Effect of Heat Treatment on Phase Transformation Temperature of NiTi Shape Memory Alloys

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Abstract

Together with the rapid advances in technological fields, new types of materials have begun to be researched and produced. In addition to producing new materials, the studies on the improvement of both the thermal and mechanical properties of the material obtained by adding different elements to the existing materials continue in both industrial and academic fields. Shape memory alloys, which are one of these materials and which are able to return to their original shape and size, have an important place for engineering applications. Shape memory alloys commonly used in aerospace, automotive, medical and many other fields are metal alloy group which can be subjected to a shape memorization process between two transformation phases depending on temperature, pressure or magnetic field. There are many alloys including iron-based, copper-based and nickel-based. Ni-Ti alloys are the most attractive alloy systems in scientific and commercial fields with their general characteristics such as simplicity in thermomechanical motion mechanisms, highly recoverable strain, and high corrosion resistance. The inclusion of elements in different proportions of this alloy system is important for strengthening the alloy. In addition, it can increase the performance of Ni-Ti shape memory alloy in applied heat treatments. Based on this property of shape memory alloy, the effects of heat treatment applied to Ni-Ti shape memory alloy on the conversion temperature and crystal structure of alloy have been investigated.

Keywords: Shape memory alloys, Martensitic transformation, DSC, Aging

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Introduction

For centuries, metals have structurally played an important role in human life. Since ancient times, societies have used and developed alloying, melting and forging techniques. In recent years, important developments have been experienced in the field of materials science with the developments in science and technology and a better understanding of the effects of microstructure and processing techniques on materials. The properties of new alloys and composites have been improved by utilizing the mechanical, thermal and electrical properties of the materials. The demand for stronger and lighter materials with special properties that meet structural requirements and provide additional engineering functions has created a new branch of materials called smart materials [1].

Certain metals and alloys, which are among the smart materials, exhibit certain properties when externally applied effects such as temperature, pressure, light etc. Such materials in which the desired reactions can be received in the direction of external forces are called smart materials. Piezoelectric materials, ceramics, magnetic strong materials, smart polymers, shape memory alloys are among these materials. Along with shape memory alloys, these materials are widely used both in industry and academia and developed with various studies. Shape memory alloys are metal alloy systems capable of returning to their true shape and size by a suitable heat treatment. These unique properties of shape-memory alloys have made them popular for applications such as detection, operation, vibration damping [2].

The first discovery of shape-memory alloys begins with the Au-Cd alloy found by Chang and Read in 1932, which is later observed by Arne Olander in 1938 in Cu-Zn alloys [3]. But until the 1960s, important studies on shape-remembered alloys have not been conducted. It was a coincidence in 1961 that W.J. Buehler et al. Found the shape-remembering effect in the Ni-Ti alloy [4-6]. Shape memory alloys are now divided into three main groups; NiTi, Fe and Cu, of these structures, Fe-based alloys are relatively weaker than others; NiTi-based shape memory alloys are more expensive but more effective than Cu-based alloys [7, 8].

The shape memory effect (SME) is effected by the solid state phase transformation without diffusion in the material. These phase transformations are generally provided by temperature or magnetic action between the phases known as austenit and martensite. In the alloys, the crystalline structure of the austenite phase in the solid state is transformed to martensite phase by external effects such as temperature [9]. In the shape memory alloys, the transformation of the martensite phase to austenite phase is described as a thermodynamic cycle and generally exhibits a reversible structure. During the transformation between phases, the release of chemical free energy creates the driving force under the shape memory effect. This force occurs the shape memory effect. The location of the atoms during the phase transformation, although the amount of displacement is very small, this movement is made in the same direction as a collective movement on the material causes large scale deformation. Crystal structure change in alloy provides high quality properties such as shape memory effect and superelasticity [10-14]. The temperature at which the martensite phase starts during the phase transformation is expressed as M_s, and the temperature at which the phase transformation finishes completely is expressed as M_f. These abbreviations are used in the literature as A_s and A_f for the start and finish temperature values of austenite phase [15-18]. The transformation of thermally driven shape memory alloys to the desired range depends on variables such as the ratio of alloying elements, thermal and mechanical processes. After these processes, it was observed that the transformation temperatures changed as well as the physical properties of the alloy [19].

DSC analysis is performed to determine how the heat capacity in materials changes against temperature. In this way, phase changes analysis can be made on the material. A typical DSC curve and a graph showing the phase start and finish of the peaks in this curve is shown in Figure 1. In this study, the effect of aging process applied to Nickel-Titanium alloy at the same time and at different temperatures on phase transformation temperatures was investigated based on these properties of shape memory alloys.

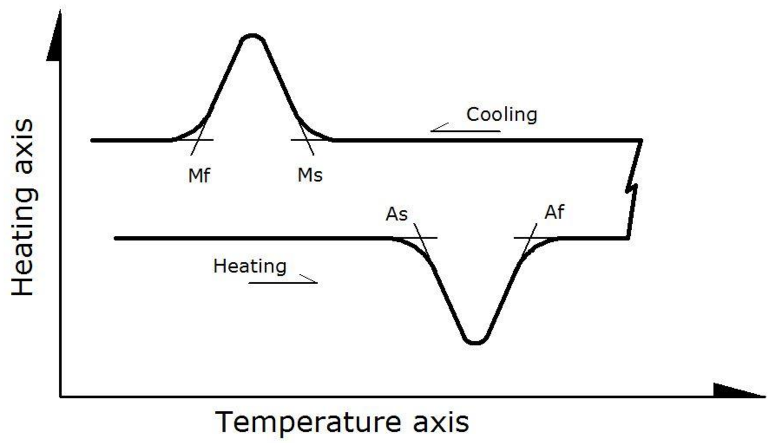

Figure 1. DSC martensitic transformation curve [20]

Experimental Details

The 1 mm thick NiTi shape memory alloy whose chemical composition is given in Table 1 is divided into four equal samples (NiTi0 -NiTi1 - NiTi2 - NiTi3 - NiTi4) with a length of 6 mm. NiTi0 is an untreated reference sample. The chemical composition of the samples was determined on the EDS. Aging process was applied to the samples at the temperature values and times given in Table 2. Then DSC (differential scanning calorimetry) analysis of the samples were performed. In this technique, the heat flow generated by heating and cooling the mass is monitored. In this way, phase changes analysis can be made on the material. The DSC results of the samples at a running speed of 25 °C / min are shown in Table 3.

Table 1. NiTi chemical composition

	% at	**% wt**
Nickel	46.84	51.93
Titanium	53.16	48.07

Table 2. Heat treatments applied to samples

	Temperature	**Time**
NiTi0	-	-
NiTi1	350°C	2 hour
NiTi2	400°C	2 hour
NiTi3	450°C	2 hour
NiTi4	500°C	2 hour

Table 3. DSC results at 25 °C / min operating speed

	A_s (°C)	**A_f (°C)**	**M_s (°C)**	**M_f (°C)**
NiTi0	57.52	75.01	36.42	30.26

NiTi1	60.48	81.19	37.41	31.05
NiTi2	61.99	84.25	37.34	30.85
NiTi3	64.96	86.45	39.65	32.51
NiTi4	67.29	89.39	42.28	33.98

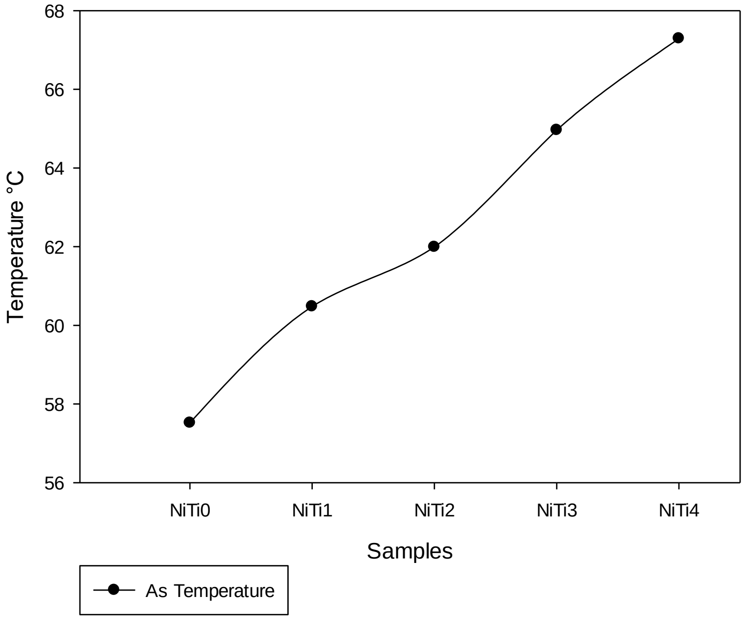

Figure 2. A_s change of transformation temperatures

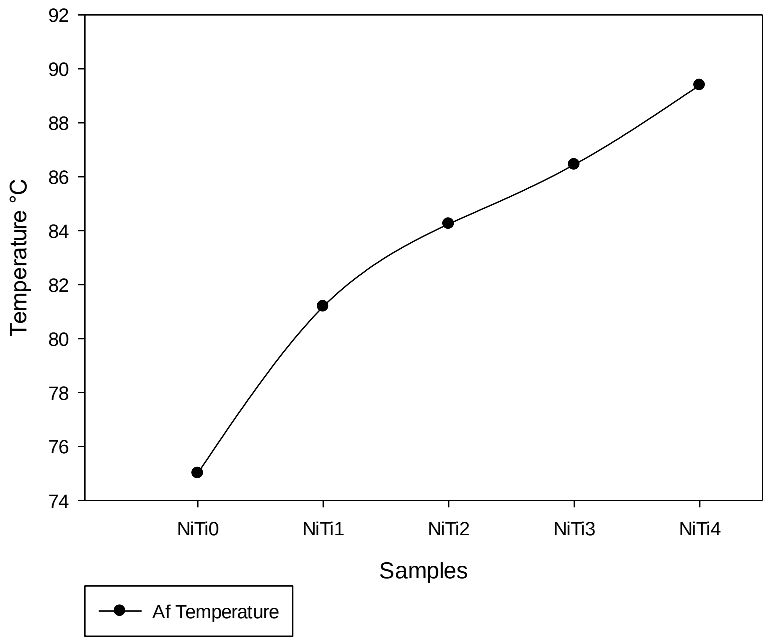

Figure 3. A_f change of transformation temperatures

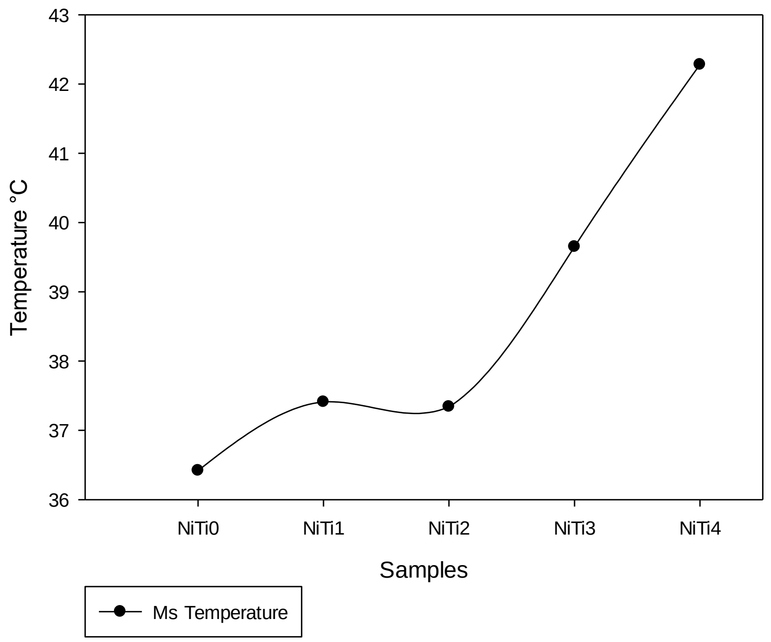

Figure 4. M_s change of transformation temperatures

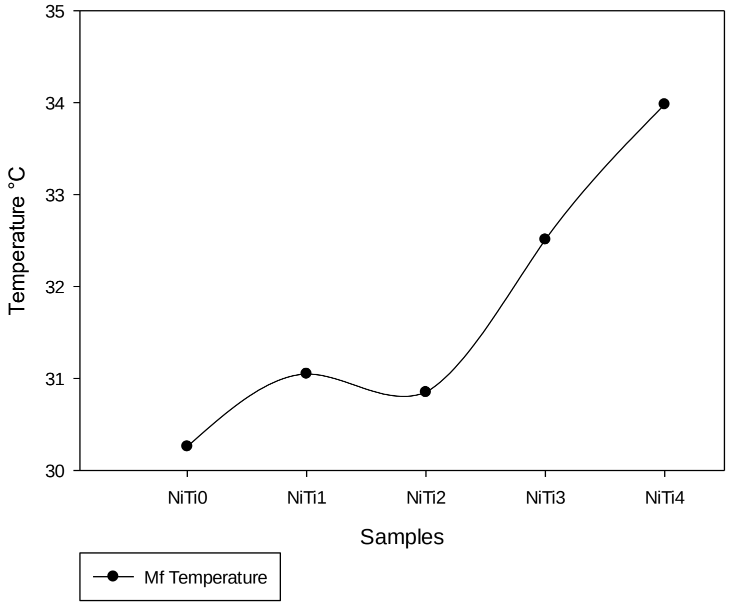

Figure 5. M_f change of transformation temperatures

Conclusions

Shape memory alloys are classified in non-conventional materials. They have significant features like diffusionless martensitic transformation. That provide unique features to material like shape memory effect. That magnifying features give inspiration many applications. However, shape memory alloy can be induced many type ways such as, temperature, magnetic, electrical and stress. Temperature is widely used to induce the shape memory alloy for solid state transformations. It provides external energy to phase transformations. If the material subjected too many times, the sample can be losing original features because of aging effects. In this study aging effects were studied and with 50°C incremental form 350°C to 500°C aging temperatures experienced. The results showed significant differences between ~10 – 3 °C in martensitic and austenite phase start and finish temperatures.

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