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ELECTRICAL ACTIVATION OF THE SHAPE MEMORY EFFECT FOR NiTi WIRES

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ABSTRACT: The basis of shape memory alloys is the martensite - austenite transformation. For this transformation of the lattice structure the temperature change is one of the driving forces. In most cases electrical or thermal energy is used to activate the memory effect. In this paper, the tests and results regarding the required electrical energy to activate the memory effect will be described. If the shape memory wires work like actuators in automotive industry it is important to find the best values for the current intensity and the electrical tension. One of the questions of this investigation is to find the electrical value when the contraction and mechanical stress is constant. The defined goal is to obtain in less than one second 4-4,5% contraction at different stresses between 100-450 N/mm^2 and to analyze the electrical behavior of the samples. A great focus was given to the electrical connection to realize the activation of the actuator wires. Different parallel and serial connections were investigated and the advantages and disadvantages of each installation will be presented in this paper. The final goal of this research is to find a matrix where it will be possible to choose the wire and the mechanical load and to read out the values for the electrical tension and the current intensity.
KEYWORDS: NiTi wires, shape memory alloy, electrical energy

INTRODUCTION

Shape memory alloys (SMA, smart metal, memory metal, memory alloy, muscle wire, smart alloy) are alloys that "remember" their original, cold-forged shape by returning to the pre-deformed shape by heating. This material is a lightweight, solid-state alternative to conventional actuators such as hydraulic, pneumatic, and motor-based systems. Shape memory alloys are finding applications in industries including medical and aerospace [1].

In automotive industry they can replace electrical, thermal, hydraulic, magnetic actuators from different systems, like safety systems, clutch drive, folding and setting mirror, and others by showing additional advantages.

Today the following alloys are used in engineering: Nickel-Titanium (NiTi), Copper-Zinc-Aluminium (CuZnAl), Copper-Aluminium-Nickel (CuAlNi) and iron based alloys [3].

The difference between the heating transition and the cooling transition gives rise to hysteresis where some of the mechanical energy is lost in the process.

The one way shape memory effect takes place when a shape memory alloy is in its cold state (below A_s): the metal can be bent or stretched and will hold those shapes until heated above the transition temperature. Upon heating, the lattice changes to its original lattice structure and therefore to its original shape. When the metal is cooled again it will remain in this "hot" shape, until it is deformed again. Deformation in this case can be up to 8%.

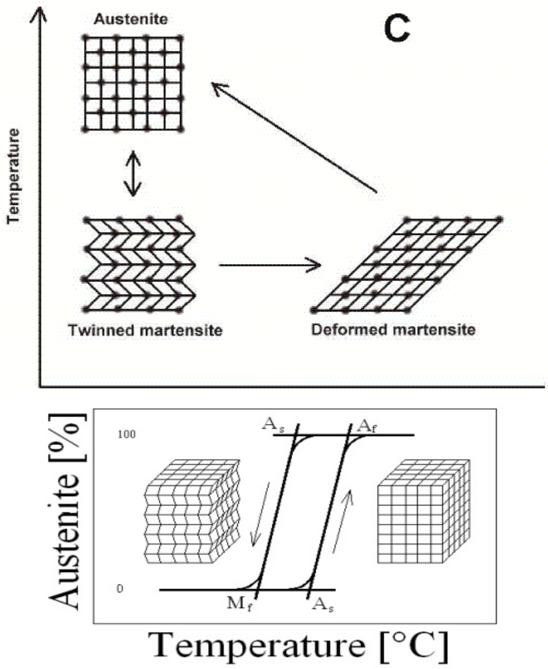

Figure 1.Martensitic transformation and shape memory effect [1],[3]

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During the two way shape memory effect the material remembers two different shapes: one at low temperature, and one at the high-temperature. This can also be obtained without the application of an external force (intrinsic two-way effect). The reason that the material behaves so differently in these situations is due to a special thermo-mechanical training process [3].

The pseudo-elastic propriety occurs in the austenitic temperature. For example, the frames of some eyeglasses are made of shape memory alloy as they can undergo large deformations in their high-temperature state and then instantly revert back to their original shape when the stress is removed. This is the result of pseudo-elasticity; the martensitic phase is generated by stressing the metal in the austenitic state and this martensitic phase is capable of large strains. With the removal of the load, the martensitic phase transforms back into the austenite phase and resumes its original shape. The shape memory effect can be activated by changing the thermal or electrical energy [2], [5] and in the case of pseudo-elasticity by changing the applied stress upon the material.

This paper presents the results regarding electrical activation of the shape memory effect in NiTi wires at different loads. The goal of the test is to obtain at least 4.5% contraction in less than 1s.

METHODOLOGIES AND DEVICES USED IN RESEARCH

There are numerous available methodologies for testing the shape memory alloy wires. Because they will be activated by using the electrical energy in this subchapter an electrical circuit is presented where the sample is like a variable resistance. This method (that is not standardized) presents a sample of Ni-Ti alloy that is fixed with one side in a frame. At the other side free in the air (fig. 2) will be attached the mechanical load (weight) that causes the stress upon the sample. The sample is "electrically" heated by Joule effect and cooled by convection at room temperature.

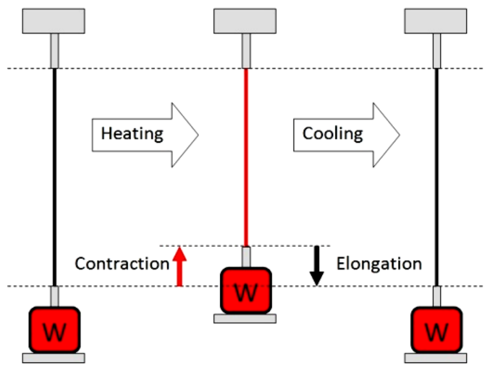

Figure 2. Model of the test

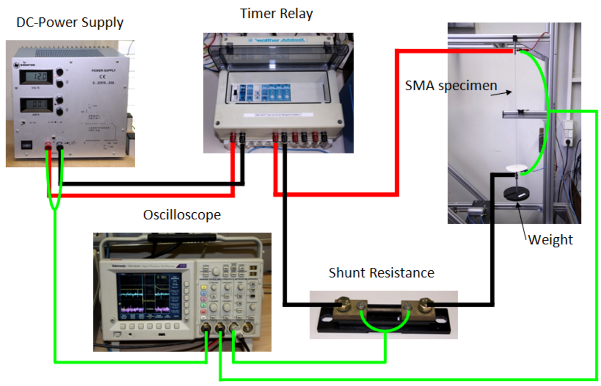

Figure 3. Electrical circuit of the test

This testing method uses a wire which was loaded with a weight at the end in vertical axis. The weight is calculated for each sample to get values very close to the presented stresses in the table 1. The ends of the wire are connected with the power supply. Between power supply and positive pole from the sample it is a timer delay used, where the activation time can be adjusted. For the minus line of the electrical energy is inserted a shunt resistance. The value of the resistance is constant and in that way it can be calculated the current intensity, if the electrical tension is measured.

During the heating process the lattice is changed from the martensite to austenite causing a rapid contraction an up moving of the weight (see fig 2). Afterwards the NiTi wire is cooled down to room temperature in the unmoved air. In this period the lattice of the sample will change again into the martensitic form.

During the test the electrical tension at the power supply, sample and shunt resistance are recorded.

ELECTRICAL ACTIVATION OF NiTi WIRES

The goal of this experiment is to identify the electrical energy to activate the actuator wires with different diameters(0.5, 0.4, 0.3, 0.2 and 0.1 mm) at different mechanical stresses (100, 150, 200, 250, 300, 350 and 400N/mm^2).The length of each sample is 500mm and the activation time is 1s. These values were determined, because it is planned to use SMA wires in applications for passengers' cars, in comfort and safety areas. The electrical energy was scanned until the contraction is higher than 4%.

Table 1. Mechanical stress for the specimen

Diameter	Constant stress (N/mm^2)						
	100	150	200	250	300	350	400
0.1							
0.2							
0.3							
0.4							
0.5							

gray box = the specimens was tested, write box = the specimens was not tested

After the first tests the Kirchhoff theory could not be confirmed. To prove the theory the shunt resistance was removed. First graphic without the Shunt resistance is presented in the next figure.

In the fig. 4 the blue line represents the electrical tension measured at the power supply and the green one is the value of the electrical tension measured at the sample. At the graphic are defined: 1 – value of the tension at power supply, 2 – value of the tension *at sample, 3- value of the tension at power supply when the sample is activated, 4- value of the tension at the sample when it is activated and 5 – activation time.*

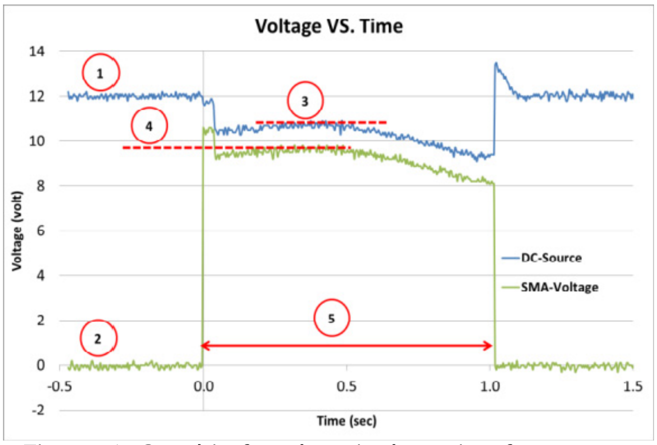

Figure 4. Graphic for electrical tension from power supply (blue line) and sample (green line)

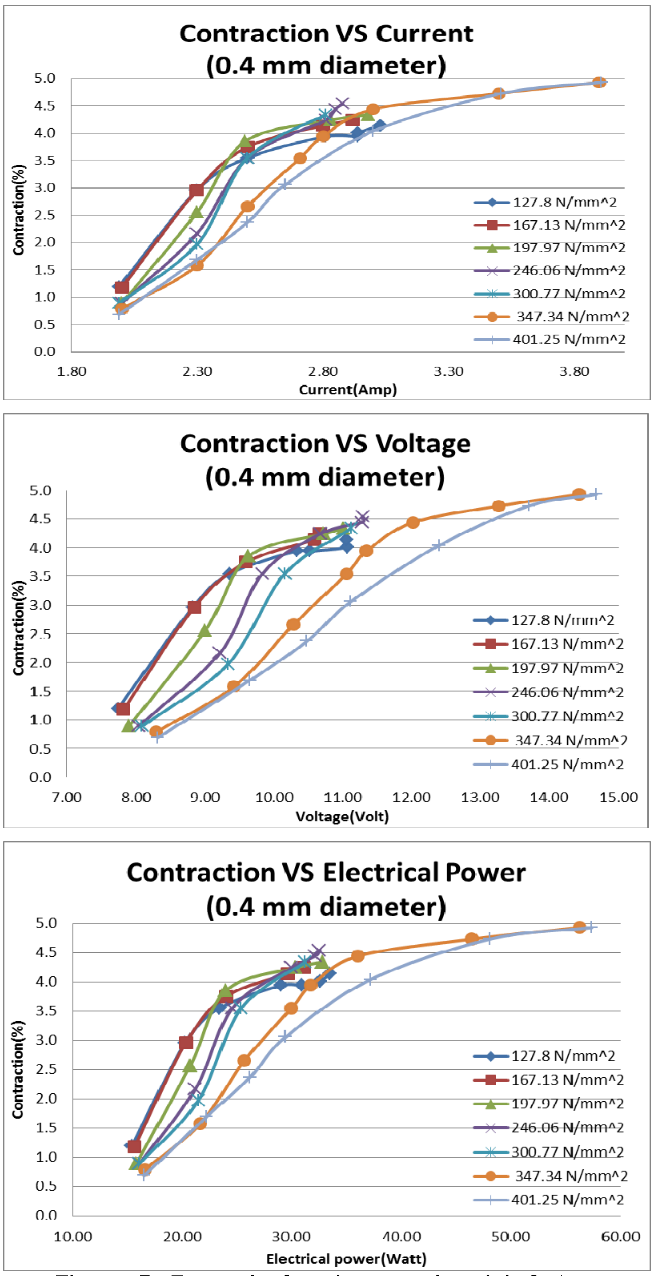

Figure 5. Example for the sample with 0,4mm diameter and length 500 mm

In this case the characteristic curve from sample should be "negative" compared to the characteristic curve from the power supply. In the graphic can be observed a difference between curve 3 and 4 when the sample is activated. The reason for this difference is the internal resistance from the timer delay. In this case the registered value which will be recorded is the value from the sample (green curve).

According to this method samples presented in the beginning of the chapter were tested. Each sample produced at least seven graphics, but in this paper only the final results will be presented, exemplarily for the samples with 0.4 mm diameter (fig. 5).

The contraction and current graphs for sample with 0.4 mm diameter show an increasing of contraction until more or less 4.5% with the range of current about 2.8-3.8A. If the reference is the graph voltage vs. contraction it can be observed that for 4.5% at different loads an electrical tension of at least 11 till 14.8 Vis necessary.

It can also be observed that the sample needs more current to achieve higher stresses.

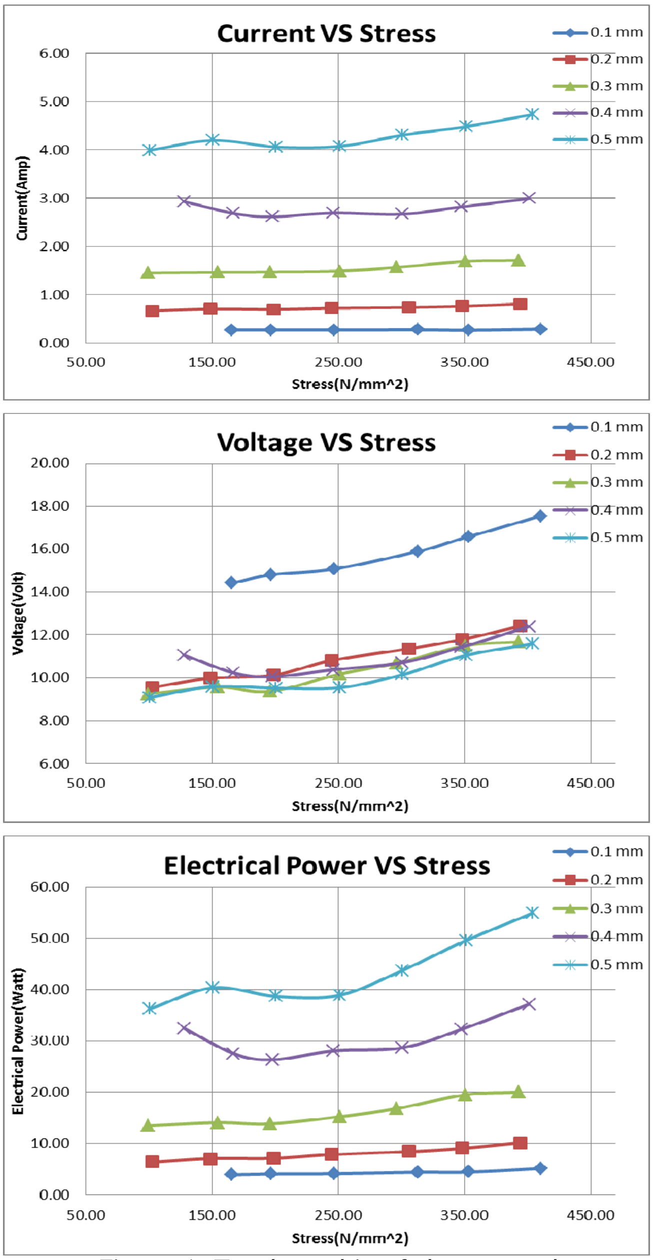

Figure 6. Total graphic of the research

In figure 6 is presented the total graphic of the research for 4%. An important fact of the research is the point when the samples reach 4% contraction. In this figure, the characteristic curves show that the current values slightly increase when the stress values are higher. It can also be observed that the current levels are higher when the diameters are bigger. It can be concluded that when the diameter is bigger and the mechanical stress increases is necessary to insert a bigger electrical energy quantity. By means of this total graphic the necessary quantity of electrical energy can be read out for any application according to the assumed conditions.

If the desired mechanical stress, for another application is higher than the mechanical stress which was tested in this work, the required condition possibly can be achieved by using several wires in parallel. When the wires are used in parallel the current intensity is growing up. Using several NiTi wires in serial connection the electrical tension is growing up. A special research work concerning the different electrical connections has been carried out and published [6].

The behavior of the sample is like an electrical resistance and the results can be calculated when the input values contraction, mechanical tension, diameter and length of the wire are known.

CONCLUSIONS

After this research it can be concluded that the results can be very useful for the actuator industry when shape memory activator wires are applied in different fields. For example these alloys are able to replace hydraulic, mechanical, electromechanically and pneumatic actuators from the automotive industry. For this it is necessary to know from the beginning what are the requirements for the new system in order to replace another one. This paper gives some answers for NiTi wires used in automotive industry and also other actuator fields.

One of our concrete applications of these alloys is to replace the clamping system from steering column [7] through a new system using NiTi wires. In this sense further developments are going to be undertaken in order to use the wires in future safety systems.

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