ABCM Symposium Series in Mechatronics - Vol. 3 - pp.487-492

SHAPE MEMORY ALLOY CHARACTERIZATION

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Abstract. *The present work aims to establish the repeatability, reproducibility, hysteresis and uncertainty of measurement, of the displacement in thin Ni-Ti alloy wires under constant axial load when electrically heated. An experimental setup was built for carrying out the measurements in air, samples of 1 m length wires with two diameters: 100 and 150 μm were analyzed. The readings were done in a digital length gauge. The arithmetic means of the readings, both in air, had a nonlinear behavior and showed a temperature hysteresis. All results had good repeatability and reproducibility in increasing measurements of displacement. The expanded uncertainties found were the expected for this length wire. The results have shown to be in accordance with other Ni-Ti shape memory alloy literature.*

Keywords*: shape memory alloy, displacement, uncertainty budget.*

1. INTRODUCTION

Shape Memory Alloys (SMAs) are alloys that have adaptive capabilities (can sense changes in their environment and respond appropriately) to external stimuli such as load and/or temperature. The principal characteristic of SMAs is their ability to memorize their original configuration after they have been deformed, by heating the alloys above their characteristic transition temperatures, hence recovering large strains (shape memory effect). Their ability to sustain large forces and displacements, to alter their shape, to change their stiffness and damping characteristics with temperature or applied load, and the potential to act as compact powerful actuators, has made them excellent candidates for active or “smart” structure applications. Although a relatively wide variety of alloys are known to exhibit the shape memory effect (SME), only those that can recover substantial amounts of strain or that generate significant force upon changing shape are of commercial interest, mainly, the nickel-titanium alloys and copper-base alloys, such as: CuZnAl and CuAlNi (Hodgson *et al.*, 2005).

For a given SMA, the hysteresis is dependent on the composition of the alloy and the manufacturing processes. Most Shape Memory Alloys have a hysteresis loop width of 10 to 50° C. Figure 1 shows a characteristic curve of hysteresis loop in SMA.

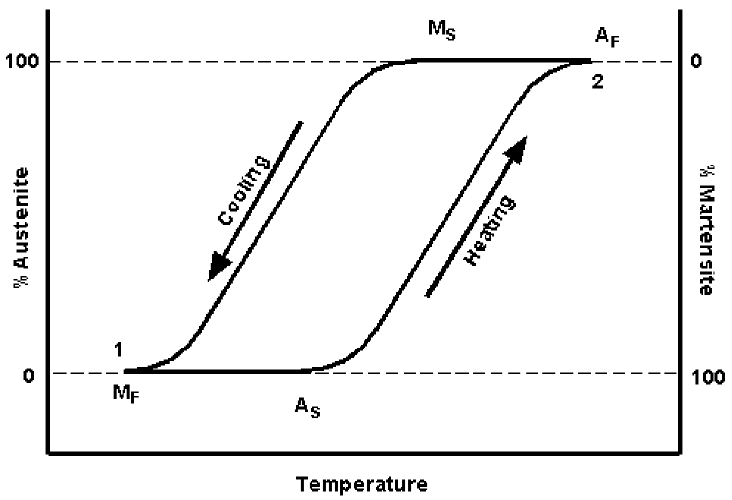


Figure 1. Hysteresis Loop in Shape Memory Alloys (Waran, 1993).

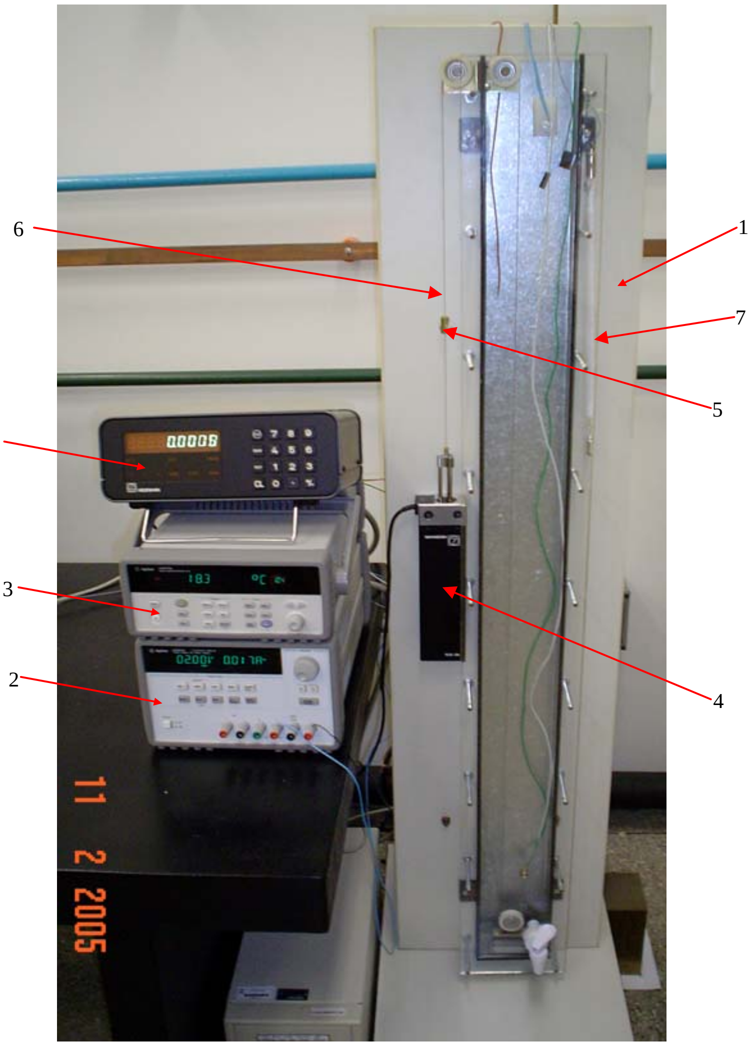
This work will characterize the displacement, repeatability, reproducibility, temperature hysteresis and measurement uncertainty of a Ni-Ti shape memory alloy wire of 1 meter of length and two diameters 100 and 150 μm in air. For this a experimental setup was built. This paper is based in work of Souza (2005).

2. METHODOLOGY

To characterize the wires to be analyzed, a experimental setup was built, a procedure was done, a mathematical model and a uncertainty budget was described in this section.

2.1. Experimental setup

The experimental setup presented in Fig. 2 was built in a coated wood with adjustable feet, in which the galvanized steel structure, a support of the wire of Ni-Ti and the supports of the pulleys, were screwed. An acrylic cover was used to prevent air temperature changes. The digital length gauge was screwed in the wooden structure and leave space to put the weights of lead responsible for the recovery force. The wire of Ni-Ti was screwed to the support of Teflon, between two brass washers. The power wire was fixed in the same support of Teflon. The functioning mechanism consists of four main components: a wire actuator of Ni-Ti, weights support, a sensor, and the structure. The measured actuators are wires of Ni-Ti with 1 meter of length and two diameter: 100 and 150 μm. The wire is connected in the support of Teflon and a isolated steel cable. The support is fixed on the galvanized steel structure by a screw. The connection between the cable and the weights is made by pulleys. The wire of Ni-Ti is connected to the symmetrical digital source by commercial wires. The injected current (mA) causes the heating of the wire that contracts and pulls the piston of the digital length gauge, indicating the dislocated length. When removing the current (mA), the weights straining the wire, which returns to the initial position. In the beginning of the process, the wire is submitted to a previous tension by the weights, and soon after, the electronic comparator of displacement is put in "zero".



1. Support of the device;
2. Symmetrical digital source;
3. Data acquisition/switch unit;
4. Digital length gauge;
5. Weights support;
6. Steel cable;
7. Liquid in glass thermometer.

Figure 2. Experimental setup.

2.2. Experimental procedure

The measurements, in the samples with 1m and two diameters 100 and 150 μm, in air, were done in 10 points between zero and the limits establish by the wire's maker (Tab. 1).

Twelve measurement cycles were done. After the current application, we waited a time for stabilization of the displacement in micrometers.

The readings of wire deformation were done in a digital length gauge with 0,005 mm resolution and 100 mm of range. The readings of current wire temperature and resistance were done in a data acquisition/switch unit.

A recovery force of 1.58 N was applied in the 100 μm wire and 3.00 N in 150 μm wire.

The ambient air was measured by a liquid in glass thermometer, and the environment in the course of all cycles varies from 19.9 ºC to 20.4 ºC. The wire temperature was measured by a thermistor.

Table 1. Ni-Ti properties.

Wire diameter (μm)	Linear Resistance (Ohms/m)	Recommended current, at 20ºC (mA)	Max. Recovery force (N)	Rec. Recovery force (N)
100	150	180	4.69	1.50
150	50	400	10.56	3.30

2.3. Mathematical equations

Until now an ideal mathematics model for shapes memory alloys was not discovered, so a linear regression was done to find the measurements uncertainties of the displacements of the wires. Equations of propagation for wires of 100 and 150 μm had been developed. Such equations are shown to follow.

Equation of the propagation of uncertainties for wire of 100 μm in air:

$$L_T = 0{,}0008T^3 - 0{,}0526T^2 + 1{,}2594T + E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7 + E_8 \quad (1)$$

Equation of the propagation of uncertainties for wire of 150 μm in air:

$$L_T = -0{,}0026T^3 + 0{,}3452T^2 - 12{,}785T + 141{,}81 + E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7 + E_8 \quad (2)$$

Where: L_T total displacement;
E_1 repeatability error;
E_2 digital length gauge certificate error;
E_3 thermistor certificate error;
E_4 liquid in glass thermometer certificate error;
E_5 digital length gauge resolution error;
E_6 thermistor resolution error;
E_7 liquid in glass thermometer scale interval error;
E_8 misalignement system error.

2.4. Results analyses

After all measurements were done and using the Eqs. (1) and (2), the following results were obtained.

For the Ni-Ti 100 μm wire in air can be observed in Fig. 3 that the strain of total wire length was -3.6%, and the temperature hysteresis varies from 1.6 ºC to 12.3 ºC. The displacement uncertainty measurement was 0.93 mm in increasing readings, and 2.20 mm in decreasing readings (Tab. 2).

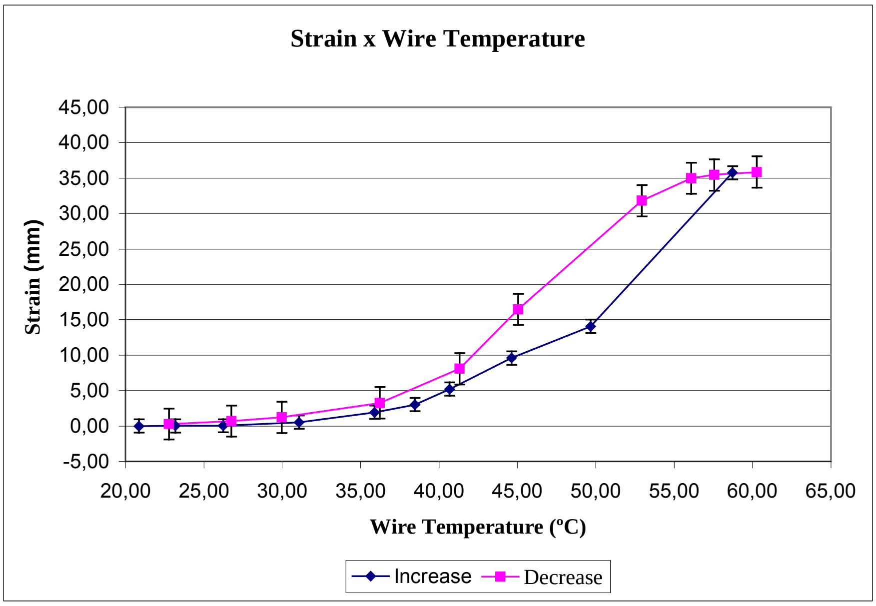


Figure 3. 100 µm wire in air Strain versus Wire temperature.

Table 2. Uncertainty budget 100 µm wire.

Quantity	Estimate	Standard Uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution
X_i	x_i	$u(x_i)$		c_i	$u_i(y)$
D_{rep}	35.756	0.398	Normal	1.00	0.398
C_{ced}	0.005 mm	0.002	Normal	1.00	0.003
C_{ter}	1 ºC	0.400	Normal	0.57	0.227
C_{tlv}	0 ºC	0.015	Normal	0.57	0.008
R_{ced}	0.005 mm	0.001	Rectangular	1.00	0.001
R_{ter}	0 ºC	0.029	Rectangular	0.57	0.016
V_{tlv}	0.1 ºC	0.029	Rectangular	0.57	0.016
D_{sis}	0 mm	0.058	Rectangular	1.00	0.058
				uc(y)= 0.4623 *U*= 0.93 mm	

Components of the uncertainty budget:

D_{rep} measured repeatability
C_{ced} digital length gauge calibration certificate
C_{ter} thermistor calibration certificate
C_{tlv} liquid in glass thermometer calibration certificate
R_{ced} digital length gauge resolution
R_{ter} digital thermometer resolution
V_{tlv} VDD liquid in glass thermometer
D_{sis} system misalignement.

The strain in Ni-Ti 150 µm wire in air, presented in Fig.4, was -5,0% of the total wire length, and the temperature hysteresis varies from 0.46 ºC to 9.09 ºC. The displacement uncertainty measurement was 1.86 mm in increasing readings, and 0.63 mm in decreasing readings (Tab. 3).

We notice too that the behavior was the same of a characteristic curve of Ni-Ti shape memory alloy.

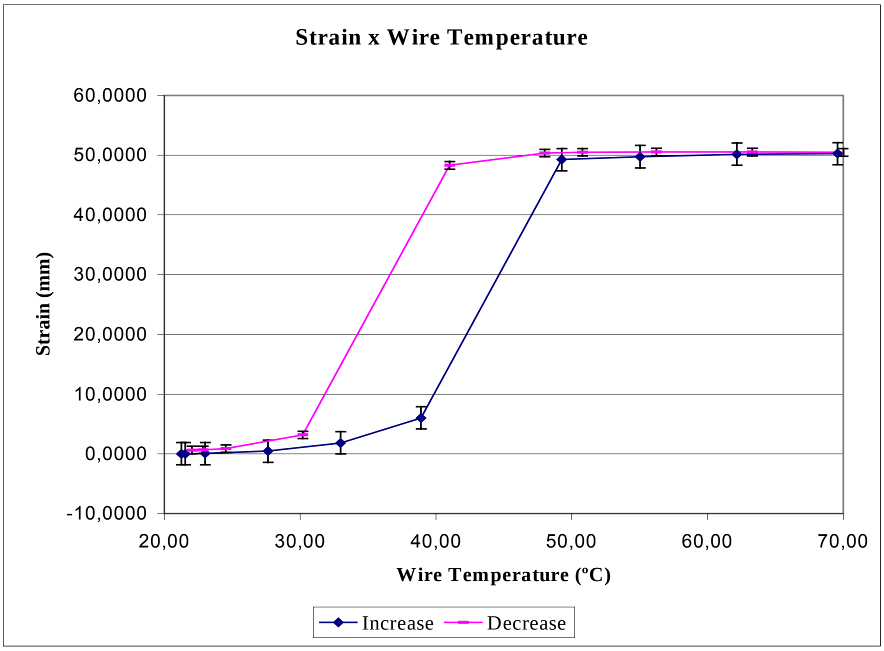


Figure 4. 150 µm wire in air Strain versus Wire temperature.

Table 3. Uncertainty budget 150 µm wire.

Quantity	Estimate	Standard Uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution
X_i	x_i	$u(x_i)$		c_i	$u_i(y)$
D_{rep}	49.7364	0.1973	Normal	1.000	0.197
C_{ced}	0.005 mm	0.003	Normal	1.000	0.003
C_{ter}	1 ºC	0.400	Normal	2.26	0.903
C_{tlv}	0 ºC	0.015	Normal	2.26	0.034
R_{ced}	0.005 mm	0.001	Retangular	1.000	0.001
R_{ter}	0 ºC	0.029	Retangular	2.26	0.065
V_{tlv}	0.1 ºC	0.029	Retangular	2.26	0.065
D_{sis}	0 mm	0.058	Retangular	1.000	0.058
				uc(y)= 0.9297 *U*= 1.86mm	

3. CONCLUSIONS

All measurements done have a nonlinear behavior and the temperature hysteresis was 12.3 ºC in 100 µm wire and 9.1 ºC in 150 µm wire in the air. All results showed good repeatability and reproducibility in increasing measurements of displacement.

The founded expanded uncertainties of measurement were 0.9 mm and 1.9 mm in the measurements in air for wires of 100µm and 150µm of diameter, respectively. These expanded uncertainties were the expected for these lengths wire.

The strains of 3,6% and 5,0% for the wires of 100µm and 150µm are in accordance with the specifications of the manufacturers. Such manufacturers specifies the strains between 3 and 5% of the total length.

Comparing the graph of Fig. 1 with the results obtained in the experimental tests (Figs. 3 and 4), we verify that the graph is the characteristic curve of a shape memory alloy.

4. REFERENCES

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5. RESPONSIBILITY NOTICE

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