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EXPERIMENTAL CHARACTERIZATION OF LINEAR SHAPE MEMORY ALLOY ACTUATORS

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Abstract. *The use of shape memory alloy actuator in high-technology application is increasing. Shape memory alloys* (SMA) *became an important material due to its capacity to shape recovery when subjected to a thermomechanical load. This work aims to develop an experimental investigation of linear shape memory alloy actuator using stress-assisted two-way memory effect. An experimental apparatus is built to characterize a linear SMA actuator bias spring. Several situations are investigated highlighting the general thermomechanical behavior of the system. The experimental results show that the characterization methodology used can be employed for design purposes, defining the best configuration and parameters according to the desired actuation condition.*

Keywords: *Shape memory alloy, actuator, thermomechanical coupling, experimental analysis*

1. INTRODUCTION

SMAs (Shape Memory Alloy) have been used in a wide variety of applications in different fields. The SMA elements used within actuators are normally biased by conventional springs or by another SMA element. There are many factors that need to be taken into consideration, such as power-to-weight ratio, the force/displacement produced and operation frequency (Lagoudas, 2008). Shape Memory Alloy is widely used as actuators since it can achieve high power-to-weight ratio when restricted produce very high stress (300-400 MPa) and gives large displacement, around 4-5% (Banerjee and Gurung, 2016). Cycling of 3% strain and over 200 MPa stress generates more than a joule of work output per cycle, this places SMA actuator among the highest known work densities (Krulevitch et al., 1996). Therefore, the research regarding SMA actuators has increased over the last years.

The properties aforementioned are a consequence of the singular behavior provided by this class of materials, this is a consequence of the martensitic phase transformations (Otsuka and Wayman, 1999). The physical behavior of an SMA is given as a function of temperature, strain and stress. It is necessary an exhaustive investigation about the thermomechanical behavior to better understand and successfully applicate these alloys.

Shape memory actuators can be arranged in different configurations, this is achieved using an SMA element coupled with a spring or another SMA in antagonistic configuration (Monteiro et al., 2013; Sofla et al., 2008; Strelec and Lagoudas, 2002).

Technological progress trends toward smart systems with adaptive or intelligent functions which implies in an increase use of sensors, actuators and micro-controllers (Jani et al., 2014). SMAs is commonly applied as sensors and actuators in smart systems, as a consequence, proper evaluation and investigation of the behavior for different designs of SMA actuators turns into a crucial task (Monteiro et al., 2017). This being said, the present work aims to further describe the thermomechanical behavior of linear SMA actuators, parameters such as temperature, displacement, electrical current (for heating by Joule Effect) and actuation force generated are investigated. For this, an experimental apparatus is built in order to test the performance of a linear SMA actuator bias spring.

2. EXPERIMENTAL SET-UP

The thermal characterization of SMA wire (Flexinol, from Dynalloy) with 0,381 mm diameter is performed considering a Netzsch Digital Scanning Calorimeter (DSC) 200 F3. The austenite phase transformation starts at 72.9ºC and austenite finish at 85.6ºC, while martensite starts at 73.3ºC and martensite finish at 17.5ºC. Tensile tests are carried out using an INSTRON universal testing machine (Model 5996) at a constant temperature of 21ºC and with a prescribed strain rate $\dot{\varepsilon} = 0{,}6\ s^{-}$. Figure 1 presents result stress-strain curve.

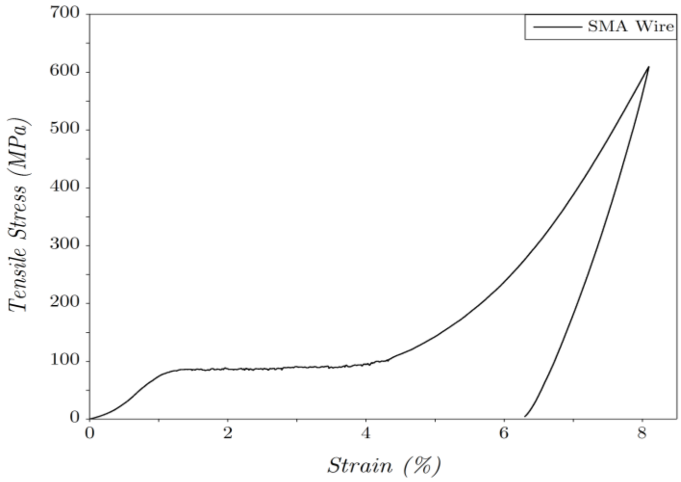


Figure 1 - Stress x Strain of a NiTi wire.

An experimental apparatus is developed in order to characterize the thermomechanical behavior of SMA actuator, illustrated in Figure 2. An actual photo of this apparatus is shown in Figure 3, the screw holds the system while the is applied the deformation on the SMA wire. The configuration is the one employed throughout this work. For electrical current measure, it's employed a Hall Effect-based linear current sensor. The temperature of the wire is measured with a thermographic camera (FLIR A320, from Flir Systems). Displacement is measured with the help of a displacement transducer (PY-1-F-025-S01M, from GEFRAN) and for the actuation force, a load cell sensor is applied (SV-20, from Alfa Instrumentos). The spring stiffness is estimated as 1500 N/m. A predefined set of initial conditions is tested. All tests are carried out using 20 N for pre-load (linear spring) and 4.5% of SMA wire pre-strain, this mechanical loading produces a stress-induced reorientation of martensite, that can be done through the apparatus. Heating–cooling cycles through Joule effect are employed in order to induce SMA actuation. Joule effect is used for heating and natural convection for cooling.

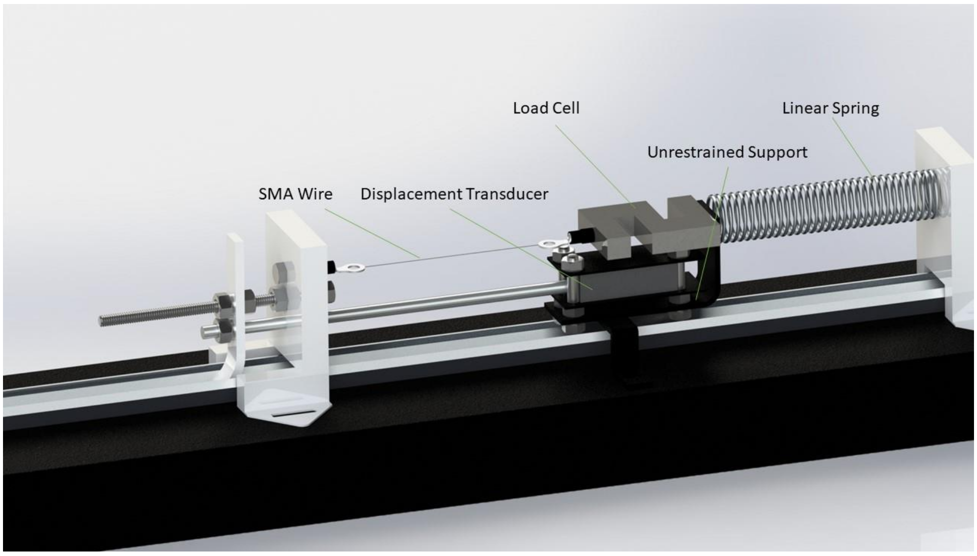


Figure 2 – Conception of the Experimental Apparatus

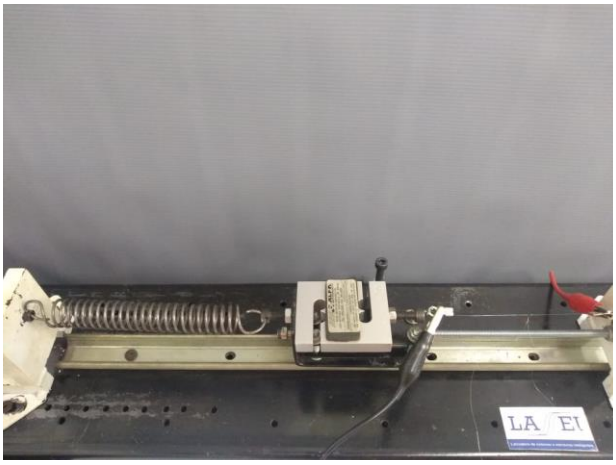


Figure 3 – Experimental Apparatus

3. RESULTS

The results related to SMA Actuator are presented. Basically, electrical currents of 0.5 A, 1.0 A, 1.5A and 2.0A are imposed to the SMA actuator and different responses evaluated. Ten heating–cooling cycles are employed in order to induce SMA actuation. Figure 4 illustrates the parameters of a typical test with 1.0 A and 20 N pre-load, this result suggests a cyclical behavior from this actuator.

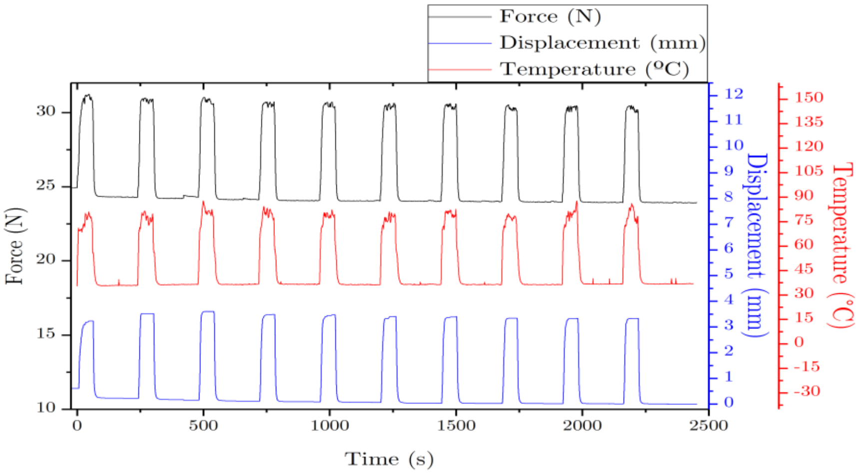
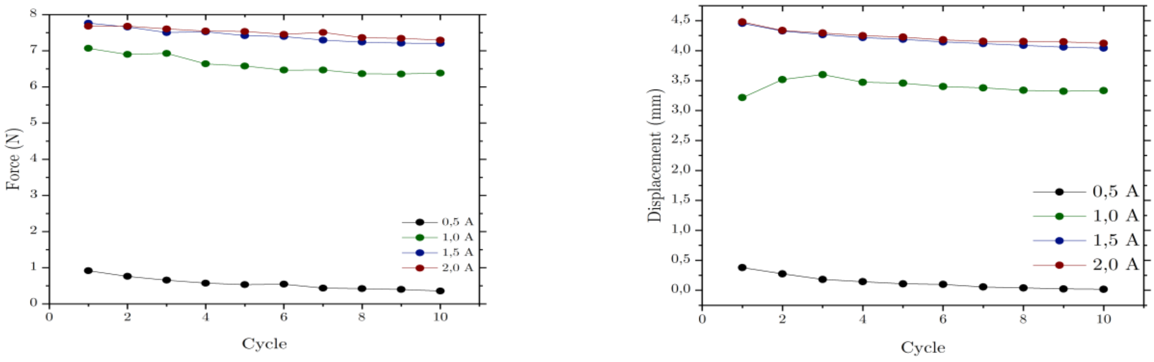


Figure 4 - Force x Displacement x Temperature in Time with 1.0 A.

For a better understanding of how the electrical current affects each mechanical property, each parameter is singled out and placed against another parameter. Figure 5(a) displays the amplitude of force in each cycle, indicating a stabilization around the fifth cycle and, as expected, shows an increase in force produced as the current goes up, until a limit. The same can be observed in figure 5(b) although, in this case, for displacement. As expected, actuator stress and displacement increase as the applied electrical current is increased. However, with 2A, the results are very similar to 1.5A, indicating that the transformation phase temperatures have already been achieved with 1.5A. Furthermore, Figure 4 and 5 proves the repeatability of this actuator, since (after the fourth cycle) the change of force and displacement – from one cycle to the one preceding it – is minimum.



(a) (b)

Figure 5: (a) Force x Cycle and (b) – Displacement x Cycle

Figure 6 exhibit the last cycle of displacement versus temperature for electrical currents of 0.5 A, 1.0 A, 1.5A and 2.0 A. When submitted to 0.5 A, the displacement attained is not big enough to be perceived. Figure 7 shows force versus displacement curves for each electrical current, the data plotted shows that this actuator dislocate according to the spring and its maximum when the current is of 2.0 A.

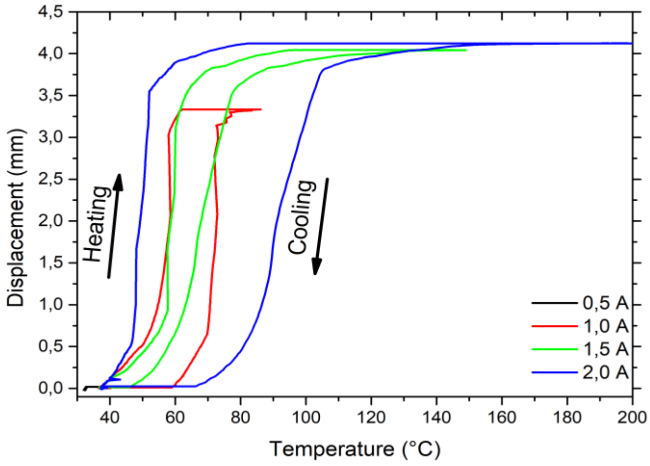


Figure 6 – Displacement x Temperature – 1.0 A

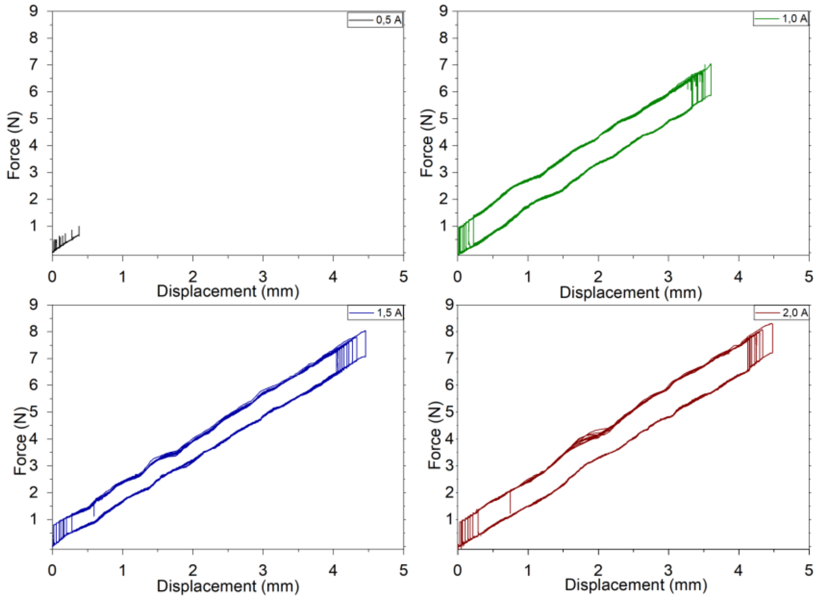


Figure 7 – Force x Displacement for 0.5 A, 1.0 A, 1.5 A and 2.0 A electrical current

For the last cycle the data gathered is shown in Table 1. The wire employed and the steel spring implemented, electrical current of 1.5 A seems to be enough for complete transformation into austenitic phase, since from this point the apparatus doesn't present significative variation of displacement and force.

Table 1. Main results for each Electrical Current – Last Cycle

Electrical Current (A)	Displacement (mm)	Force (N)	Temperature (ºC)
0.5	0.02	0.39	40
1.0	3.32	6.36	88
1.5	4.05	7.2	144
2.0	4.14	7.34	234

4. CONCLUSION

The ability to outline the behavior of actuators under different circumstances is important to develop an optimized actuator for each application. This paper presents an experimental characterization of a linear shape memory alloy actuator in a bias spring configuration. The data collected presents repeatability of displacement, force produced and temperature when submitted to the same initial conditions, as well for each thermal cycle. The experimental procedure adopted and the results produced in this work shows that this actuator allows one to choose parameters such as electrical current and spring stiffness required to reach the desired application, predicting how the SMA actuator will respond under different conditions. Furthermore, this research can be used as an experimental methodology to define the best configuration and parameters according to the actuation requirements. At this point, the experimental apparatus proved capable of evaluate displacement, force and temperature. Besides, it is possible to single out the cycle where stabilization occurs and the minimum electrical current for maximum actuation, resulting in energetic efficiency.

5. ACKNOWLEDGEMENTS

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