two critical points are: As = 76 °C and Af = 80 °C. So it is possible to determine the transformation hysteresis as Af-As = 4 °C, a very low specific heat range that is a certificate of quality memory alloy used in applications such as precision of robotics.

In Fig. 2 are presented the results of tested shape memory element behavior under, find on continuous action of a load of 300 grams, in two distinct phases by applying different values of current (at constant voltage). The temperature variations are plotted versus time under varying conditions of application in this way in the first case to apply a voltage of 10 Vdc and current limited to 3A, which led to a gradual heating from ambient temperature value ambient (20-25 °C) to a high value area of mechanical work. In this way is highlighted the relationship between temperature and time required shape memory material to reach maximum clamping position (complete martensitic transformation). A variation of 25 mm in 45 seconds of heated element making an active stage was obtained and putting the shape memory element under the action of an electric current in 5 seconds and 40 seconds time for cooling. Times were adopted on the basis of material characteristics, particularly thermal and electrical conductivity, but also taking into account the thickness and mass weight of the spring wire used.

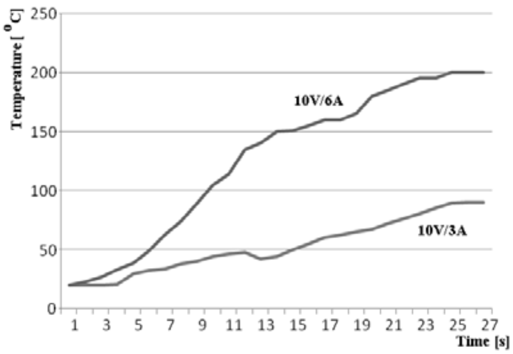

Fig. 2. Spring shape memory alloy behavior under different electrical activation regimes a) 10V, 3A and b) 10V, 6A.

After the upper threshold martensitic transformation memory actuator heating continued but is not accompanied by a change in actuation element length.

The experiment was repeated keeping the weight of 300 grams and 10Vcc voltage, but changing the current value, which is up from 3A to 6A value. The consequence of this change was in modification of time by reaching the bow of zero position (under the influence of weight) in final position (complete martensitic transformation).

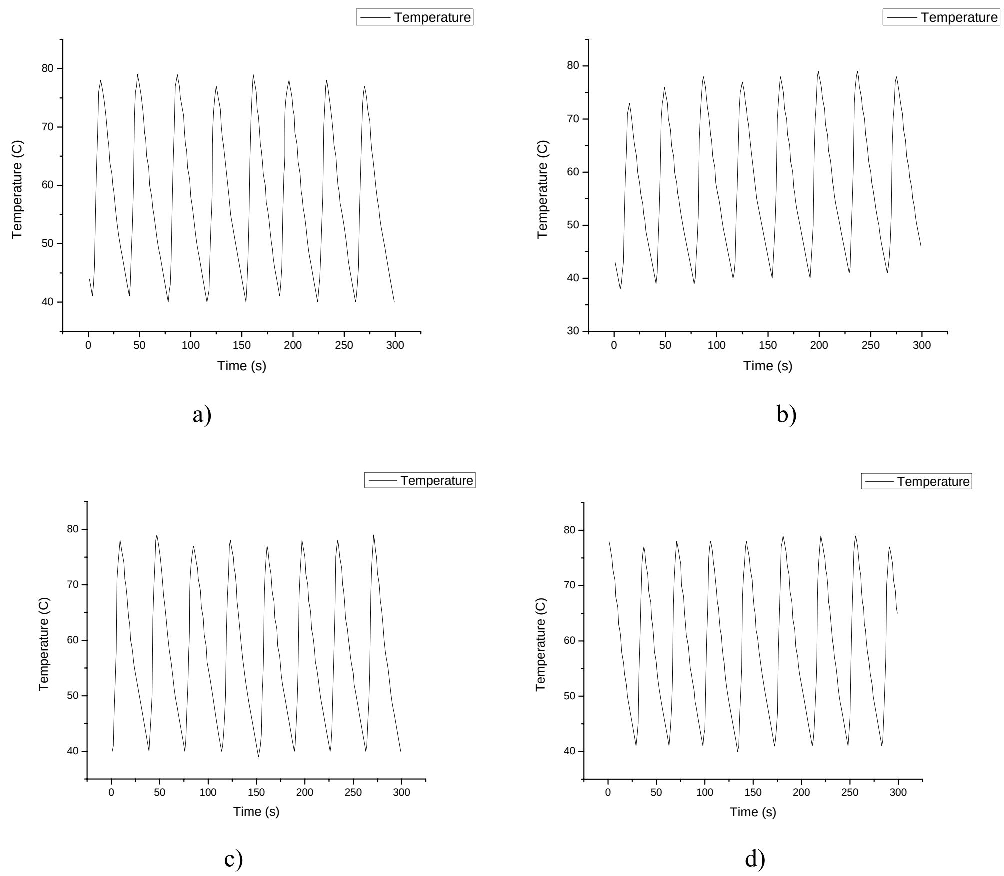

Fig. 3. Temperature – time variation of a shape memory alloy based on NiTi at different moments a) first 5, b) second 5, c) after 15 and d) after 30 minutes of mechanical work in the same experimental conditions.

This time has decreased from 45 seconds to 42.2 seconds while retaining the same cooling period and modifying the heating period (effective activation of memory element) by changing the heating current properties. The spring realizes a full action around temperature of 80 °C, increasing its asset item and not modifying his state. Analysis of the active element behavior after different cycles is shown in Fig. 3 by applying a larger number of cycles under the same conditions (action of a weight of 300 grams) for both extension and grip by shape memory effect.

Following the change of temperature charts note that the temperature reaches of material to make a complete cycle of tightening is similar to the one determined experimentally by differential scanning calorimetry situated between 76 and 80 °C range. From variations obtained experimentally can be observed the effects of actuators to modify the environment temperature, particularly in Fig. 3 a) in fourth cycle of actuators and in

b) the first two cycles and forth and stabilize it after 30 minutes operating primarily because the room temperature stability.

The operation of active element in all cases was the same job for the exercise of shape memory effect and it was not influenced by ambient temperature changes.

4. Conclusions

This contribution presented about experimental investigations on the effect of using trained shape memory alloy wires as actuators in all time under stress mechanism. The mechanism is smart n such a way that it exploits shape memory effect of SMA as actuator for applications under stress in austenitic and martensitic states as well. Different experiment conditions exhibit a variety of responses based on thermal and electrical material properties showing a large range of applications especially in mechanical work actuation elements.

Financial support was obtained from Romanian National University Research Council under the form of the PCE-IDEI grant 616, project 83/01.10.2007.

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