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NEW TESTING MACHINE FOR MEASURING THE DAMPING PROPERTIES OF SHAPE MEMORY WIRES IN DYNAMIC CONDITIONS

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ABSTRACT: The shape memory alloys are special materials which can remember their shape. This phenomenon is known to arise from reversible transformation between two solid phases, martensite and austenite. Some shape memory alloys like NiTi-nol present high damping properties. They are able to dissipate the energy of a mechanical system, resulting from the energy conversion during the phase change processes. This paper focuses on the damping proprieties of pseudo-elastic NiTi wires. In the first part results of tested wires with 0.1 to 0.5 mm maximum diameter are shown. The influence of the testing speed is classified as follows: 'slowspeed' and 'high speed' defines the slowest and the highest speed which can be realized with the adapted testing machine and varies between 0,1mm/s and 20mm/s. The temperature range of the specimens was defined from -20°C to +25°C. In this test method it could be shown that with increasing testing speed for a given specimen the reversible plateau area decreases. In the second part of this paper a new testing machine is presented, which is able to realize test speeds up to 6000 mm/s. This speed can be achieved when the drop weight will contact a bottom plate and the impact is transferred to the sample. Because the weight is dropped the stroke for the sample is measured in two points. The force of this impact will be parallel measured and if the sample will be electrically activated during this test it is also possible to record the electrical tension. The maximum length of the sample is 1m.Withthis new machine it is able to test pseudo-elastic wires as well as actuator wires when they are electrically activated. To enlarge the application range for the shape memory alloys it is necessary to study their behavior in the dynamic area. With the new testing facility it is expected to test the damping proprieties of SMA wires. In that case, these results can be followed in finding new applications for shape memory alloys especially in the automotive industry.
KEYWORDS: shape memory alloy, dynamic area, dynamic testing plant

INTRODUCTION

Shape-memory alloys have unique properties which do not exist in many materials traditionally used in engineering applications. NiTi alloys are known as the most important shape memory alloys (SMAs) because of their multitude of applications based on the shape memory effect (SME) and pseudo- elasticity (PE) [1], [2]. Those properties are related to the martensite austenite (and reverse) transformation. This comes from the fact that NiTi alloys have superior properties in ductility, fatigue, corrosion resistance, biocompatibility and recoverable strain [4]. It is also known that the NiTi alloys present a high mechanical damping capacity that means they are able to be used in energy absorption applications. Some research has been done in this field and first applications in the civil engineering area exist, e.g.: earth quake protection devices for bridges and old churches using shape memory elements [7], [8].

Another possible application of these alloys can be found in safety systems of the passenger cars. In case of the crash a part of the safety system has to absorb the mechanical energy. Reaction speed of these systems should be under 1s [6]. To demonstrate that the NiTi wires are able to absorb mechanical energy in high dynamic automotive areas is necessary to follow the next steps: 1 – determination of the damping capacity when the specimen is thermal activated (tests at lower speeds), 2 – design of a new testing device to measure the damping capacity when the specimen is electrical activated (tests at higher speed).

DAMPING CAPACITY AT LOWER SPEEDS (v<20mm/s)

These tests are made with W&B machine (fig. 1). The machine is a tensile testing machine in horizontal position with devices to measure and control the velocity, stroke, mechanical tension or *electrical resistance. Additionally it has a Peltier furnace, a computer and a device which can control the temperature (see fig. 2) [5]. The machine is controlled by the computer with the tensile testing controlling program while the temperature is regulated with a separate controlling program. Maximum testing speed of this machine is 20mm/s and maximum length of the specimen is 250mm.*

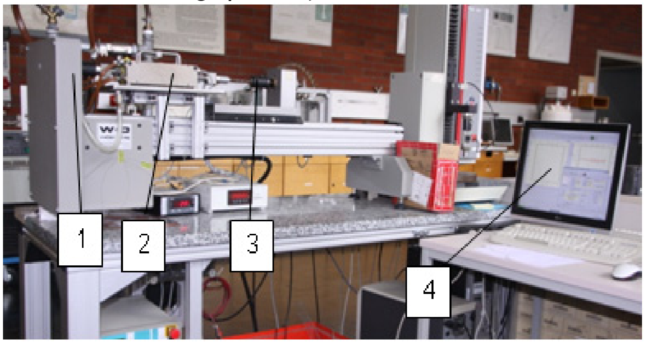

Figure 1. W&B testing machine

The specimen is fixed on the machine, one side to the fix part (1) and the other side to the mobile part (3). The Peltier furnace (2) can be opened by hinges and is tempering the specimen. Heating and cooling processes are controlled by computer (4), with temperature program (special designed for this device). The slide part of the machine contains the force sensor assembly and in this way the force and mechanical tension in the specimen can be recorded. At the same time the elongation, the temperature and the speed are recorded. The program allows the user to measure also the electrical resistance values of the sample in every moment of the test.

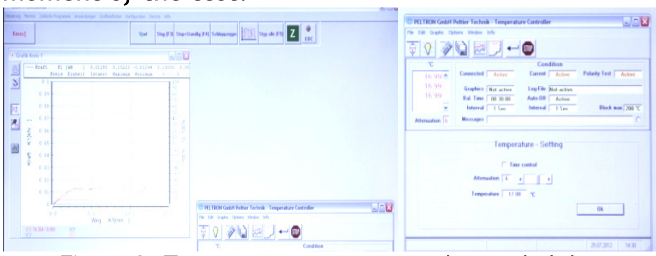

Figure 2. Temperature program and recorded data form W&B Device

The tests with this machine are carried out with actuator and pseudoelastic-wires in the diameter range of 0.1 till 0.5 mm. The goal was to define the reversible plateau when they are thermal activated at different speeds.

The test for actuator wires was realized according to the following procedure: fixing of the sample in the machine, heating of the Peltier furnace up to 100°C and elongating the wire with a defined speed, first until the plateau was reached and then further until the break of the specimen to know the maximum point of the plateau). The testing speeds are defined at 0.1 mm/s, 0.5 mm/s and 20 mm/s. The same types of tests are made for pseudoelastic wires but at different constant temperatures ranging between -20°C till 25°C. To show the trend only the results for pseudoelastic wires tested at 20°C are presented, see Figure 3. Also the results for actuator wire present the influence of the speed to the reversible plateau and are in the trend.

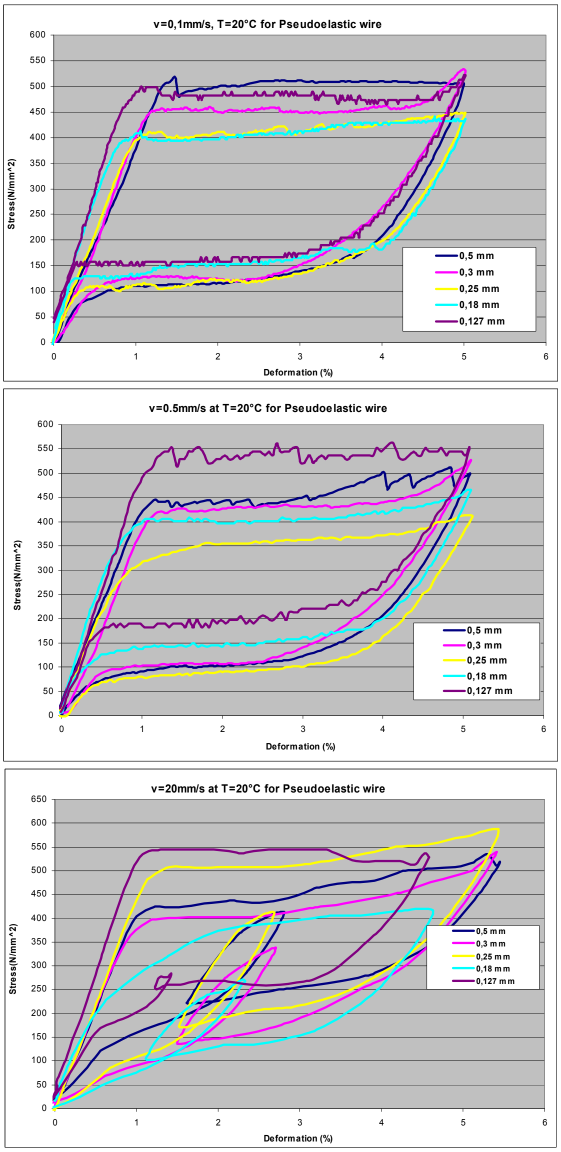

Figure 3. Results for different pseudoelastic wires tested at 20°C for different speeds

In Figure 3 is presented the trend: when the speed grows up the stress plateau slightly decreases for most diameters and elongation also. For example let's follow the wire with 0.3 mm diameter. It can be observed that at the speed of 0.1mm/s the plateau stress is 450 N/mm^2 and at the speed of 20 mm/s the plateau stress is 400 N/mm^2. But for the 0.25 mm specimen the plateau stress is first dropping to 350 N/mm^2 at the speed of 0.5 mm/s and then increasing to 550 N/mm^2 and more at a speed of 20 mm/s compared to 400 N/mm^2 at the slowest speed of 0.1 mm/s. So the next step within this research is to examine the influence of the speed upon the reversible plateau and elongation, when the testing speed is higher than 20 mm/s.

To follow this idea a new testing device is under development in our laboratory. This new device should be able to test shape memory alloy wires with higher speeds much higher than20mm/s. The new device is called "drop impact testing machine" and is presented in the next paragraph.

DROP IMPACT TESTING MACHINE

The main idea of this machine was to suddenly release a high quantity of energy (Figure 4). This energy should be absorbed by the shape memory alloys wires. For the actuator wires it additionally necessary to create a system to activate the memory effect by heating them.

In the passenger cars single source of the electrical energy is the car battery. So the new machine should be able:

- *to test actuator and pseudoelastic wires;*
- *to test samples with a maximum diameter of 0.5 mm and a maximum length of 1000mm;*
- *to test the samples at testing speeds much higher than 20mm/s;*
- *to activate electrically the memory effect for the actuator wires;*
- *to control the activation time of the wires and the dropping time of the weight;*
- *to adjust the stroke of the dropping weight;*
- *to measure the force, the electrical energy (at the source and at the samples) and the elongation of the wires;*
- *to record the release time and contact point of the dropping weight (it can be calculated the speed from measured value and in this way the errors);*

With this tasks it was designed the new "drop impact testing machine" (fig 4), where : 1 - shape memory samples, 2 - force sensor, 3 – distance sensor, 4 – magnetic band for distance sensor (3), 5 – wire ropes, 6 - pneumatic cylinder, 7 - dropping weight, 8 – second distance sensor, 9 - high speed camera.

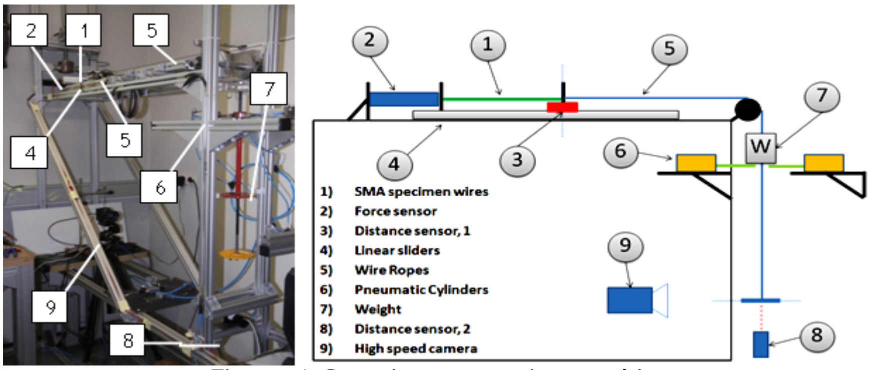

Figure 4. Drop impact testing machine

At the moment the maximal achievable velocity by using the longest dropping distance of a given weight is calculated to more than 6000mm/s. The drop impact testing machine is a testing device to realize vertical-shock tests using drop or impact energy generated by a dropping or falling weight. In the beginning of the test the weight is in the upper position containing a high potential energy. When the weight is dropped, the speed of the weight will increase. The potential energy is changed into kinetic energy. When the weight impacts onto the support which is connected with the SMA wire, the force will be applied to the SMA wire. The kinetic energy is changed into the work and is applied to a SMA specimen or several wires, respectively. The maximum height of dropping the weight is 2 m and therefore maximal velocities up to 6000 mm/s can be realized. Because of this higher speed (compared to the tests upon the mentioned tensile testing machine) these tests give the opportunity to analyze the specimen behavior in the dynamic area. Impact time is less than 0,1s, the maximum weight which can be dropped on this machine is designed to 50 kg.

The sample is fixed on the machine: One side of the sample (1) will be connected with the force (2) sensor and the frame and the other side will be connected with the mobile wagon. Attached on carriage is a distance sensor (3). At the same time this sliding carriage is connected with the second distance sensor (8) using wire ropes (5). The dropping weight (7) is held by the pneumatic cylinders (6) which are controlled using a PLC (programmable logic controller).

During the activation of the wire and the impact, the carriage will move and the distance sensors will record that motion. In parallel to this the force will be recorded. Controlling and data measurement are made with computer using LabView. The electrical circuit is presented in Figure 5. To calculate the current intensity it is used an r-shunt (constant resistance) where the electrical tension is measured. For controlling the activation time of the wire it is used a timer delay. This device is able to control activation times in range of 0.1s till 2h.

The frame built-up of the machine permits to assembly samples until 1000mm length.

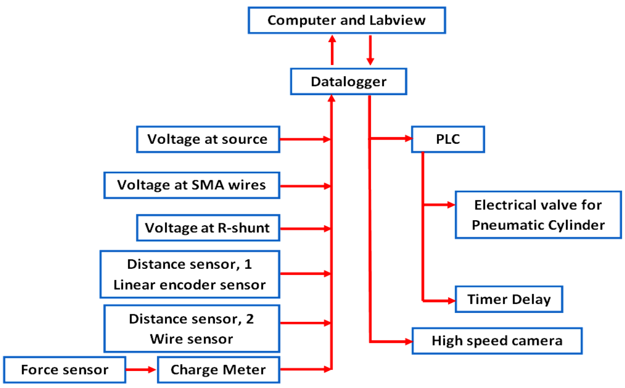

Figure 5. Circuit plan of the signals

The main signal comes from the computer (programmed with LabView) and goes to the DAQ (Dataloger). DAQ sends the signal to PLC which will start the timer delay (activating a relay) and will *send electrical energy on to the sample. At the same time the drop weight will be released. The instant of time when the weight has to be released is calculated. The main factor for these actuator samples is the time point when the weight impacts them: exactly at this moment they should have reached their maximum contraction. In parallel with the sample activation the system starts to measure the different values from the sensors. These values are saved automatically in the computer. Additionally from each test a movie is going to be recorded with the high speed camera.*

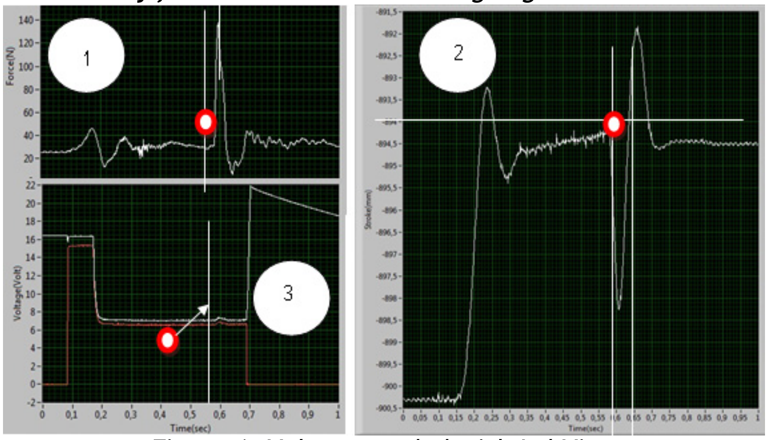

Figure 6. Value recorded with LabView

First results are presented in fig. 6, where graphic no. 1 is the signal from the force sensor, graphic no. 2 is the signal from the distance sensor and graphic no. 3 is the signal form the power supply (red line measured at the sample and white line measured at the power supply).

These results are for a sample - actuator wire- with 0,5mm diameter and 250mmlength. It can be seen in graphic no. 3 that the zero-point represents the time when the test starts. After 90ms the samples is activated, first with all voltage from the power supply and then engaging to a constant voltage at 6,2V till 0,7s. The red point illustrates the contact point between the dropping weight and the sample. After this point an inflexion can be observed that appears because of the structure of the samples. To keep the austenite structure when mechanical energy is dropped it is necessary to take more electrical energy and this is the reason of the inflexion. Graphic no. 2 shows the same behavior. When the sample has reached its maximum contraction the dropped weight contacts it (red point). First the sample makes a loop (the reason of this loop is inertia of the system) and then the contraction is constant. The time of contraction is 555 ms. In the range of 555 ms and 647 ms is the energy absorption time. Form the graphic no. 3 the value of the force can be observed. It grows up after the contact point (red point) until 139 N. During time 555 ms and 647 ms the sample absorbs energy. Using the impulse theory for this test the speed is calculated to 400 mm/s.

It is important to record electrical energy. If the samples will be used in actuators assembled in passenger cars is necessary to know electrical energy for activation.

CONCLUSIONS

In this paper a new testing machine is present to enable tests upon shape memory wires (or single specimens) in the dynamic area. With the so-called "drop impact testing machine" speeds up to 6000 mm/s with dropping weights till 50 kg over maximal dropping distances of 2 m can be realized. Using different sensors and even a high speed camera the values for displacement, force, speed, electrical tension and current can be recorded in order to analyze the sample behavior during this vertical-shock impact. Another advantage of this new testing machine is the possibility to test superelastic wires at different constant temperatures as well as electrically activated actuator wires. As the described testing machine still is under development only very first tests are reported in this paper.

With the new testing facility it is expected to test the damping proprieties of SMA wires. In that case, these results can be followed in finding new applications for shape memory alloys especially in the automotive industry.

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