

Developing shape-memory materials using fast acting cyclic stresses for memory stabilizing

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Shape-memory alloys are intelligent materials, with a high density of energy and the ability to “remember” their initial shape when subjected to a plastic deformation. The shape-memory effect can be defined as a reversible thermoelastic martensitic transformation. This phenomenon is enabled by a bidirectional transformation of the crystal phase, from martensite to austenite, under the effect of heat. During the transformation phase non-recoverable plastic deformations may occur, limiting the memory effect. A method to reduce remanent plastic strain and stabilize the memory effect (also known as the training of the memory-effect) is to apply cyclic thermomechanical stresses at constant load or temperature on the memory-material. This paper presents a concrete procedure and an experimental device developed for training memory effect samples. The memory effect of a Ni-Ti alloy sample was measured before and after the sample was trained. A gain of 15 % in memory effect was determined, between the trained and the untrained material sample.

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1. Introduction

The memory effect, existing in some alloys known as shape-memory materials, refers to the material’s ability to memorize its default shape under the control of heat, after being subjected to a plastic deformation. There is a certain interest in the market for memory-materials, from medical and automotive applications to the aerospace industry. Because of superior mechanical properties, resistance to corrosive environments and biocompatibility, they are suited to be used in various actuator applications, from basic on/off switches to more complex parts for controlling satellite solar panels [2]. Memory materials are mostly alloys based on Ni-Ti or Cu. Ni-Ti alloys are the most used in commercial application because of their good mechanical properties and stable shape memory effect. [3] Shape memory materials are classified according to the capability of their memory effect, of about 3 to 8% strain recovery [5], [6]. An important feature of the memory effect is that it can be trained, by subjecting the material sample to a cyclic mechanical stress. This procedure determines the preservation of the memory effect during the scheduled lifetime of the application.

2. Material and method

2.1 Theoretical details regarding the shape-memory effect

The shape-memory effect can be defined as a reversible thermo-elastic martensitic transformation, as

shown in Fig. 1. Shape-memory alloys have two different crystal phases: martensite and austenite. Martensite is a soft, monoclinic crystal phase, occurring at lower temperatures. Austenite is a hard crystal phase formed at higher temperatures. Shape-memory alloys are able to basically shift between this two phases, under the effect of heat.

When kept under its transformation temperature, a memory alloy sample can undergo significant amounts of plastic deformation, its crystal phase being changed from martensite to austenite. If heated above its transformation temperature, the crystal phase changes again, from austenite to martensite, the alloy sample returning to its default shape. The transformations take place at different levels of temperature, forming a thermal hysteresis curve [4].

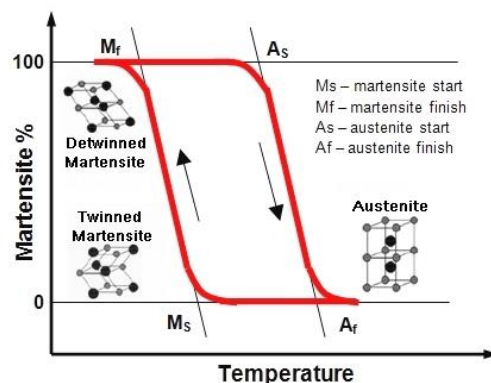


Fig.1. Thermal hysteresis curve of the martensitic transformation.

2.2 Thermomechanical training of memory-materials

As shown in Fig. 1, the memory effect is a phenomenon where plastic deformations produced by an applied mechanical stress below the A_s temperature, recover by heating above A_f temperature. If deformed, the martensitic crystal phase (also called twinned martensite) morphs into a detwinned martensite [1]. If heat is applied, the detwinned martensite morphs into austenite. Upon cooling, the material returns to its initial martensitic phase.

New shape-memory materials cannot be used directly in applications because of the transformation-induced plasticity (TRIP) effect [1]. This phenomenon assumes that non-recoverable plastic deformations occur at new and untrained memory materials, during each mechanical and thermal cycle. It has been observed that the TRIP effect is very pronounced during the first initial cycles and stabilizes as the number of cycles increases. One way to reduce plastic strain is to apply cyclic thermomechanical stress at constant load or temperature on the memory-material. This procedure is also known as the memory-effect training. During the first thermomechanical cycles, there is a significant amount of remanent strain, not recovered from the material. As the amount of thermal cycles increases, the remanent strain stabilizes and plastic strain growth saturates [1].

3. Results - experimental setup

The main challenge was to develop a testing device, capable of generating cyclic thermomechanical stresses at a given constant load and temperature. The schematic diagram of the testing installation is presented in Fig. 2. Constant mechanical load is applied on the material sample by a straining installation, consisting in a stepper motor and a load cell. The material sample (usually in form of a wire) is mounted between two clamps, one fixed to the machine and the other to the load cell mounted on a sliding beam. The stepper motor moves the sliding beam into the desired position, tensioning the material sample with a constant mechanical load.

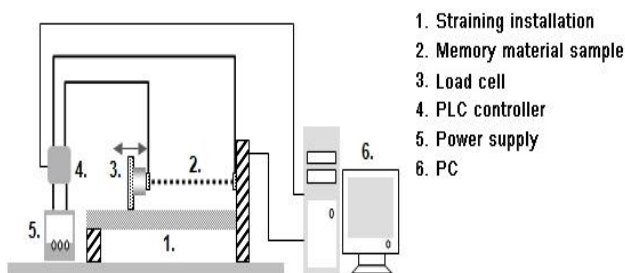


Fig. 2. The schematic diagram of the training installation.

By using a power supply connected to a programmable logic controller (PLC), voltage at a given

current rate is applied on the memory material sample. The cyclic stress acting on the material is achieved by programming the PLC to generate a cyclic voltage output. As shown in Fig. 3, a power relay controlled by the PLC, opens and closes the electrical circuit connected to the sample. A transient voltage-suppression (TVS) diode was added to the circuit, to protect sensitive electronics like the relay and PLC from voltage spikes that can be generated by quick power transitions.

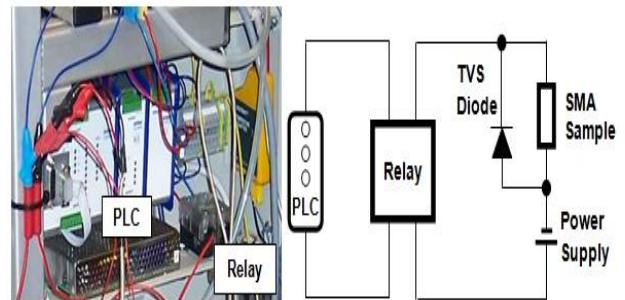


Fig. 3. The electric circuit for generating cyclic stresses.

The frequency and duration of the training cycle is given by the shape of the output pulse of the PLC, as shown in Fig. 4. The output pulse can be controlled by programming the PLC controller, using a variant of C++.

Following input parameters were defined:

- PLC output voltage for controlling the power relay, P[1];
- time interval between two cycles, P[2];
- cycle duration, P[3];
- number of cycles, P[4].

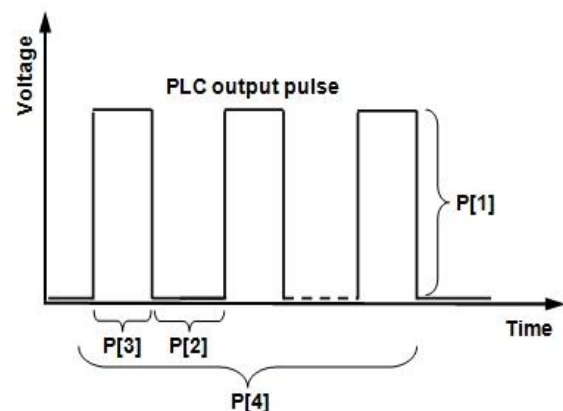


Fig. 4. The pulse generated by the PLC voltage output.

The PLC was programmed by using the following command lines:

```
CALL ConfigJetter (JNANOA, "COM4", True,
False)
VAR i NUM
FOR i=1 TO p[4]
```

```

SLEEP p[2]
CALL JSETREG (3010, p[1])
SLEEP p[3]
CALL JSETREG (3010, 0)
NEXT
INFOBOX ("Training Finished")

```

3.1. The training procedure for shape memory materials

For validating the experimental setup, an untrained Ni-Ti memory alloy wire with a diameter of 0.245 mm and length of 290 mm was chosen to be tested. Before the training procedure, the memory effect of the untrained sample was measured by using a tensile-strength machine and a heating/cooling device.

The material sample was subjected to a constant load of 8N (135 N/mm²) and heated up to 150°C and then cooled back to room temperature. As shown in Fig.6, a memory effect of about 3.4 % was achieved. The TRIP effect did occur because of the residual strain of 0.7 % which was not recovered after the cooling phase. The same memory material sample was then mounted in the training device and tensioned with a constant load of 8N (similar to the previous test). The following input parameters for the training procedure were used:

- number of cycles: 80;
- time interval between two cycles: 45 s;
- duration of one cycle: 5 s;
- power supply voltage: 7.5 V.

Voltage was chosen in accordance with the specifications provided by the material supplier. More voltage might cause an overheating and destruction of the sample. The time interval between two cycles is limited by the speed of the stepper motor and by the capability of the samples to cool down. No rule or procedure has been established yet by researchers or suppliers, regarding the duration and the number of cycles a memory material sample should be subjected to. It's usually chosen in accordance with the application specifications, alloy type or sample geometry. The results of the training procedure are shown in Fig. 5.

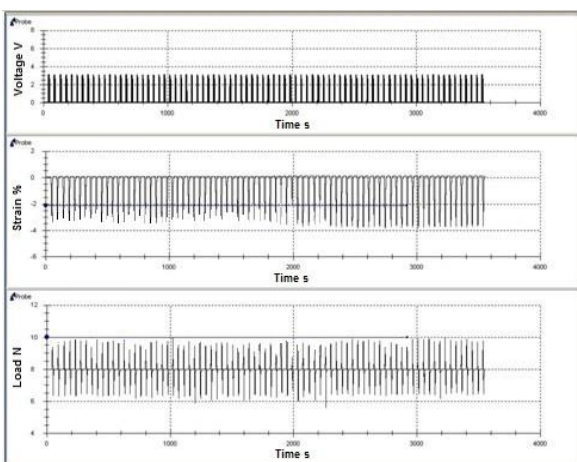


Fig. 5. Test results of the training procedure.

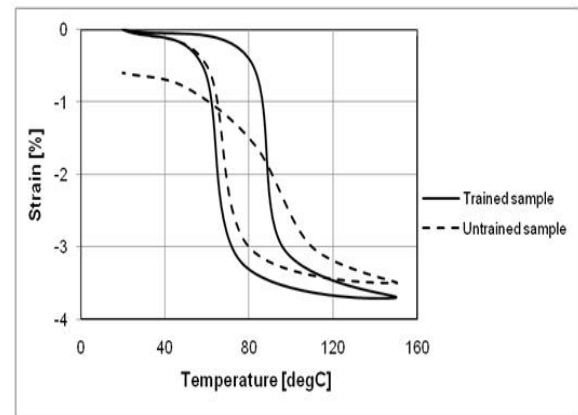


Fig. 6. Thermal hysteresis curve of the trained and untrained sample.

At the start of the training procedure, an average memory effect of 3.6 % strain was achieved. The peak of strain values is oscillating, proof that the memory effect is not stable. After about 60 cycles, the value of strain stabilizes at about 3.9 %. It can be assumed that the maximal value of the memory effect lies within 4 %. The trained sample was tested again using the heating/cooling device. As it can be seen in Fig. 6, the shape of the thermal hysteresis curve is now very pronounced. Because the trained material sample has the same initial strain of 0%, it can be assumed that there is no remanent plastic strain and the material can be considered as fully trained. The difference in memory effect between the trained and untrained sample is about 15 %.

4. Conclusions

A method was developed, to stabilize the memory effect of shape-memory alloys, by using fast acting cycles. Memory alloys, are considered intelligent materials, with a high density of energy and the ability to “remember” their initial shape when subjected to a plastic deformation. This phenomenon is enabled by a bidirectional transformation of the crystal phase, from martensite to austenite, under the effect of heat. New memory alloys, if subjected to mechanical stresses, have a certain amount of residual strain which decreases the memory effect. If subjected to cyclic thermomechanical stresses, the strain grow can be saturated and the entire memory effect of the sample can be used. This is a time consuming procedure, also known as training, that often requires expensive experimental devices, because the sample has to be heated and then cooled during a certain amount of cycles.

The developed training method uses voltage for heating the samples. The number and cycle duration is controlled through a PLC device. The required constant mechanical load that tensions the sample is achieved by a sliding bar connected to a stepper motor. The main advantage of this method is the duration of the training procedure. A conventional heating/cooling device requires

about 5 to 15min to cool down (depending on the employed cooling technology) for one cycle. As described above, the developed training procedure required less than 1min for one cycle. Also, applying voltage directly on the sample, is a more efficient process than induction heating. A conventional Ni-Ti shape memory alloy was used to validate the training procedure. The memory effect was stabilized after 80 cycles. Also, a gain of 15% in memory effect was determined, between a trained and an untrained sample of the studied Ni-Ti alloy.

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