Effect of temperature changing rate on phase transformation in magnetic shape memory alloy.

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Abstract. The magnetic shape memory alloy (MSMA) possesses an attractive property to regain its original shape after undergoing a pseudo-plastic deformation due to phase transformation and/or martensite reorientation. Understanding the phenomenon behind this strain change would assist its use in engineering applications. This report studies the effect of heating and cooling rates on the temperature-induced phase transformation and the temperature-dependent martensite reorientation in Ni-Mn-Ga single crystal – the most common magnetic shape memory alloy. The microstructural evolutions of the material under different temperature changing rates are observed by the Digital Image Correlation (DIC) technique. Preliminary tests have shown some interesting microstructures and studies are still underway to understand the observed phenomena.

Introduction

Magnetic shape memory alloy (MSMA) is a typical smart material that can be actuated by temperature, mechanical stress and magnetic field. Large reversible strain up to 10% can be achieved due to the mechanisms of martensitic phase transformation and martensite reorientation [1]. Many potential applications of MSMA have been found, such as actuators, sensors and energy harvesters. Among them, the high-frequency (> 100 Hz) large-stroke (~ 10%) magnetic actuator is the most promising one [2,3]. The behaviours of MSMA-based high-frequency magnetic actuators are determined by the thermo-magneto-mechanical coupling property of MSMA. To further understand this multi-physics coupling phenomenon, systematic experiments on the kinetics of temperature-induced phase transformation and temperature-dependent martensite reorientation in MSMA are conducted.

Experimental results and discussions

Experiments are conducted on single crystal Ni-Mn-Ga alloy – the most common magnetic shape memory alloy. Rectangular samples (20 x 2.5 x 1 mm^3 with faces parallel to the {100} planes of the parent austenite) of single crystal $Ni_{50}Mn_{28}Ga_{22}$ (at.%) from Goodfellow Cambridge Ltd. are used. The material is in the martensitic phase at room temperature.

Figure 1 shows the experimental setup. The sample is placed on a heating mat and the temperature is measured by a thermal couple attached to the sample holder. The heating rate is controlled by the input voltage of the heating mat. Before each test, the sample is compressed to ensure that a single martensite variant occurs in the sample and then heated to 50 ºC (where the martensite-to-austenite transformation completes) under different heating rates and finally cooled down to room temperature. Each test contains three cycles of heating and cooling. During the test, a microscope camera (Microscope (Celestron 44308 Microscope Pro) takes photos of the sample surface. The local strain distributions are determined by treating the photos using Digital Image Correlation (DIC) technique (using an open-source MATLAB program: ncorr).

Figure 2 shows one example of the experimental results. It is seen that the duration of phase transformation shortens as the heating rate increases, e.g., 41, 21 and 19 secs respectively for the heating rate of 0.14 ºC/sec (3 V), 0.16 ºC/sec (4 V) and 0.32 ºC/sec (5 V) in Fig. 1(b). Moreover, heating ceases to be homogenous when the heating rate of 0.16 ºC/sec and above is reached. Furthermore, after cooling, the sample consists of a mixture of multiple martensite variants in a random order (Figure 2). Studies are still underway.

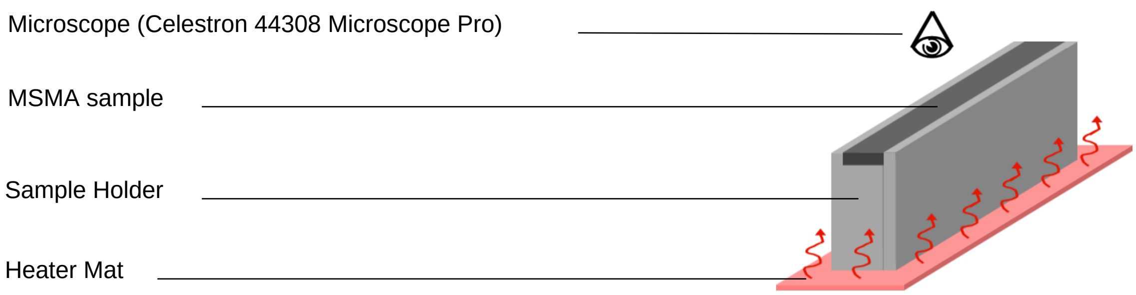

Fig. 1. Experimental setup

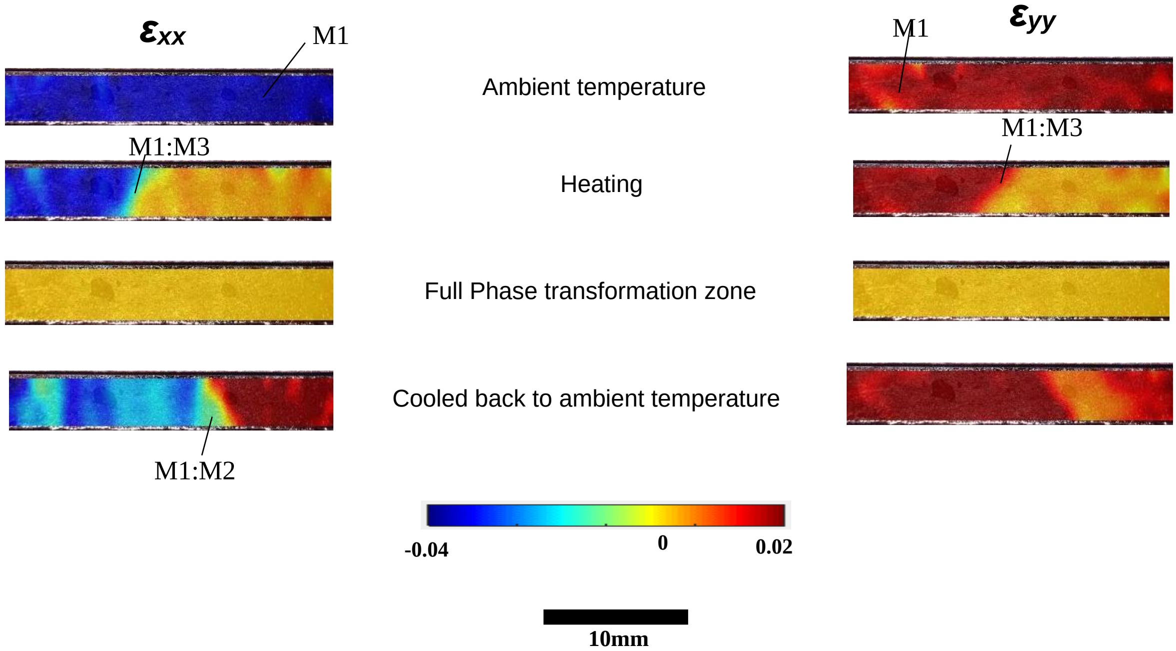

Fig. 2. Digital Image Correlation (DIC) of the MSMA

Conclusion

The duration of phase transformation in MSMA shortens as the heating rate increases. It is also observed that at high heating rates, the MSMA sample ceases to be homogenous as the temperature of the sample in contact with the holder is different from the sample surface temperature exposed to the atmosphere. Therefore, to achieve a homogenous heating, the sample must be slowly heated. Also, during cooling, the composition of multiple martensite variants is observed with random composition ratio. Further studies are still underway.

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