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Scaling law in fatigue tests of shape memory alloy specimens

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ABSTRACT

Nickel-Titanium shape memory alloys are used in several areas, spanning from surgery to automotive industry and from dental devices to civil engineering applications. In all these cases the material undergoes cycles of loading-unloading and the fatigue life is the basic ultimate limit state.
The literature is rich of fatigue studies on short specimens, but the accumulation problem was discussed only recently (see the reference below). In addition, sometimes the applications require that long wires are adopted and one meets the problem of scaling the results achieved for short specimens to these long elements.

This paper reports the results of an experimental campaign where the results achieved for short and long specimens are compared, and a suitable scaling law is derived.
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1. INTRODUCTION

The fatigue issue is quite special when dealing with shape memory alloys (SMA) (Casciati et al, 2007; Casciati and Marzi, 2010). Provided that the material is sent by the producer after the suitable ageing process, the specimen must first undergo a mechanical training and this results in a residual elongation often reported as “creep”. The cycles of loading-unloading to fatigue are then planned from this residual to a desired final elongation. Sometimes the fatigue test starts from this residual but the cycles are conceived up to a maximum elongation, which is then decreased cyclically to respect a given variation between the minimum and the maximum of each cycle.

During such a test, one reaches the stress after which the hysteresis is significant. This stress does not vary in a significant way up to strains of 6-10% and this suggests that the test must be performed in span control.

When the universal testing machine is used, the specimen is mounted vertically. For bars one must pay attention to drive the unloading in force control, to avoid unstabilizing compressions. The adoption of wires and suitable articulated grips allow one to conduct all the test in span control. But the maximum length of the specimen is limited to a few centimeters.

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In civil applications this SMA elements are anchored between distant points and this suggests to carry out test on long specimens. This can be done with the help of a shaking table, where the specimen is mounted horizontally.

The problem is to check the consistency of the results obtained following these two procedures.

2. THE EXPERIMENTAL MOCK-UP

The author managed two different sets of Ni-Ti alloy: for both of them wires of diameters 0.1, 0.2 and 0.5 mm are available. This paper only reports about tests on the 0.2 mm diameter wires.

The way wire specimens are mounted on the testing universal machine is shown in Figure 1. It is seen that the specimen length can range in the interval from 3 to 10 c. It is worth noting that the weight of each device is 124 g. The tests are carried out in span control, with the readings of the load cell not fully reliable, since one is working under 1/1000 of the machine load potential.

Fig. 1 Universal testing machine: detail of the additional devices used to fix the specimens to the grips.

For longer specimens (from 15 to 120 cm), the experimental mock-up is the one in Figure 2. There is a reinforced concrete mass on the ground close to the shaking table: the wire links opposite points on the two sides.

Fig. 2 Experimental mock-up adopted for testing wire specimens of length from 15 to 100 cm.

The test is defined by the following steps, all steps with sampling rate 100 points per second:

1) the specimen training is made of 100 cycles from 0 to 8% of deformation at 0.2 cycles per second;
2) after the training there is a permanent elongation of the wire: further cycles at 0.2 cycles per second move from this new starting point to a final length which corresponds to 4, 6, or 8% in the different tests;
3) the cycles are continued up to the specimen failure.

3. A SYNTHESIS OF THE RESULTS

Just to clarify the difference between the two sets of material, Figure 3 shows 10 cycles after the training of material 1, while Figure 4 is referred to material 2. It is seen that the two materials differ mainly for the position of the hysteresis loop in relation to the stress level. There is a high frequency content which could be easily removed by filtering, as well as an offset in the initial value of the load cell (the measures are quite close to its resolution) which requires a vertical translation of the plot.

For both the materials, and specimens of different lengths, the number of cycles to fatigue failure was always of a few thousands.

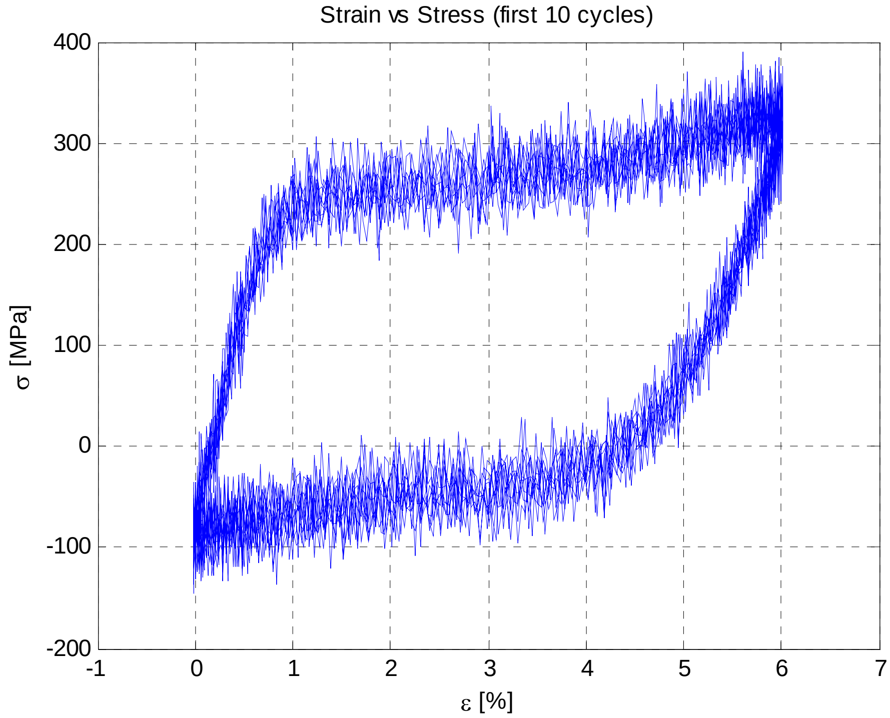

Fig. 3 Hysteresis cycles for material 1. Specimen length 100 mm. Training 8%.

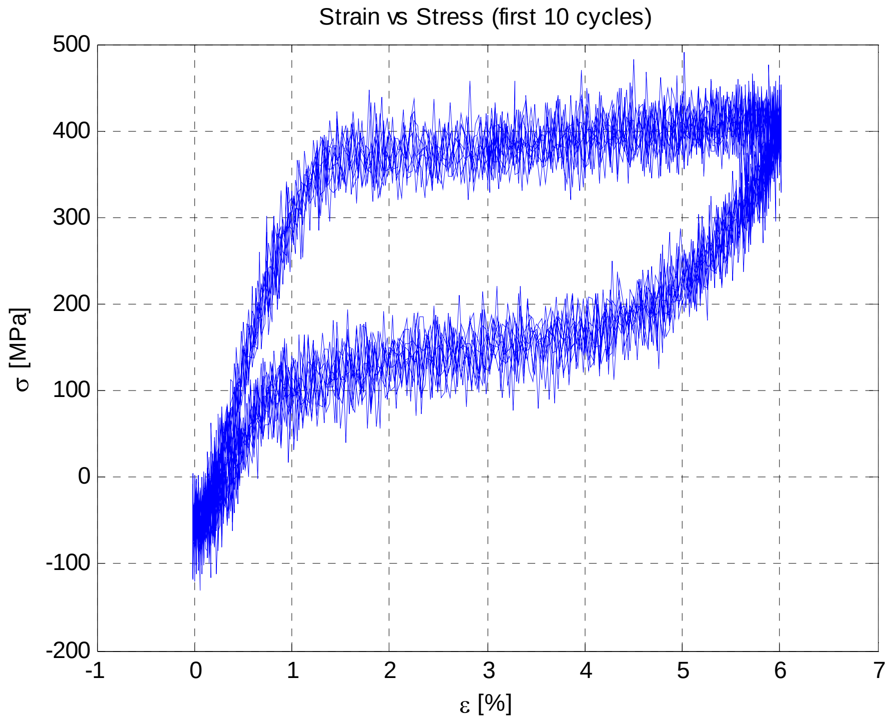

Fig. 4 Hysteresis cycles for material 2. Specimen length 50 mm. Training at 10%.

4. CONCLUSIONS

The experimental effort reported in this paper confirms once again that the exploitation of shape memory alloy (SMA) properties as energy dissipater, i.e., as additional damping, in a structural system may enter in conflict with the limited number of cycles to failure the specimens show when submitted to fatigue tests.

In particular, despite studies cited in the literature seems to be promising, the absolute value of the stress has no meaning in this kind of study. Indeed, in order to produce hysteresis cycles, the loading has to achieve the plateau of transformation, whichever its stress is, and the number of cycles at this level of stress always results in a few thousands. A deeper report on the results will be provided in the companion extended paper.

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