Characterisation of Nitinol for the Design of Tuneable Transducers

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1. INTRODUCTION

Nickel-titanium (Nitinol) is a type of shape memory alloy (SMA) which has found popularity in a wide range of engineering applications. The material possesses a number of transformation temperatures which govern its behaviour, and these can be characterised by using a thermo-analytical technique, namely differential scanning calorimetry (DSC). In order for Nitinol, and similar SMAs, to be adopted in tuneable transducer technology, the transformation behaviour must be well understood. Nitinol can exist either as cubic austenite, intermediate rhombohedral R-phase, or monoclinic martensite. The material can be switched between these phases by stress or temperature influences [1], with each phase emerging through a start to finish temperature range. In addition, the heating and cooling of Nitinol exhibits thermal hysteresis. This paper discusses the characterisation of two types of Nitinol, one being superelastic and the other shape memory. The results allow for assessment of the effectiveness of the DSC technique in extracting the material behaviour. This assessment is complemented by dynamic characterisations of two cymbal ultrasonic transducers, one constructed of each type of Nitinol. The dynamic characterisations show how the Nitinol can be used to create devices that can be actively tuned by exploiting the different properties of each material phase.

2. DIFFERENTIAL SCANNING CALORIMETRY

The two types of Nitinol, superelastic (Johnson Matthey Noble Metals) and shape memory (Memry GmbH) alloys, were subjected to DSC analysis (Perkin Elmer Diamond), which records the heat flow in a sample as a function of temperature. The peaks and troughs on the respective heating and cooling cycles allow the transformation temperatures to be extracted from the data [2]. Figure 1 shows the DSC data obtained for each sample at a scan rate of 10°C/min.

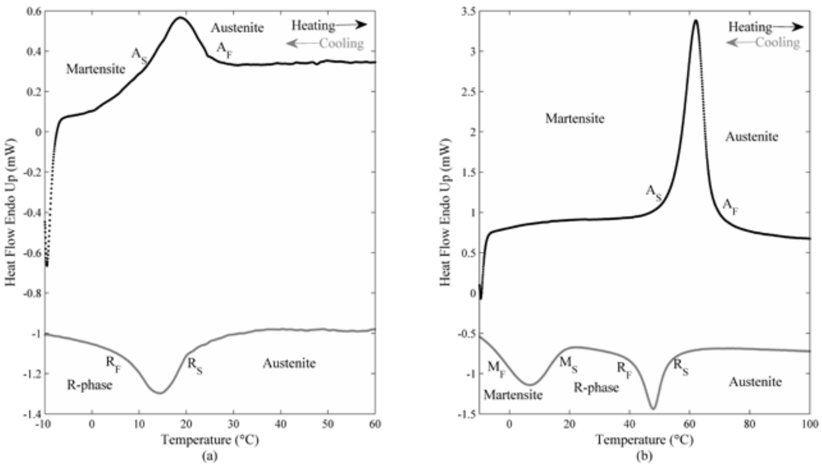

Figure 1. DSC of (a) superelastic and (b) shape memory Nitinol.

Table 1 shows the transformation temperatures extracted from the DSC data shown in Figure 1, as per the standard method described in the literature [2].

Table 1. Transformation temperatures (°C) of the alloys at a scan rate of 10°C/min.

Material	A_F	A_S	M_F	M_S	R_F	R_S
Superelastic	23	16	-	-	9	19
Shape memory	68	55	-6	16	44	52

The superelastic alloy results show that the material should exist as austenite around room temperature, at approximately 25°C, according to the endothermic peak on the heating curve which represents a transition to austenite. There is another peak on the cooling curve which is exothermic. This trough is indicative of the R-phase based on the very low thermal hysteresis when compared to the austenite, much lower than would be expected for an austenite to martensite transformation [2]. The results of the shape memory sample show that austenite, R-phase and martensite phases have all been observed. Devices can now be assembled using this characterised material.

3. DYNAMIC CHARACTERISATION OF NITINOL CYMBAL TRANSDUCERS

A cymbal transducer is a type of flextensional device composed of a hard piezoceramic driver disc (Sonox P4, CeramTec) with two cymbal shaped metal end-caps, one bonded to each side of the disc using epoxy resin (Eccobond, Emerson & Cuming). The radial mode of the piezoceramic is used to drive axial motion of the two end-caps. A fully assembled Nitinol cymbal transducer is shown in Figure 2.

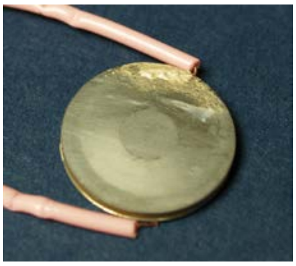

Figure 2. A cymbal transducer with Nitinol end-caps.

Once the devices were constructed, electrical impedance measurements (Agilent 4294A) were made at different temperatures to show that the Nitinol end-caps behaved as predicted by the DSC. The results are shown in Figure 3.

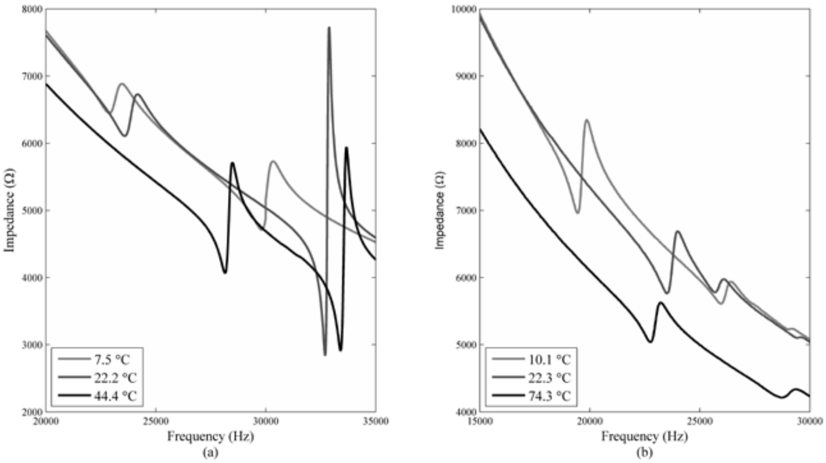

Figure 3. Impedance-frequency spectra for a (a) superelastic and (b) shape memory Nitinol cymbal transducer.

It is clear that the shape memory device transforms to austenite at a temperature consistent with the DSC analysis. The transducer resonant frequency increases at this temperature, indicating a transition from relatively soft R-phase to stiffer austenite. However, the superelastic device does not exhibit behaviour consistent with the DSC analysis data, the transformation temperature being approximately 20°C higher than the DSC suggests. This discrepancy is likely to be a consequence of the processing history of the material. It has been acknowledged that there can be difficulties associated with DSC analysis of alloys fabricated for superelastic capability [3], however there has been no experimental evidence reported in the literature of the consequential discrepancies we have identified. This is significant for the understanding and future design of tuneable transducer technology using smart materials and SMAs, and in particular Nitinol.

4. CONCLUSION

It is clear that the DSC technique is suitable for Nitinol alloys fabricated for shape memory applications, but that the data obtained from tests of the superelastic material are unreliable. Further research is required into the thermal characterisation of this type of material in order to establish consistency, but in general it is important to consider the advantages and drawbacks of these techniques for future tuneable transducer design.

References

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