CYCLIC LOADING EFFECTS ON NITI ALLOYS UNDER BIAXIAL CONDITIONS

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Summary In this work, the influence of the direction and the history of thermomechanical loading of NiTi shape memory alloys on the overall material behavior is experimentally investigated. In the first part, cyclic biaxial mechanical loading has been applied to cross-shaped specimens under constant temperature. The residual strains of selected points from the sample surface are extracted and analyzed. The second part of the study concerns thermomechanical testing of textured samples cut from a laminated plate under complex cyclic loading at different temperature levels. The evolution of residual strains and the transformation threshold are correlated to the history of loading and the amplitude of transformation strain. Anisotropic effects are studied by performing those same experiments on different directions according to the rolling direction of the laminated plate.

INTRODUCTION

Cyclic mechanical loading on NiTi shape memory alloys (SMA) induces a noticeable change in the actuation stroke – recoverable transformation strain and martensitic transformation stress limits. The general behavior under one-dimensional loading conditions depends on the temperature of the sample. This is a phenomenon commonly associated to transformation-induced plasticity [1], but retained martensite that can transform back at higher temperature is also present [2]. If such behavior is well understood for uniaxial tests, the anisotropic evolution of the SMA response upon cyclic has not been extensively studied. Moreover, SMAs are known to exhibit strong anisotropy for superelastic loading cases [3], since forming conditions induce texture in the polycrystal. This has a direct effect on the behavior under biaxial loading as well, as has been investigated in recent works [4].

In this paper, a series of thermomechanical cyclic tests on NiTi samples is presented. It aims at investigating the effect of three separate parameters of cyclic loading to the change of the material response, namely the evolution of residual strains and the transformation threshold in terms of stresses. These three parameters are the number of cycles, the magnitude of ultimate applied strain and the loading direction. The first part of this series concerns isothermal biaxial loading of cross-shaped specimens along their two directions. The evolution of the overall kinematic fields of the specimen surface is monitored using DIC. The second part concerns thermomechanical loading of one-dimensional specimens at different temperatures. A complex cyclic loading path is applied to observe the evolution of material properties, followed by heating to measure the recoverable residual strain.

THERMOMECHANICAL TESTING IN ONE DIMENSION

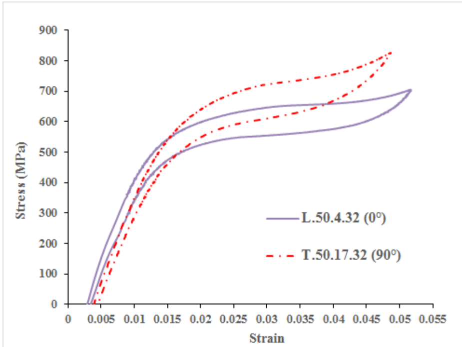
One-dimensional samples cut along the two directions of a rolled NiTi plate at 50.6% Ni atomic content were subjected to the following loading path: tension towards 3% strain and return to zero force, repeated 15 times in total. Then, tension to 5% strain and return to zero force. This sequence of 16 cycles is repeated a second time, followed by two last cycles to 3%. Tests were performed at a strain-rate up to $10^{-4}s^{-1}$ and the temperature was always controlled at 30, 40 or 50°C. At the end of the mechanical loading, the samples were heated up to 100°C to measure the recoverable residual strain. In the results presented in Figure 1, it seems to reach saturated values for the loading of 3%, but the 5% target in terms of strain induces further residual strain.

ISOTHERMAL NON PROPORTIONAL BIAXIAL TESTING

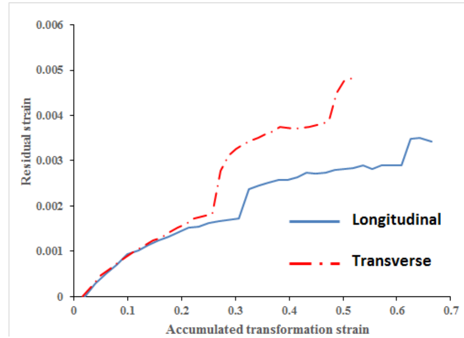
Cross-shaped samples are subjected to repeated biaxial loading at a temperature of 50°C. The first sequence is composed of tension cycles along the East-West direction and compression along the North-South direction. In the second sequence, the force is maintained at zero along East-West, whereas tension is applied in North-South. Two cycles of the first sequence are repeated during the third sequence. Figure 2 follows the overall force-displacement response for the specimen, as tracked by the test machine controller. Strain fields on the surface of the sample are tracked by Digital Image Correlation (DIC) [5].

CONCLUSION

The aspects of residual strain and transformation threshold are investigated experimentally for the superelastic behavior of NiTi alloys. Cyclic loading has been applied in one- and two-dimensional configurations. The effects of transformation strain magnitude and anisotropy have been studied and related to the material properties.

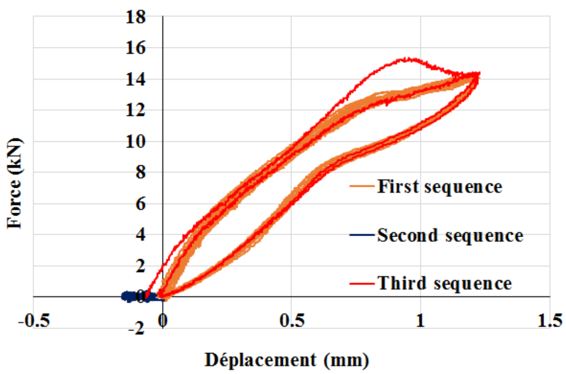


(a) Stress-strain diagram for the 32nd cycle

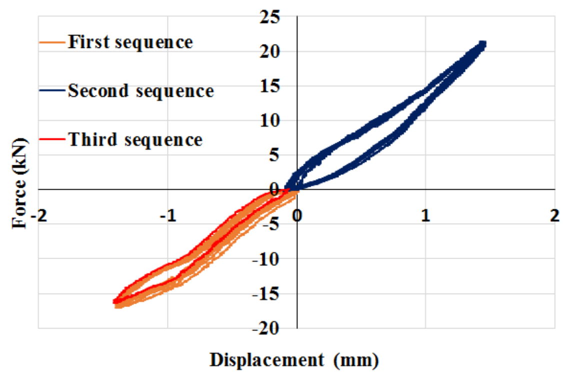


(b) Residual strains as a function of accumulated transformation strain

Figure 1: Mechanical material behavior (a) and evolution of residual strains (b) for two samples in the longitudinal and transverse direction of rolling, subjected to cyclic loading at 50°C.



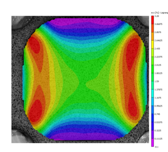
(a) East-West direction



(b) North-South direction

Figure 2: Force-displacement diagrams for the overall behavior at 50°C of a cross-shaped specimen in its two directions.

(a) Cross-shaped NiTi specimen for biaxial tension test



(b) DIC tracking for ε_{xx}

Figure 3: The NiTi biaxial sample used (a) and a experimental strain field ε_{xx} under tension-compression loading @50°C.

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