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Effects of strain aging in NiTi SMA wire for dampers

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Abstract

The thermo-mechanical properties of Shape Memory Alloys (SMA) as smart materials suggest their application as actuators, but also as dampers, thanks to the high damping properties during the hysteresis of the thermo-elastic martensitic transformation. Damping in civil engineering is needed to minimize earthquake effects on buildings, and also to limit the damage produced by wind or traffic induced oscillations in stayed cables in bridges. In this work, we explore the consequences of strain aging the material at moderate temperatures (100ºC). A quasi-static stress and temperature aging of NiTi SMA wires of 2.46 mm diameter was done at 373 K. The experimental measurements establish a monotonic effect related to the introduced strain. Aging under larger strains modifies the hysteretic shape and induces an increase in the maximal stress on the transformation from 600 MPa to 800-1000 MPa. Aging at 373 K under 7-8 % strain, the effect was up to 200 MPa in three months and near 400 MPa in eight months. The modified stress-strain curves suggest potential application as dampers under larger summer-winter temperature changes, i.e., from 233 to 323 K.

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Keywords: SMA; NiTi; dampers; aging; strain aging

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1. Introduction

Shape Memory Alloys have particular thermomechanical properties due to a martensitic phase change between metastable phases. The phase change can be induced thermally or mechanically in thermoelastic alloys [1]. The SMA materials can be used as actuators (SME) but also as dampers (hysteresis in the transformation).

SMA dampers in civil engineering have been proved to be efficient in specific cases. In the first place, for smoothing the earthquake effects, SMA dampers have been tested in a steel portico [2, 3]. In the second place, SMA dampers made of NiTi wires have been also tested for reducing vibration amplitude of stayed cables in bridges [4, 5]. Several issues on real application refer to limit stress amplitudes to obtain favorable fatigue life [5-8]. However, other concerns might exist, essentially due to accidental overstraining of the wires that form the dampers, for instance, during installation, and to effects of local temperature (because of sunlight) over the strained dampers. In this work, we report results on the behaviour of SE (superelastic) NiTi wires under these situations.

2. Experimental

For NiTi alloy, several effects induced by temperature aging have been described, usually for temperatures greater than 473 K, which induce measurable structural effects [9, 10]. For our experimental study, focused on engineering applications, we used a NiTi alloy in the pseudo-elastic state, furnished by Memry (CT, USA), a division of SAES Getters (Italy), and previously, by Special Metals Corp. (New Hartford, New York, USA). For the wires, the surface of the samples was finished in a light (gray) oxide surface with a diameter of 2.46 mm. The nominal composition from the furnisher was Ti and 55.95 wt% Ni. The As temperature measured by DSC was 237 K. We study here the stress-temperature aging.

A “static” strain and temperature aging of a NiTi SMA was performed at 373 K, using wires with a diameter of 2.46 mm, using the device shown in Fig. 1a. Strain-temperature aging consists in inducing a constant strain on the sample, and “at constant strain” the material is introduced inside a furnace at constant temperature (i.e., 373 K) for different times. We have performed experiments between one month and 7.5 months of strain-temperature aging. The wires were tested in a conventional MTS 810 mechanical testing machine that works at room temperature in an air-conditioned room (293 K), at a speed of 100 s/cycle.

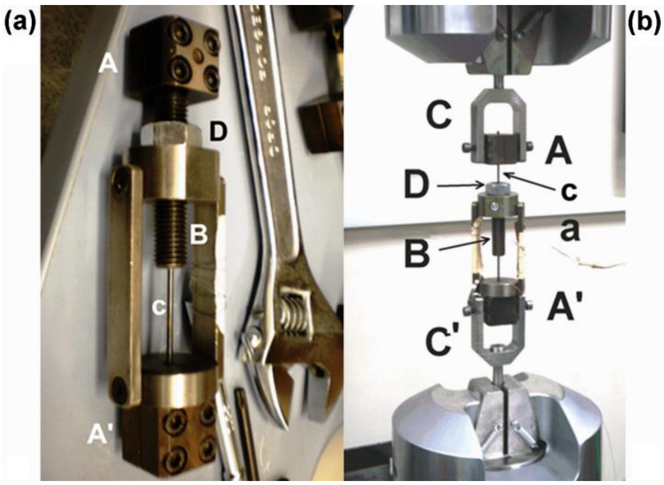

Fig. 1. (a) adapted device for stress-temperature aging. A, A’: the cubes that fasten the ends of the sample “c”. B and D: screw and bolt that allows to modify the sample length by stress; (b) positioning the device in the MTS without dismounting the sample, to work under traction. C and C’: auxiliary grips; “a”: room temperature thermocouple.

After aging, the stress-strain working cycles are performed at 100 s/cycle, on 12 cm long samples. The cycling is performed using the auxiliary grips C and C’ in Fig. 1b, which are joined to the cubes by screws inserted into the appropriate holes. Fig. 1b shows the positioning of the device when working in traction. The shape of the samples is strictly cylindrical. The use of the same device in the aging and in the MTS prevents the parasitic effects created by the grips at the ends of the samples when mounting and dismounting. In Fig 1b the letter “a” indicates the thermocouple situated in the neighboring of the sample. It is possible to place a K-thermocouple in the sample c for measurement and to record the sample temperature and its cycling evolution.

3. Results and discussion

The experimental measurements established a monotonic effect related to the strain introduced. As a constant strain is applied, the stress state is initially in the plateau of the transformation cycle; in our case it is approximately 600 MPa at room temperature. Increasing the temperature produces, via the Clausius-Clapeyron relationship, an increase of stress of 6.3 MPa/K for these wires in the zone of beta-martensite coexistence [11]; then approximately 1000 MPa would be applied to the samples at 373 K. Aging under moderate strain produces a strong change in the hysteresis shape. The Fig. 2 shows the stress-strain cycles for a non-aged wire (a), and the first cycle for a wire aged at 373 K with 4.5% strain (b). Note that two zones can be pointed on the cycle: to near 4% (corresponding to “previously in martensite”, where stress to cycle is reduced) and from 4 to 8% (corresponding to “non-transformed material”, where stress to transform is increased). The cycles for aged samples result spanning a larger stress interval.

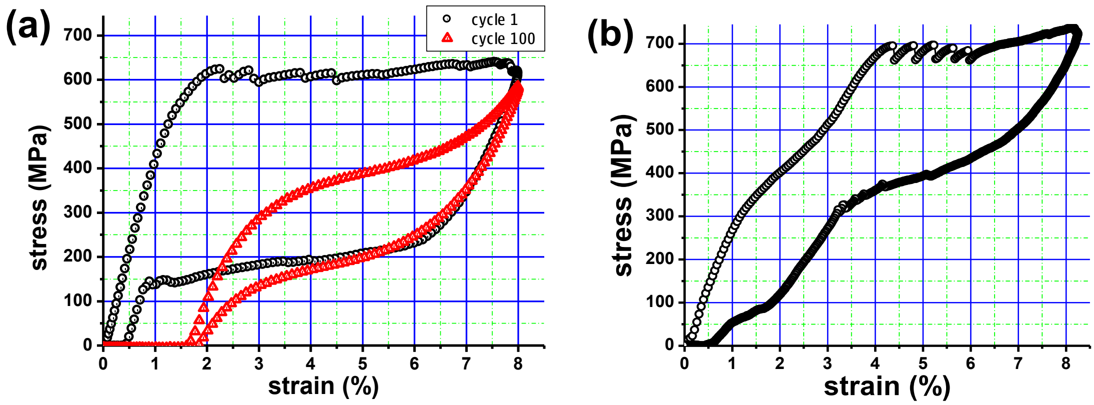

Fig. 2. (a) Stress-strain at room temperature for NiTi wire (cycle 1, black circles; cycle 100, red triangles). The flag-shaped cycle transforms to an “S” shaped cycle. (b) First cycle for a sample strained to 4.5% and then aged at 373 K for 93 days. The shape of the cycle has changed considerably from the non-aged wire, and the maximum stress has increased.

Aging under larger strains modifies the hysteretic shape and induces an increase in the maximal stress in the transformation from 600 MPa to 800-1000 MPa (Fig. 3). Applying an aging at 373 K and a strain of up to 7-8 %, the effect was close to 200 MPa the first three months, and slower evolution afterwards, near 400 MPa in eight months (Fig. 3, (a) and (b)). The modification of the stress-strain pattern of the NiTi wires, in the sense of qualitatively approaching the cold worked wire cycles [12] should be interpreted as due to the high stresses applied to the samples in the constant strain aging at 373 K. The sample aged one month at 100ºC under strain of 6.8% had an As 6ºC higher than the non-aged sample, as measured by DSC. The small change of thermal transformation, as compared to the mechanical one, together with the Clauius-Clapeyron coefficient value relating stress at transformation and temperature, near 6.3 MPa/K [11], suggests that some plastic deformation of martensite might exist, leaving a distribution of internal stresses provoking the observed cycles with displacement and extension of the transformation.

The results suggest potential application in dampers under larger summer-winter temperature changes, i.e., from 238 K to 323 K, as sloped cycles spanning larger stress interval mean that significant hysteresis cycles exist in these wires for a wider temperature interval [4], allowing damping at different temperatures.

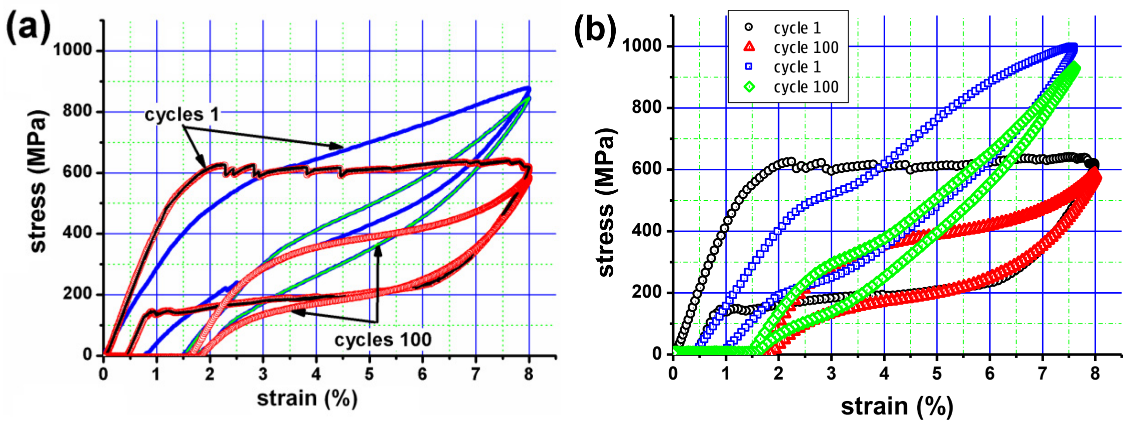

Fig. 3. (a) Stress-strain for non aged NiTi wire (cycle 1, black and red; cycle 100, red), and for NiTi wire strained to 6.8 % and aged 87 days at 373 K (cycle 1, blue; cycle 100, green). (b) Stress-strain for non aged NiTi wire (cycle 1, black circles; cycle 100 red triangles), and for NiTi wire strained to 6.8% and aged 230 days at 373 K (cycle 1, blue squares; cycle 100. green diamonds).

4. Conclusions

Strain aging of NiTi pseudoelastic wires intended for dampers has been studied. Aged wires under strain had a larger spanning of stress to reach 8% strain. The increase of stress was near 200 MPa for three month aging at 373K, and 400 MPa for eight month aging at 373 K. The change of stress-strain cycles is attributed to the possibility of martensite plastic deformation at the high stresses implied by the aging under large strain at 373 K. The martensite plastic deformation would leave a distribution of residual stresses causing displacement and increased extension of the transformation.

The hysteresis cycles showing a large stress span could be useful to damp vibrations in civil engineering because an extension on working temperatures is obtained.

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