Functionally graded NiTi obtained by heat treatment

Fernando Ferreira [1], Ana R. Alves [2], João Pedro Oliveira [3], F.M. Braz Fernandes [4]

Structural Materials, [1] fe.ferreira@campus.fct.unl.pt, [2] ar.alves@campus.fct.unl.pt, [3] jp.oliveira@campus.fct.unl.pt, [4] fbf@fct.unl.pt

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Abstract

In this study, in order to obtain a functionally graded material, NiTi strips were annealed at 350°C, 450°C and 550°C in a furnace in an assembly allowing a temperature gradient along them. Their transformation temperatures were studied by *Differential Scanning Calorimetry (DSC)*. Furthermore, the strips were bent at both ends and dipped into a water bath at room temperature which was then heated up to 61°C in order to observe the influence of the annealing gradient on their strain recovery. It was found out that the strips' coolest regions presented the greatest strain recovery, particularly the strips annealed at 350°C and 450°C, although no strip exhibited a full strain recovery, due to plastic deformation during bending. These results, together with the *DSC* analysis at both regions (coolest and hottest) allow to conclude that the "graded annealing" was successfully achieved for the intended functional gradient, as a gradient of transformation temperatures along the strips has been obtained.

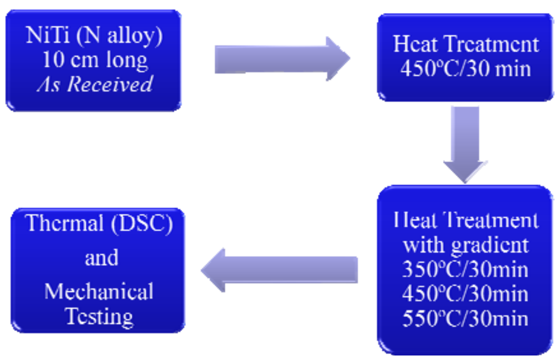
Introduction

Near-equiatomic Niquel-Titanium (Ni-Ti) alloys, are unique materials with the ability to produce large recoverable deformations and perform mechanical work when undergoing a temperature variation, thus being present in a variety of applications in actuator and control devices in several branches of science [1 - 6].

Thermally induced martensitic transformation is characterized by phase transformation temperatures for both direct and inverse transformation, namely As, Ms, Rs, Af, Mf and Rf, which are, in Ni-rich alloys, extremely dependent on the alloy composition and on the temperatures and duration of the annealing [7,8]. It occurs typically over 10K or less, thus allowing full completion of transformation rapidly, leaving no option for any progressive or intermediate state of displacement. To overcome this limitation, functionally graded NiTi materials should be created, allowing martensitic transformation to occur over a gradient of temperatures or stress along the material, improving the controllability of the devices. This capability could be obtained with a microstructural gradient along the material [1,9,10].

Experimental

Comercial NiTi (Ti-51at.% Ni) alloy (ribbon 0.9 x 3 mm, from *Memory-Metalle GmbH*), were heat treated as depicted in the following scheme followed by quenching in water. To achieve the temperature gradient, the strips were inserted in a ceramic block up to half of their length (Fig. 1) in a *TermoLab* furnace. Temperature indicated for gradient heat treatment is the temperature measured at the higher temperature region ("Q" in Fig. 1). Furthermore, strips' tips samples were collected from the annealed strips for DSC, in *DSC 204 F1 Phoenix* model from *Netzsch*,. To test the shape recovery, annealed strips were bent at both ends and dipped into a water bath .



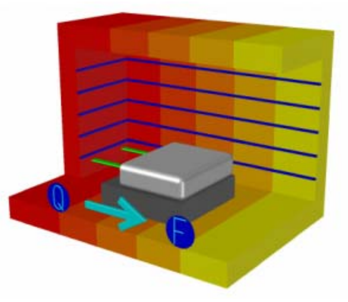


Fig. 1 – Scheme of the strips inserted on a block in the furnace, where "Q" represents the zone with higher temperature and the "F" the zone with lower temperature.

Results

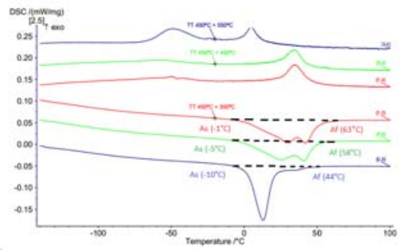


Fig. 2 – Results of the DSC analysis for the strips' portions inside the ceramic block.

- Strips' tips from graded annealing at 350ºC and 450ºC exhibit martensite, R-phase and some residual austenite, while strips' tips gradient annealed at 550ºC are almost fully austenitic with some residual R-phase and/or martensite that, according to DSC, is fully transformed to austenite at 50°C.

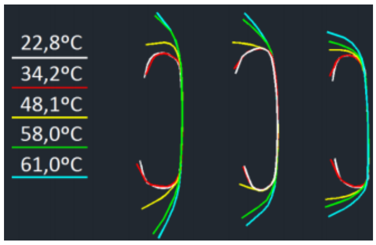


Fig. 3 – Scheme of the strips with the different annealing temperatures.

- Strips' portions inside the ceramic block (the bottom part of the strips in Fig. 2) have a greater recovery of their original shape at all temperature stages.
- Their strain recovery decreased with increasing annealing temperature and complete strain recovery does not occur in any strip, suggesting that plastic deformation occurred during the strips' bending.
- The lower strain recovery at 61ºC of the "hotter" zone portions may be justified by plastic deformation.

Conclusions

The functional gradient caused by the different annealing temperatures along the strips was clearly evident, despite the simplicity of the experimental work, which is a great result for a first approach. Further tests will be performed, with a new experimental procedure especially designed for this purpose, better defined and with improved resources.

Acknowledgments

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