Production and characterization of functionally graded materials from NiTi shape memory alloys

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Abstract

The low temperature range of thermally induced martensitic transformation that NiTi shape memory alloys exhibit, cause these alloys to perform a full completion of transformation when a threshold value of temperature is reached, rendering difficult any progressive control of displacement during shape recovery. The aim of this work was the production of controlled functionally graded NiTi through the injection of electric current on small sections of Ni-rich NiTi, taking advantage of its high sensitivity to heat treatments. The gradient annealed samples were first subjected to different thermo-mechanical treatments, in order to study their influence on the subsequent annealing, and thermal characterization was performed to assess the influence of the heat treatments on the transformation temperatures. Some authors have been investigating other methodologies to obtain functionally graded NiTi [1-5] but the procedure used in this work, due to its high control of the annealing sections and parameters, is believed to be the more versatile and easier to be implemented [6]. The functional gradient also affects the stress induced transformation, as the critical stress to induce the martensitic transformation varies along the given length, eliminating the characteristic superelastic plateau observed in NiTi shape memory alloys.

Experimental

Table 1 - Descryption of the thermo-mechanical tratments prior to current annealing, and gradient annealing temperature range for each specimen.

Sample	Thermo-mechanical treatment			Gradient annealing temperature range
	Solution treatment (950ºC,1h)	Cold work (33%)	Ageing (450ºC,30')	
A	X			350-600
B	X	X		300-600
C	X	X	X	

- The electrical contact with the NiTi strips was made using two copper clamps, delimiting the annealed section. Current, voltage and temperature were measured and controlled in a LabVIEW environment. The sections were then analyzed by Differential Scanning Calorimetry (DSC).

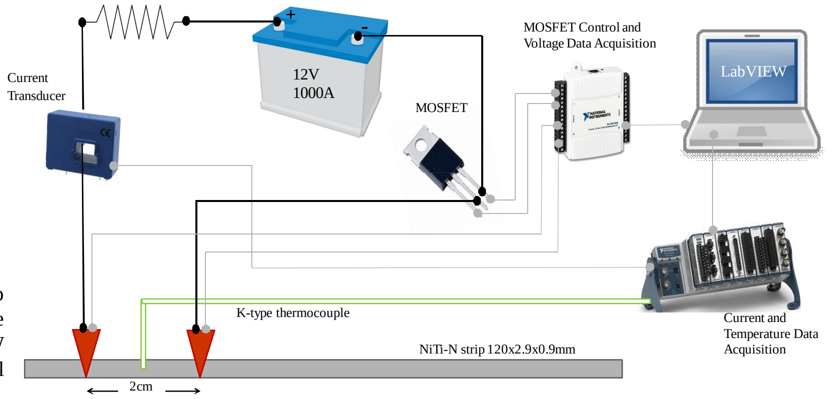

Figure 1 - Schematic of the experimental setup used for the heat treatments with electric current.

DSC Results

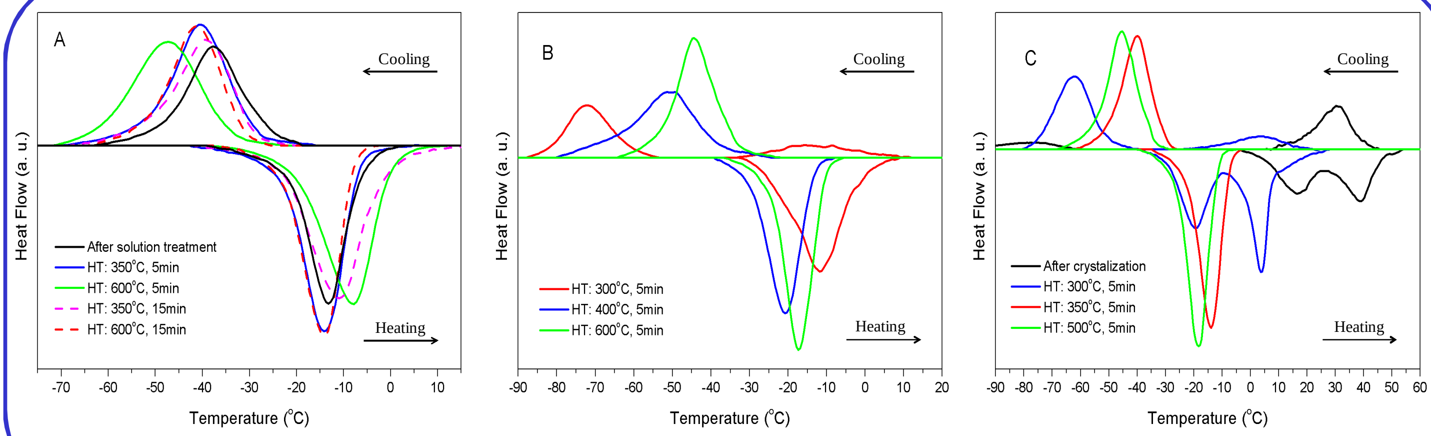

Figure 2 - DSC curves for different annealing conditions of the samples with diferent previous thermo-mechanical treatments (A, B and C) that better describe the capacilty to obtain a functionally graded material with this experimental procedure.

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Conclusions

- Solution treated strips without any cold work or ageing did not present R-phase, and had the lowest transformation temperatures and the greatest thermal hysteresis from direct to inverse transformations (40ºC peak to peak).
- The samples subjected to cold work after solution treatment were more sensitive to heat treatments, presenting a greater functional gradient. Some R-phase is now visible.
- The samples subjected to ageing presented a better defined R-phase peak, with corresponding low thermal hysteresis, and the transformation temperatures were quiet above room temperature.
- The experimental procedure may need some adjustments, but its capability to achieve a controlled functional gradient in NiTi is quite evident. It allows to control the transformation temperatures along a given length as desired, and with minor geometry constraints.