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Shape Memory Investigation of Smart CAMAR Logo Using NiTi Alloy Wire

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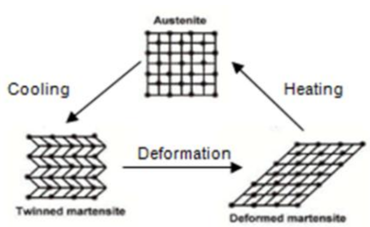
Graphical abstract



Abstract

This project is investigates of NiTi shape memory alloy for simple smart application. The shape memory effect (SME) is attributed from the reversible phase transformation when subjected to stress and temperature. In this study, a small model of CAMAR logo was designed to mimic the shape memory effect. Three samples of wire were investigated; (i) Austenitic NiTi (ii) Martensitic NiTi and (iii) commercial plain carbon steel. The reversible austenite to martensite transformation of the NiTi wire was investigated by a differential scanning calorimetry (DSC) at temperatures ranging from -50 and 200°C. The wire was shaped into CAMAR logo using a mould and then heated at 500°C for 30 minutes in a high temperature furnace. To observe the shape effect recovery, the wire was straighten and reheated in warm water at different temperatures. Results showed that the austenitic wire exhibited complete shape memory recovery after heated at temperature approximately 35°C and 80°C. For the martensitic wire, complete recovery was only observed when the water temperature was ~ 80°C and no recovery was observed at ~30°C. This recovery effect was significantly influenced by the reversible phase transformation temperatures (PTTs) which attributed from the Austenite finish (A_f) temperature.

Keywords: NiTi alloy, shape memory effect (SME), X-Ray Diffraction (XRD), Phase Transformation Temperatures (PTTs)

1.0 INTRODUCTION

Shape memory alloys (SMA) belong to a class of shape memory materials, which have the ability to memorise or retain their previous form when subjected to certain stimulus such as thermomechanical or magnetic variations [1]. Shape memory effect (SME) is a transformation phenomenon when the material returns to their original form, shape or size when subjected to a memorization process between two transformation phases.

NiTi-based alloys exhibit two unique properties, known as shape memory effect (SME) and pseudo-elasticity (PE) [1]. These two properties are strongly influenced by the phase transformation temperatures (PTTs) which originated from the ration of Ni-Ti and the processing route involved. The characteristic of a shape memory alloy can be denoted as A_s = Austenite start, A_f = Austenite finish, M_s = Martensite start and M_f = Martensite finish.

The reversible phase transformation temperature (PTT) from austenite to martensite is generally characterized by differential scanning calorimetry (DSC). From the phase transformation temperatures, it gives information of what temperature should be applied to the alloy in order to allow them to return to its original shape after they have been deformed. For biomedical implants applications such as staple in foot surgery, the shape memory effect and pseudo-elasticity have to take place at the temperature of the human body, approximately at 37°C in which the alloy is completely in austenite phase [2]. Besides the NiTi ratio and the processing route employed, the homogeneity level of the alloy, particularly the contents of oxygen and carbon is also another factor that might result in shifting and broadening of the PTTs [3].

Practically, NiTi shape memory alloy can exists in two different phases with three different crystal structures as shown schematically in Fig. 1 which are twinned martensite, detwinned martensite and austenite [4]. The main objective of this research work was to investigate the effect of phase transformation temperatures (PTTs) of NiTi alloy determined by differential scanning calorimetry (DSC) on the shape memory recovery by using a simple logo, namely CAMAR.

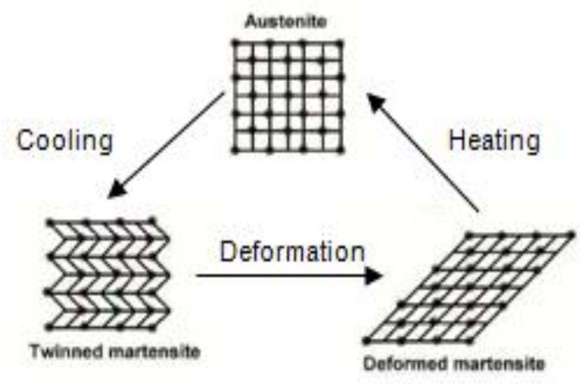


Figure 1 Three different shape memory alloy crystal structures [5]

2.0 EXPERIMENTAL PROCEDURE

2.1 Designing CAMAR mould

The CAMAR mould was designed to mimic the reversibility of the NiTi alloy. The materials used to fabricate the mould were carbon steel plate, bolts and nuts. Fig. 2 (a) shows the conceptual design (b) the dimension and (c) the fabricated CAMAR logo mould.

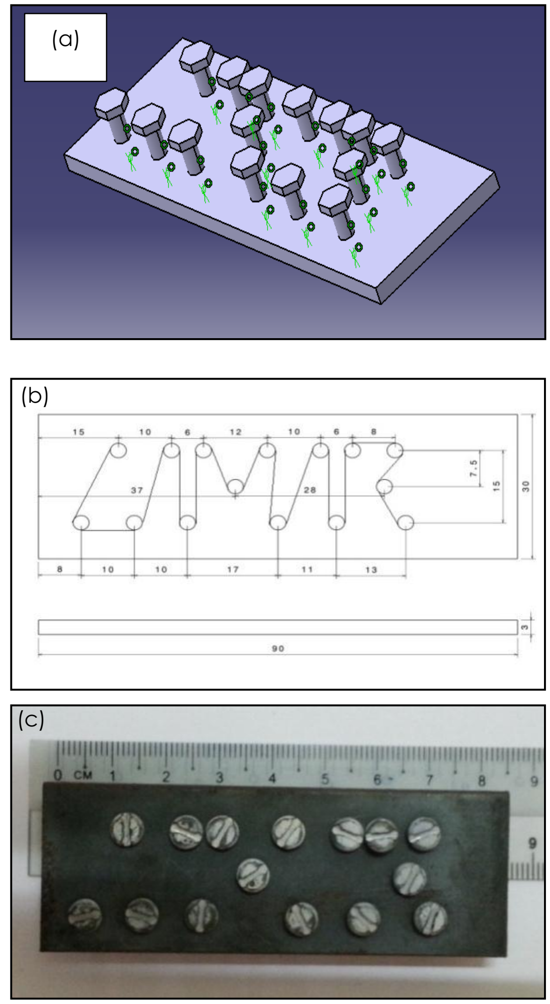


Figure 2 (a) Conceptual design (b) dimension and (c) fabricated CAMAR mould

2.1 Testing on Shape Memory Effect

Shape memory alloy have a unique ability which is remembering the specific shape after being deformed. In order to set the configuration in the alloy, the alloy need to be heated at 500°C for 30 minutes [6]. In the present work, the wires were coiled nicely following the CAMAR mould. The mould was then placed inside the furnace and the temperature and time were set to 500°c and 30 minutes, respectively. The mould was taken out after the heating process had completed. In order to observe the shape recovery of the alloy, the wires were straighten and placed in a beaker containing warm water, which was heated at two different temperatures; ~30°C and ~80°C. These temperatures were based on the temperature of austenite finish (A_f), analysed by DSC. The recovery of the wires were then observed and discussed.

3.0 RESULTS AND DISCUSSION

3.1 X_Ray Diffraction (XRD)

The samples were firstly characterized for phase identification using a RIGAKU X-Ray Diffractometer at the 2θ angle ranging from 30° to 90° with scan speed of 1°/min, and increment of 0.05°. Fig. 3 shows the XRD pattern for the three samples used in the present work.

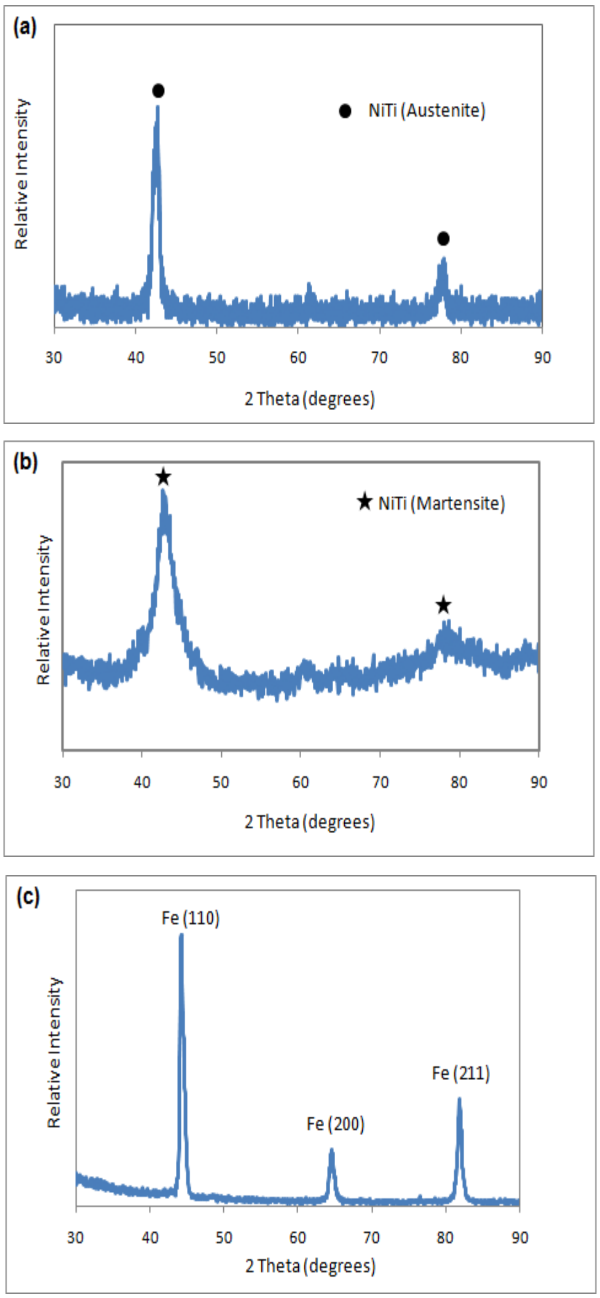


Figure 3 XRD pattern for (a) Austenitic Wire, (b) Martensitic Wire and (c) Steel Wire

From the result, it shows that austenitic wire and martensitic wire was dominated by austenite phase and martensite phase, respectively. There are no evidences of secondary phase such as Ni-rich or Ti-rich in the composition as reported in literati [1-3]. These secondary phases are not necessary needed because it can reduce the unique ability of shape memory alloy. For steel wire, it consists of ferrous metal (Fe) as identified as plain carbon steel.

3.2 Differential Scanning Calorimetry (DSC) Analysis

In this project, the reversible austenite to martensite phase transformation temperatures (PTTs) was determined using a Mattler Toledo Differential Scanning Calorimetry (DSC). The wire samples with approximately 8 mg in weight were heated to 200°C, held isothermally for 5 minutes followed by cooling process to -50°C and held isotermally for 5 minutes. The heating and cooling cycle was repeated to ensure repeatability of the result. The heating rate used during this heating and cooling process was 10°C/min. Fig. 4 shows the DSC results for both austenitic and martensitic during heating and cooling process. The values for phase transformation temperatures are summarized in table 1.

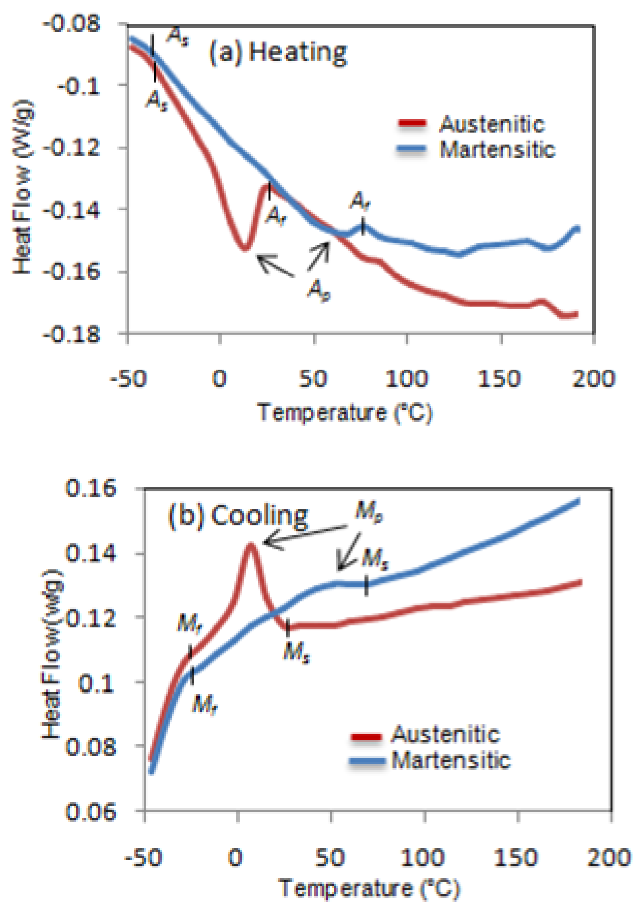


Figure 4 DSC results for NiTi wire sample during (a)heating and (b)cooling

From the DSC results, it clearly shows that the width of PTTs for the austenitic wire is approximately 17°C and the austenite peak, A_p is clearly shown in comparison with the austenite peak, A_p for the martensitic wire. The martensitic wire is more broaden and the width of PTTs for the martensitic wire is approximately 65°C. The same situation was observed during cooling step where the martensite peak, M_p for austenitic wire is more identical and less broaden compared to martensite peak, M_p for martensitic wire. The width of PTTs for austenitic wire is approximately 17°C while the width of PTTs for martensitic wire is approximately 53°C.

There are two important factors that influence the broadening and decreasing of the PTTs. The first factor is Ni-Ti ratio in which increasing the Ni content would result in broadening of reversible phase transformation from austenite to martensite [2]. The second factor is the presence of the impurities such as oxygen, carbon and nitrogen. These element need to be minimized due to tendency of oxide and carbide phases formation which result in broadening of PTTs and decreased shape recovery properties.

Table 1 Phase transformation temperatures (PTTs) of NiTi samples

Wire	Transformation temperature (°C)					
	A_s	A_p	A_f	M_s	M_p	M_f
Austenitic	-34.57	16.90	30.46	27.99	16.87	-28.82
Martensitic	-35.00	65.00	75.00	68.00	53.00	-22.00

3.2 Shape memory demonstration

After the configured CAMAR logo had been heated at 500°C in a furnace, the wire was taken out from the mould and placed in a beaker filled with water which was set at different temperatures; 35°C and 80°C. Fig. 5 shows the image of the three wires (a) before (b) heated at 35°C and (c) heated at 80°C to demonstrate the shape memory effect. It was observed that the austenite wire recovered completely to the CAMAR shape after heated at temperature of 35°C and 80°C. For the martensite wire, no recovery observed when the wire was heated at 35°C and complete recovery was only observed at temperature 80°C. For steel sample, the wire remained the same before and after heated at both temperatures indicating no shape memory behavior.

The result clearly shows that the performance of the shape memory effect strongly depends on the phase transformation temperatures (PTTs) [2,3], especially at A_f which the alloy recovers to its original shape. Based on table 1, the A_f value for the austenitic wire is 30.46°C, thus complete recovery can be achieved when the wire was heated at 35°C and 80°C. The result also shows that the A_f value for martensitic wire is double than the austenitic wire, indicating the required temperature of greater than 75°C to demonstrate full recovery characteristics. For steel sample, the wire remains the same before and after heated at both temperatures because this material does not exhibit shape memory effect.

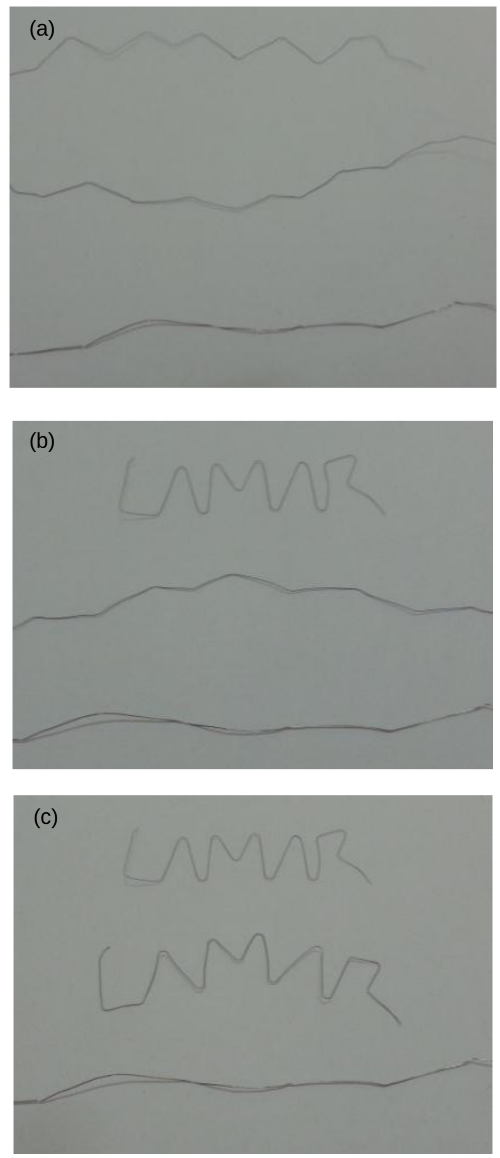


Figure 5 Shape of NiTi wires and steel wire (a) before and after heated at temperature (b) above 35°C and (c) above 80°C

4.0 CONCLUSION

A method to produce a simple smart CAMAR logo was successfull using NiTi wire. In order for the materials to demonstrate shape memory effect, information on reversible phase transformation temperatures (PTTs), determined by DSC analysis was important. From the results, it could be concluded that the lowest temperature for the austenitic and martensitic wires to exhibit complete recovery were 31°C and 80°C, resepectively.

Acknowledgement

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References

[1] Uchil, J., Braz Fernandes, F. M. and Mahesh, K. K. 2007. X-ray Diffraction Study of The Phase Transformations in NiTi Shape Memory Alloy. *Materials Characterization.* 58: 243-248.

[2] Ismail, M. H., Razali, R., Abdullah, Z., Subuki, I. and Muhamad, N. 2014. Shape Memory Behaviour of NiTi Alloy Produced by MIM using Palm Stearin Based Binder. *Advanced Materials Conference Proceedings, SIRIM*.

[3] Ismail, M. H., Bram, M., Barbosa, A. P. C., Köhl, M., Davies, H. A. and Todd, I. 2013. Phase Transformation Temperatures (PTTs) and Microstructure of Moulded NiTi Alloy Using a Water Soluble Binder System. *Sains Malaysiana*. 42(12): 1769-1773.

[4] Tan, M. J., Motemani, Y., Nili-Ahmadabadi, M., Bornapour, M. and Rayagan, Sh. 2009. Effect of cooling rate on the phase transformation behavior and mechanical properties of Ni-rich NiTi shape memory alloy. *Journal of Alloys and Compounds.* 469: 164-168.

[5] Nurveren, K., Akdogan, A. and Huang, W. M. 2008. Evoluation of transformation characteristics with heating/cooling rate in NiTi shape memory alloys. *Journal of Materials Processing Technology*. 196: 129-134.

[6] Zinelis, S., Darabara, M., Takase, T., Ogane, K. and Papadimitriou, G. D. 2007. The Effect of Thermal on The Resistance of Nickel-Titanium Rotary Files in Cyclic Fatigue. *Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontology*. 103: 843-847.

[7] Stamm, T., Hohoff, A., Wiechmann, D., Sütfeld, J. and Helm, D. 2004. Accuracy of third-order bends of nickel-titanium wires and the effect of high and low pressure during memorizing heat treatment. *American Journal of Orthodontics and Dentofacial Orthopedics*. 126(4): 477-485.

[8] Jani, J. M., Leary, M., Subic, A. and Gibson, M. A. 2014. A Review of Shape Memory Alloy Research, Applications and Opportunities. *Materials and Design*. 56: 1078-1113

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