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EXPERIMENTAL EVALUATION OF THE EMISSIVITY OF A NITI SHAPE MEMORY ALLOY

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Abstract. *In many applications of Shape Memory Alloys the most appropriate means and sometimes the only one to measure temperature is thermography, which relies on knowing the emissivity of the material. This paper aims to evaluate experimentally the behavior of the emissivity of a NiTi shape memory alloy as a function of temperature in order to check how emissivity varies with phase transformation. The SMA emissivity was determined with the use of active and passive infrared sensors in a spectral band of 8-14 µm and with temperatures ranging from 25 to 100 ºC under a vacuum of 30 kPa. The results show that the emissivity of the SMA varied approximately 15% during the heating cycle (from martensitic to austenitic phase) and 24% during the cooling cycle. This change corresponds to a variation between 3 and 5% in the temperature measured.*

Keywords: *Total hemispherical emissivity, Shape memory alloy, Thermography.*

1. INTRODUCTION

Measuring temperature is essential when characterizing and applying Shape Memory Alloys (SMAs). These alloys have four characteristic temperatures, namely: M_s (*Martensite start*) - initial temperature for formation of martensite; M_f (*Martensite finish*) - final temperature for formation of martensite; A_s (*Austenite start*) - initial temperature for formation of austenite; and A_f (*Austenite finish*) - final temperature for formation of austenite, Otsuka *et al.*, (1998). In some cases, taking into account the impossibility of measuring temperature using direct methods such as thermocouples, it becomes necessary to use indirect ones. Thermography is often the most applied and sometimes the only possible technique to measure the temperature of SMA elements since it allows temperature variations to be quantified remotely both in scientific and engineering applications Marinetti *et al*., (2012) and Delpueyo *et al*., (2011).

However, the quantitative analysis of the measured temperature depends on physical factors which are associated to the radiant properties of the material, especially emissivity Del Campo *et al*., (2010). Thus, seeking to establish a correlation between martensitic phase transformations in a shape memory alloy ($Ni_{55}Ti_{45}$ in w.t. %) and emissivity, the main objective of this paper is to investigate how the total hemispherical emissivity behaves through the phase transformation temperatures.

2. MATERIALS AND METHODOS

The investigated shape memory alloy was a NiTi alloy with nominal composition of 55 in wt% of Ni supplied by Nimesis Technology. An Energy-Dispersive X-Ray Spectroscopy test shows that the presence of small amounts of Al, Fe, Ca and Si as showed in Table 1. The Table 2 shows the phase transformation temperatures of the alloy measured by means of a Differential Scanning Calorimeter from Perkin Elmer (DSC-8500).

Table 1. Chemical composition of the as received NiTi alloy.

Chemical content	Ni	Ti	Al	Fe	Ca	Si
% wt.	55.408	43.888	0.295	0.157	0.143	0.109

Table 2. Data from calorimetry analysis.

Sample	A_s (ºC)	A_f (ºC)	M_s (ºC)	M_f (ºC)
% wt.	57.01	74.80	41.41	15.62

The cutting and grinding of the samples may induce surface tensions that consequently may induce martensitic transformation Pohl *et al.,* (2004), Escher and Hühner, (1990). For this reason, the samples were cut with a precision cutter under low speed (0.005 mm/s) with approximate sizes of 10 mm in diameter and 100 mm in length continuously cooled by a cooling fluid.

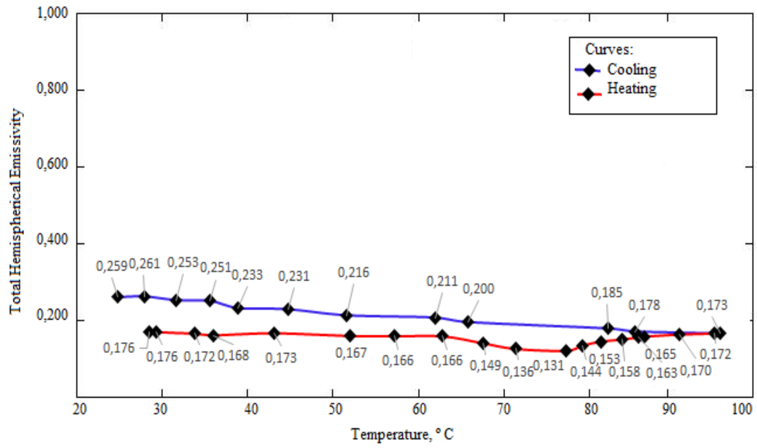
The measurement of the emissivity as a function of temperature was carried out in accordance with the ASTM E1933-99 standard (Standard Test Methods for measuring and compensating for emissivity using infrared imaging radiometers) and JIS A 1423 standard (Simplified test method for emissivity by Infrared Radio Meter). The evaluated emissivity is the total hemispherical emissivity. The developed experimental apparatus for measuring the emissivity is based on direct radiometric measurements using active infrared transmitter, in combination with an infrared detector and indirect measurements of reflectivity in reflective direct mode Silva, (2014).

The measurement is done under vacuum 30KPa condition, the is evacuated in the the pump, and then the sample is heated up at a specified temperature. In this case, the surface of a metal is kept clean without making the oxide film on its surface.

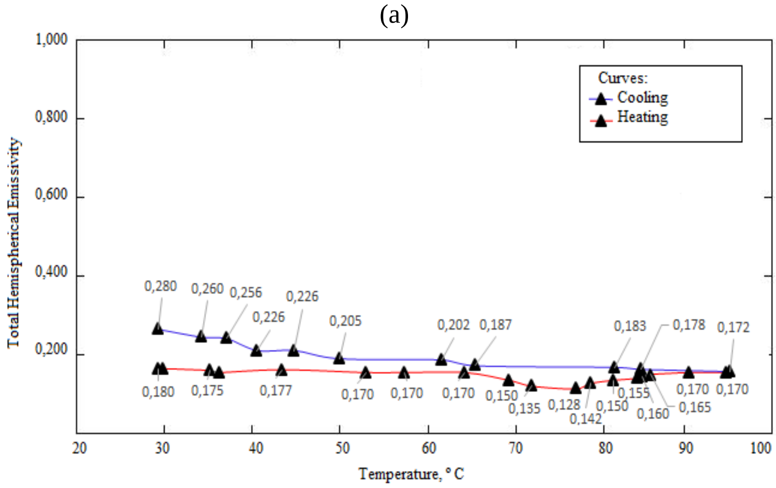
3. EXPERIMENTAL RESULTS AND DISCUSSION

Figures 1-3 show the curves for total hemispherical emissivity of the $Ni_{55}Ti_{45}$ alloy versus temperature. The data refer to the average of direct radiometric measurements using active infrared transmitter, in combination with an infrared detector (Fig. 1a) and through indirect measurements of reflectivity in reflective direct mode (Fig. 1b). As a result, emissivity is approximately constant with temperatures ranging from 26 to 65 °C during the heating cycle. However, when considering the heating curve on a smaller scale, there is a decrease in emissivity when temperature is increased between temperatures A_s and A_f – as indicated in Figure 2.

Variation between temperatures A_s and A_f was of approximately 15% when using direct measurement (Fig. 2a) and of 19.70% when using indirect measurement (Fig. 2b). This variation is explained theoretically and experimentally by the variation of the alloy roughness, which is of 0.7610 µm in the martensitic phase and of 0.8217 µm in the austenitic phase. In addition, oxide layers of only a few microns can affect the emissivity of these materials Siegel, (2002) Furukawa and Iuchi (2000). In temperature A_s the emissivity of the alloy begins to decrease due to the reduction of martensitic reliefs and emissivity directions since each surface relief caused by the martensite variant has its own normal direction. In temperature A_f the martensite reliefs completely disappeared, therefore minimizing the emissivity.

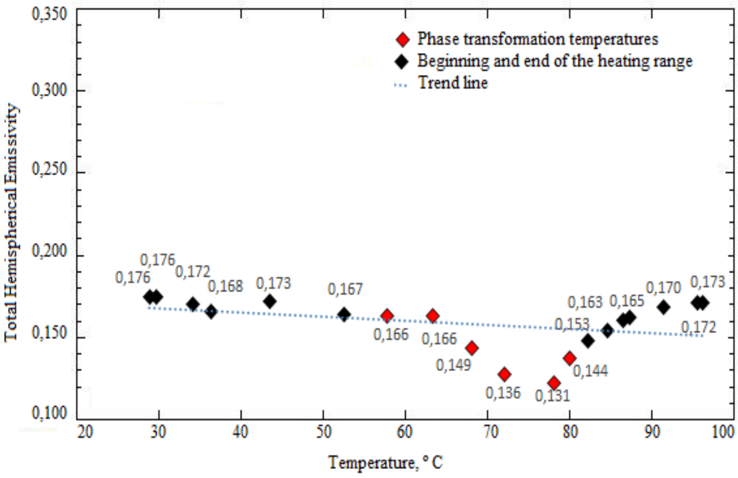


(a)

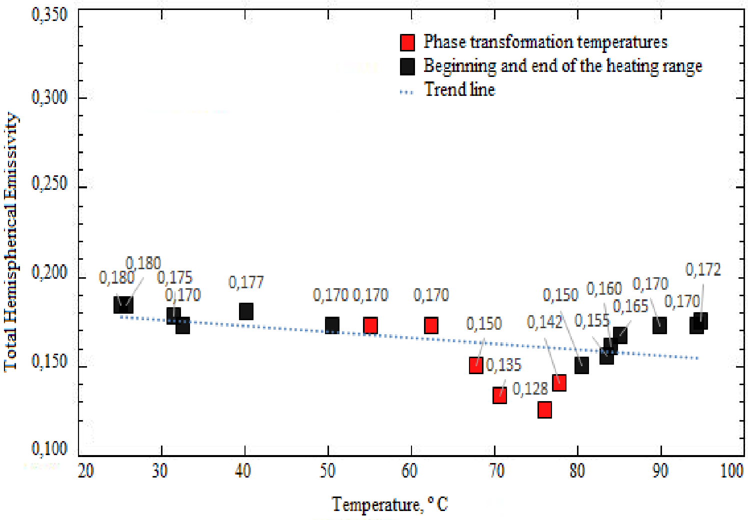


(b)

Figure 1. Total hemispherical emissivity data recorded in direct (a) and indirect (b) measurements.



(a)



(b)

Figure 2. Total hemispherical emissivity during cycle heating. Direct (a) and indirect (b) measurements.

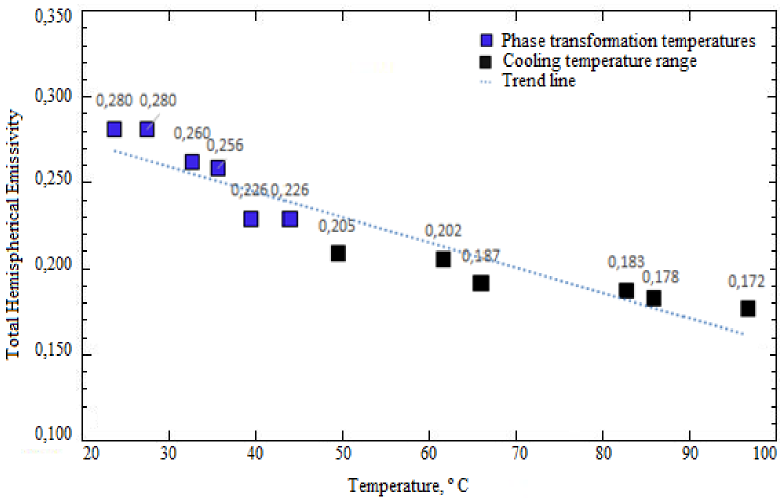


Figure 3. Total hemispherical emissivity during cooling cycle – indirect measurements.

At temperatures above A_f the emissivity increases again due to temperature rise. In contrast, the curve in Figure 3 shows the behavior of emissivity during the cooling cycle. In this case, it was observed that emissivity is inversely proportional to temperature, that is, the emissivity values increase and, starting with M_s, these values tend to increase in greater progression. As a result, the emissivity varied approximately 24% from M_s to room temperature (24 °C).

4. CONCLUSIONS

The emissivity of a $Ni_{55}Ti_{45}$ shape memory alloy as function of the temperature was experimentally evaluated. It was observed that the global average emissivity varied 9.5% between fully martensitic and fully austenitic states. Preliminary observation indicates that this change is mainly due to the surface relief associated to the martensitic phase transformation.

5. ACKNOWLEDGEMENTS

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