Effects of strain aging in NiTi SMA wire for dampers

C. Auguet[1], A. Isalgue[1], V. Torra[2], G. Carreras[2], F.C. Lovey[3]

1) EPSEB and FNB, Dep. Física Aplicada UPC, J. Girona s/n, 08034 Barcelona, Spain

2) PRG, Villarroel 162, 08036 Barcelona, Catalonia, Spain E-08003, Barcelona; Spain

3) Centro Atómico Bariloche e Instituto Balseiro, S.C. Bariloche, 8400, Argentina

Abstract

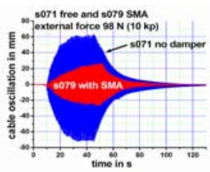
The thermo-mechanical properties of Shape Memory Alloys (SMA) as smart materials suggest their application as actuators, but also as dampers, because the hysteresis of their thermo-elastic martensitic transformation. Damping in Civil Engineering is needed to minimize earthquake effects on buildings, and also to limit the damage produced by wind or traffic induced oscillations in stayed cables in bridges. We had characterized NiTi wires for dampers in Civil Engineering, and tested them in facilities, where they showed good performance.

In this work, we explore the consequences of strain aging the material at moderate temperatures. 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 strain introduced. 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 close to 45 MPa/month. The effect was modified by the initial state of the samples (as-received or previously cycled). The modified stress-strain curves suggest potential application as dampers under larger summer-winter temperature changes, i.e., from 233 to 323 K. %.

Introduction

SMA dampers in a portico:

Left: The portico used to study the damping effect of SMA damper. The portico is fixed in a carriage over a set of wheels and oscillating by the action of an external hydraulic piston. The SMA dampers (two wires of CuAlBe or of NiTi) were situated in the portico diagonals and completed by steel wires. The reaction wall for the hydraulic piston is situated in the portico rear. The reversed V-shaped permits a direct measure of the net displacement of the upper portico beam respect the basis.

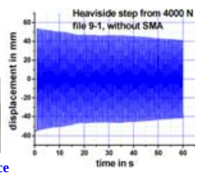


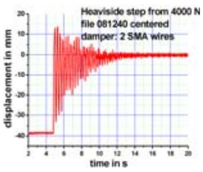
The cable displacements: for equal excitation without and with SMA damper.

SMA dampers in stayed cables of bridges:

Iroise Bridge, France

IFSTTAR-Nantes-France



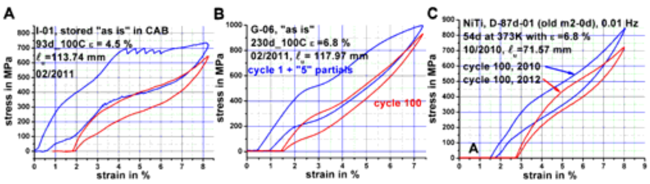


Study of the 50 m length cable of IFSTTAR. **Left::** free oscillation. **.Right::** Damped behavior by SMA

Results and discussion

Weathering? Effect of T and strain?

A "static" stress and temperature aging of NiTi SMA performed at 373 K, using wires with 2.46 mm diameter. Experimental measurements established a monotonic effect related to strain introduced and to initial sample state on the strain-temperature aging. Aging under larger strains modified hysteretic shape and induced increase in the maximal stress in transformation, from 600 MPa to 800-1000 MPa. Aging at 373 K and strain up to 7-8 %, effect close to 45 MPa/month. The effect was modified by the initial state of the samples, i.e., as-received or previously cycled. Results suggest potential application in dampers under larger summer-winter changes, i.e., from 233 to 323 K.



Temperature-stress aging in NiTi. A: cycle 1 and 100 in a sample with 3 months at 4.5 %. B: Cycle 1 and 100, sample with 7.5 months at 6.8 %. C: cycle 100 after an aging of 1.5 months at 6.8 % in a previously cycled sample. Cycle 100, 2012 was the cycle 100 of a series of working cycles realized after a year at room temperature and stress-free

The strain-aging, a "static" effect, was irrelevant for most morphing actions of immediate application with NiTi alloy. It requires at least 3 or 4 months at 373 K in a "full deformation" state. The "static" effect for strains up to 7-8 % should be avoided for morphing actions. In general, the deformation in one SMA actuator should be less than 4 % to ensure appropriate fracture-life [6]. In travels in light planes, the number of hours/day and the strains are limited, and one year of work can be considered "similar" that one complete month of stress-aging. Then, the working time and required deformation do not agree with the necessary conditions of static actions for a quantitative change of the SMA state. The critical time under temperature and stress in wings for light planes is limited in comparison with the complete time of travels. Expecting two travels each day, the total time of SMA wires being warmed and working under stress (take off and landing) remain under 1-2 h with an appropriate geometrical configuration that permits moderate strain (i.e., under 4 %) with a reduced number complete of actions on-off. In fact, if the more relevant actions of morphing only can be required in the immediate times close to take-off and landing, it is expected that the accumulative effects for several travels remain in the guaranteed working domains (more than 4000 working cycles for strains of 4%). The results of strain-temperature aging establish that partial strains cannot induce permanent changes in the hysteretic shape. The eventual permanent action associate to large flutter (turbulence) in the complete travel requires "higher" working frequencies, i.e., partial cycles and internal loops in time intervals in 1-2 s in heating-cooling cycles cannot be considered in this work.

The results of strain-temperature aging suggest that the changes produced by the strained and warmed SMA wires in take-off and landing would not be relevant. Permanent changes produced by the strain-aging require high percent of deformation (i.e., 8%, excluded in our considerations) and larger times as, for instance, more than one accumulative warmed month (i.e., figure 4).

The hysteretic S-shaped behaviour from 0 to 600 MPa allows for partial cycles at low external temperatures, as shown in Fig. 1a [5, 6, 29], and even lower temperatures with aged samples (and higher stress to fully transform) as in Fig. 4a and 4b. Progressive cooling establishes a gradual increase in the quantity of martensite with a complementary progressive reduced quantity of the parent phase and reduced hysteresis cycle. At 600 MPa, the associated temperature domain was satisfactory for use as a damper in winter weather (i.e., to a low temperature as 258 K) [6]. In extreme colder climates, the temperature oscillation between summer and winter can approach 80 K (i.e., a temperature as low as 233 K). The aging results for strains near 8% establish that an increase in the aging time (from 2 to 7.5 months) induces an increase in the maximal value of the stress (Fig. 4a and 4b). Changes in the stress up to 800-1000 MPa are beneficial for damping in extreme colder temperatures. For instance, in Fig. 1a, 600 MPa suggests a reasonable behaviour for temperatures as low as 253 K, but for aged samples with 900-1000 MPa (as in Fig. 4b), the permitted working temperatures were as low as 233 K.

The different results for samples A and B (different wire diameter, and same nominal composition) could be considered, as a working hypothesis, a radial action. The strain-aging induces an increase of critical stress in A wires and for B wires induce an increase of the Ms value. In fact, the strain-aging converts the samples of B wires to martensite. A detailed study of the structural characteristics remains a future work to be done, but it is necessary to consider that the structural changes associated to "minor" effects on the transformation temperatures (i.e., Ms) are very small and, usually, under the resolution limit. The action of quench in single crystals of Cu-based alloys changes the Ms by, for instance, 50 K. Structurally, the evolution was observed by neutrons and positrons [21, 30]. Minor actions of the tracking between the Ms and the external temperature were observed in single crystals working in the resolution limit by X-ray diffraction, and also using neutrons in the ILL facility (Grenoble, France) [22, 23]. In fact, the changes in Ms of SMA are much more sensitive that the structural changes.

Initial transformation temperatures (°C)

Cu-Al-Ag compositions

Acknowledgements

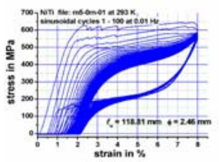
The authors would like to thank to the MICINN for financial support

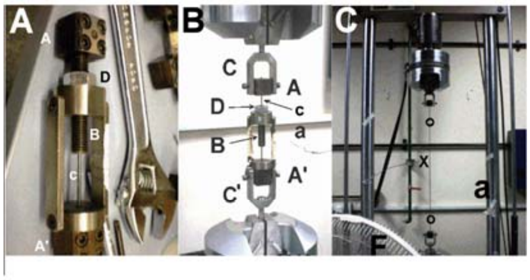
Experimental Procedure

For NiTi alloy, several effects induced by temperature aging have been described, usually for temperatures greater than 473 K, which induce measurable structural effects **[**13, 14**]**. 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. According to the supplier, the As temperatures were 248/247 K. The nominal composition was 55.95 wt% Ni. We study the stress-temperature aging.

Device for the strain-temperature aging: The sample (NiTi wire) could be strained, aged at a given temperature, and then mechanically tested

Mechanical cycles for NiTi wire as furnished





Transformation temperatures (°C) during cycling

Cu-Al-Ag at RT: martensitic (AG0 and AG3)

Conclusions

- Cu-Al-Ag exhibit high martensitic transformation temperatures
- The alloys have large hysteresis and transformation interval
- Thermal degradation properties occurs easily when cycling