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# Anisotropic Tensile Behavior Of NiTi Tubes And Its Dependence On Temperature

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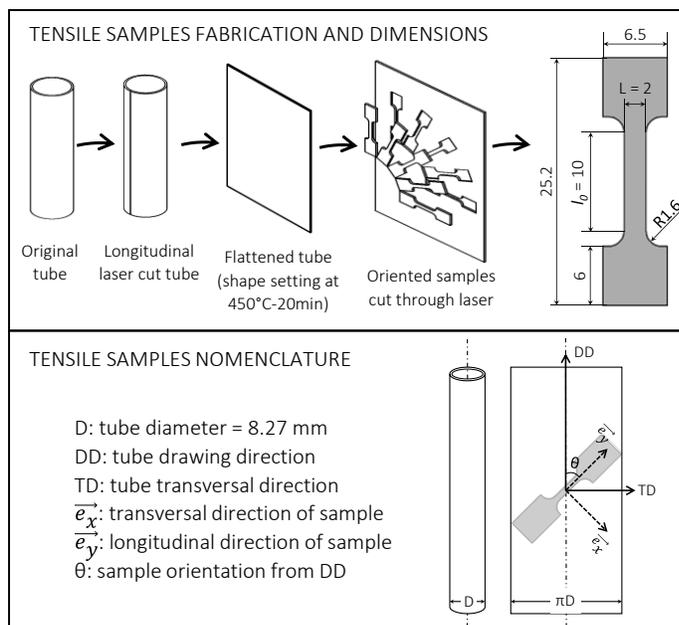
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## Introduction

NiTi thin walled tubes are highly textured structures used in the fabrication of nearly 60% of self-expanding stents. The presence of texture leads to strong anisotropic mechanical behavior, which has important consequences in the final behavior of devices manufactured from tubes. In this work the anisotropic superelastic mechanical behavior of a 50.8%atNi-Ti thin walled tube was studied through isothermal tensile tests performed in samples cut at five different orientations from the tube drawing direction. The tube was flattened by a one-step shape setting process and dogbone samples were cut by laser. Tests were performed at three temperatures above  $A_f$  (the reverse martensitic transformation finish temperature). Results show that transformation strains strongly depend on orientation but not on temperature. Transformation stresses also depend on orientation and this dependence is different for forward ( $A \rightarrow M$ ) and reverse ( $M \rightarrow A$ ) transformations. Clausius-Clapeyron coefficients also show an important orientation-dependent behavior. The observed difference between forward and reverse Clausius-Clapeyron coefficients are explained through the dependences of dissipated and stored energies with temperature, often neglected in the Clausius-Clapeyron relation.

## Experimental Results



A 50.8%atNi-Ti thin walled tube manufactured by Minitubes SA (France) was used in this study (outer diameter = 8.27 mm; wall thickness = 0.165 mm). Figure 1 shows schematically the tensile samples preparation process together with the dimensions and nomenclature used in this work.

This work will present and discuss the results of tensile tests performed in samples cut along five different orientations from the drawing direction of a thin walled NiTi tube. Isothermal tests were performed at three different temperatures, allowing to study the relation between the anisotropic properties and temperature

Figure 1. Scheme showing the fabrication process of dog bone tensile samples from the NiTi tube.

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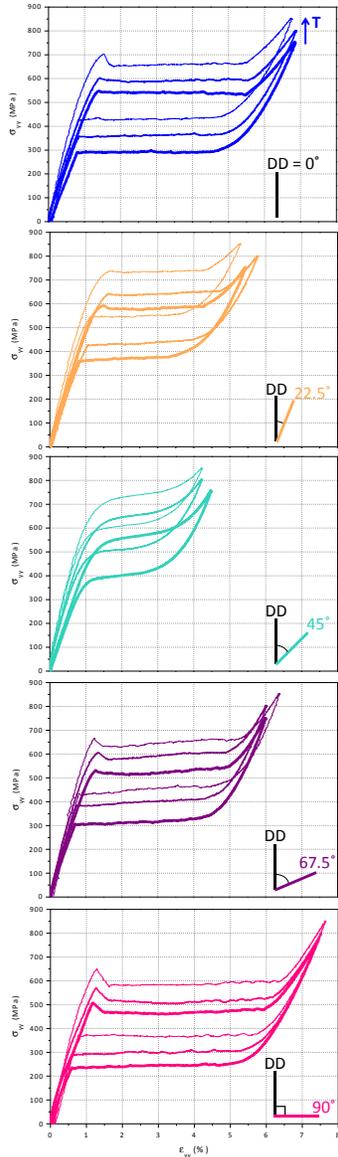


Figure 2. Nominal tensile stress versus DIC logarithmic strain curves plotted for each orientation from the tube drawing direction, at 40°C (thicker line), 50°C (medium line) and 60°C (thinner line).

Figure 2 contains a set of five  $\sigma_{yy}$ - $\epsilon_{yy}$  curves for all orientations  $\theta$  and testing temperatures  $T$ . Perfect superelastic behavior is observed for all orientations and testing temperatures, with negligible residual strain after unloading.

Through the curves of Fig. 2 it is possible to qualitatively infer a strong anisotropic behavior, perceived mainly in the amount of strain achieved at the end of loading in the stress level. Experimental results are used in the evaluation of transformation strains  $\Delta\epsilon_{tr}$ , transformations stresses and forward and reverse Clausius Clapeyron coefficients  $C_{A-M}$  and  $C_{M-A}$  (Figure 3). With a thermodynamic analysis of martensitic phase transformation, other important properties are explored, as Clausius-Clapeyron coefficients and dissipated energy per cycle.

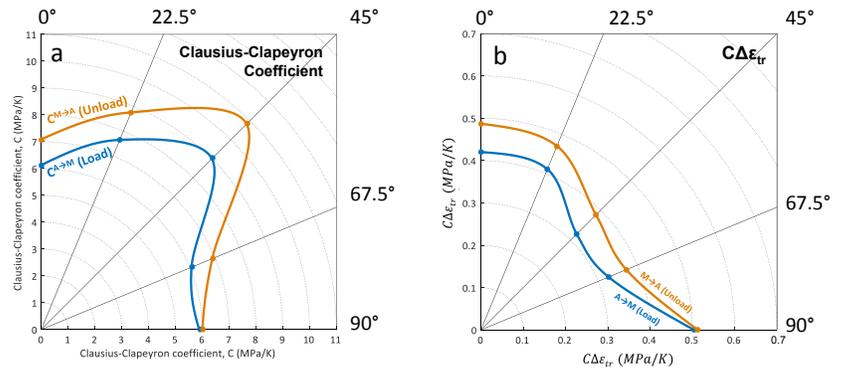


Figure 3. Clausius-Clapeyron coefficients for forward and reverse transformations. b) Product of Clausius-Clapeyron coefficients and transformation strain.

## Conclusions

Full transformation strain depends strongly on orientation but not on temperature. Transformation stresses for forward ( $A \rightarrow M$ ) and reverse ( $M \rightarrow A$ ) transformations depend on orientation, but to a lesser extent when compared to transformation strain. Stress hysteresis, calculated as the difference between transformation stresses of forward and reverse transformations, is both orientation and temperature dependent. (4) The dissipated energy per unit of transforming material was the property that showed the greater variation with orientation.

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