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Study on Heat-induced-shape-shifting-memory Alloy on Motorcycle Body Panel

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Abstract

Shape memory alloys (SMAs) have the ability of memorizing the original or pervious states such as size or shape when applied to certain process. The objective of this study was to identify the transformation temperature value for a nickel–titanium (Ni-Ti) sample. The experiment was conducted for a one-way shape memory effects in utilizing the high temperature tube furnace, whilst, the Scanning Electron Microscope (SEM) and Differential Scanning Calorimetry (DSC) were used to examine the sample. The result showed that sample which undergone heat treatment up to 610^{0}C was able to produce the one-way shape effect with better characteristics and better austenite phase recovery rate. From the DSC curve, it was found that the transformation temperature value was within the range of 67 and 68^{0}C. The other values obtained via the DSC are as follow: Austenite Start (As) = 76^{0}C, Austenite Finish (Af) = 53^{0}C, Martensite Start (Ms) = 22^{0}C, and Martensite Finish (Mf) = 49^{0}C. Based on the result of this study, the two-way shape memory effect experiment could now be performed. For the future, more studies on the nickel–titanium (Ni-Ti) material's thermomechanical behavior is recommended since the demand in the use of piezoelectric materials and electro-rheological material are rapidly increasing due to their flexible and unique properties.

Keywords

Shape Memory Alloys (SMAs), Ni-Ti nickel–titanium, Heat-Induced, Shape-shifting,Motorcycle

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Introduction

Smart materials show response to the stimuli and environmental changes and activate their function according to these changes. For example, the material will react and show change in volume, color or viscosity in result to any change in the temperature or stress applied (Akhras, 2000).

There are many types of smart materials such as shape memory alloys (SMAs), piezoelectric materials, electro-rheological materials, and chromic materials, but SMAs are the most well-known type and have gained a big attention recently due to their flexible and unique properties (Goddard et al., 1997). Shape memory alloys have two phase transformation, high temperature phase (austenite) which is also called (parent phase cubic B2), and low temperature phase (martensite) which is also called (monoclinic phase B19) (Woodford, 2018). Furthermore, it was observed that different mechanisms are active, and the process of transformation becomes stable as result of microscopic state irreversible changes at the time of the thermal cycling. (Fernandes et al., 2011). In 1932, the solid phase transformation in gold-cadmium (Au–Cd) was first discovered by Ölander. Later in 1938, Greninger and Mooradian first observed the SME for copper-zinc (Cu–Zn) alloys and copper-tin (Cu–Sn) alloys. Similar affects in other alloys such In–Tl and Cu–Al–Ni were discovered in the 1950's. (Jani et al., 2014).

The medium temperature treatment is used to improve the One Way Shape Memory Effect (OWSME) while the aging treatment which is also known as training process is commonly used for the improvement of the Tow Way Shape Memory Effect (TWSME) (Laureanda, 2008). Transformation Temperatures (TTRs) is the key for any use of SMA, they can be defined as the temperatures at which the shape memory alloy changes from the Martensite at low temperature to the Austenite at high temperature or the other way around. (Swardz, n.d.).

At high temperature the austenite structure is stable while at lower temperatures the martensite structure is stable. The transform from martensite into austenite phase starts when the shape memory alloy is heated. (As) is the austenite-start-temperature where the transformation starts (Af) is the austenite-finish-temperature where the transformation is complete. At low temperature, the structure of the material begins to transform into martensite when the shape memory alloy is being cooled. Ms is the martensite-start-temperature where the transformation starts. Mf is the martensite-finish-temperature where the transformation is complete (Kumar et al., 2008)

The percentage of composition in Ni and Ti plays a major rule in the temperature of transformation. Hence, a small change as 1% in the composition results in a change of 100◦C in austenite finish temperature (Af). In commercial Nitinol alloys are available with an Af range of 100◦C -20◦C with a tolerance of ±3◦C to ±6◦C. (Firdhaus, 2011). In constant load test a load can be applied to the alloy and its deformation along with its shape recovery is monitored at the same time as temperature while the material is undergoing heating and cooling during its transformation, the particular load used during its application is the same load used during testing and simulations. (Johe, 2009).

A Differential Scanning Calorimeter (DSC) measures the amount of heat absorbed or given off by the alloy small sample during heating or cooling this sample through its phase transformations. However, on fully annealed samples (above 700 deg C) which take around 10 to 13 minutes for small sample, the DSC provides excellent, repeatable results. Samples which undergo heat treatment (400-600 degrees Celsius) after cold work have a disadvantage of having inconclusive results when it comes to using this method (Wang et al.,2011). A method is called the Active Af or Functional Af test and it has been used to determine the TTRs for the shape memory alloys. This test can be performed when the sample of the alloy which can be a wire of NiTi is below Ms, by bending the sample and then monitor the shape recovery of the sample while is being heated (Patel et al., 2005). At high temperature the austenite structure is stable while at lower temperatures the martensite structure is stable (Ozbulut et al., 2010). Another unique property of shape memory alloy is Super elasticity or pseudo elasticity which involves stress. When the shape memory alloy is deformed at temperature which is above the temperature of transition, it springs back into shape (Martin et al, 2019).

In order to understand and have a clear detail about the mechanisms that are involved in the one way and tow way shape memory effects, the material's thermomechanical behavior was investigated in this experiment. The objective of this study was to identify the transformation temperature value for a nickel–titanium (Ni-Ti) sample for a basic one-way shape memory effects. This information is vital for the nickel–titanium (Ni-Ti) material's thermomechanical behavioural studies, mainly the two-way shape memory effects.

Methodology

The experiment was conducted for a one-way shape memory effects in utilizing the high temperature tube furnace, whilst, the Scanning Electron Microscope (SEM) and Differential Scanning Calorimetry (DSC) were used to examine the sample. The equipment and the experiment was conducted at the Faculty of Mechanical Engineering, Universiti Teknologi Mara (UiTM), Shah Alam, Selangor Darul Ehsan, Malaysia. The tube furnace used is has the heating rate of 5^0C per minute, whilst, the SEM has the resolution and magnifying range of 50 to 100 nm and 20X to approximately 30,000X respectively. The DSC has the temperature range from −150◦C up to +700◦C and the resolution, data acquisition rate and measuring range of 0.125 μ, 0.1s up to 3600s/data point and ± 2, 5upto ± 250mW respectively.

The wire used in this experiment is equiatomic Ni–Ti50% type M wire which has diameter equal to 7.6 mm. The samples of Ni-Ti wire was applied to heat treatment of 620◦C using the High Temperature Tube Furnace and then it was allowed to cool down for 15 min at room temperature. For the one-way shape memory effects, the wire was deformed at martensite phase which is the low temperature phase then it was heated using a hot water bath of (100^0C). The Differential Scanning Calorimeter (DSC) test was done for the both samples heat treated sample and cold worked sample to determine the Transformation Temperatures (TTRs) values of the alloy. The heating DSC analysis which was done in this experiment from room temperature to 100◦C while the cooling analysis was from 100◦C to room temperature using cooling rate of 40◦C/min and heating rate of 10 ◦C/min.

Results and Discussion

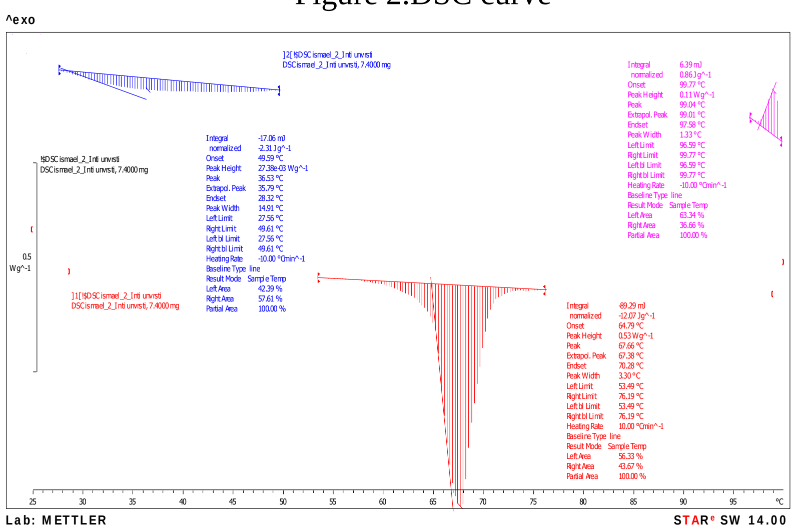
The results showed that the sample which undergone heat treatment up to 610^0C was able to produce the one-way shape effect with better characteristics and better austenite phase recovery rate. The figure at the life shows the deformed wire in martensite phase at room temperature while the eight the figure in the right shows the same wire after being heated by placing it in a hot water bath of 100^0C, as it is shown, the wire induced one-way shape memory effect and returned to the original shape which is straight. The other values obtained via the DSC are as follow: Austenite Start (As) = 76^0C, Austenite Finish (Af) = 53^0C, Martensite Start (Ms) = 22^0C, and Martensite Finish (Mf) = 49^0C.

Figure 1. (a) The deformed shape in martensite phase, (b) Recovered shape in austenite phase

(a) (b)

From the DSC curve in Figure 2, it was possible to determine the transformation temperature values and these values were important to conduct the second experiment which is training the Ni-Ti wire to induce the two-way shape memory effect.

Figure 2.DSC curve



Conclusions

Ni-Ti alloy has unique properties such as one-way shape memory effect, two-way shape memory effect and these unique properties is the reason behind the demand of this alloy. The objective of this study was to identify the transformation temperature value for a nickel–titanium (Ni-Ti) sample for a basic one-way shape memory effects. From the DSC curve, it was found that the transformation temperature value was within the range of 67 and 68^{0}C. The other values obtained via the DSC are as follow: Austenite Start (As) = 76^{0}C, Austenite Finish (Af) = 53^{0}C, Martensite Start (Ms) = 22^{0}C, and Martensite Finish (Mf) = 49^{0}C. For the future, more studies on the nickel–titanium (Ni-Ti) material's thermomechanical behavior is recommended since the demand in the use of piezoelectric materials and electro-rheological material are rapidly increasing due to their flexible and unique properties. Ni-Ti could be the material of interest since this alloy has better mechanical properties compared to other SMA.

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