DEVELOPMENT OF NITI SHAPE MEMORY ALLOY MESHES

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Abstract. *This work consists primarily in manufacturing and characterizing shape memory alloy (SMA) NiTi meshes. These meshes have functional properties of Shape Memory Effect (SME) and Superelasticity (SE) have the potential of various applications by presenting mechanical characteristics which are compatible with meshes made of conventional materials, such as titanium. However, these SMA meshes evince the advantage of providing new capabilities for different applications with large strains and force generation in different temperatures, what can be very important for a specific traumatology or cardiovascular treatment. For the development of these new products, one chose a NiTi SMA and manufactured them by using a plasma melting (PM) process followed by injection in a ceramic coating mold. The raw meshes were then heat treated and hot-rolled for thickness reduction. The obtained components were characterized by Differential Scanning Calorimetry (DSC) and tensile tests. At room temperature, the obtained meshes have shown superelastic characteristics by recovering strain levels up to 4%.*

Keywords: *Shape memory alloys, NiTi, SMA mesh.*

1. INTRODUCTION

Shape Memory Alloys (SMA) are special materials once they have the ability to recover residual strains of values above the elastic limit. A mechanical component made of SMA can either recover permanent deformations or even generate significant forces when restricted to recover its original shape after thermally excited. These "shape memory" effects can be found in alloys like In-Ti, Cu-Zn-Al, Cu-Al-Ni and others, but they have been further studied in alloys from Ni-Ti system (Otsuka and Wayman, 1998).

The use of SMA in mechanical devices comes out to be a reasonable option, as these components may have structural and active function supporting loads and performing mechanical work at the same time. This ability to perform work (force and displacement generation) makes SMA components to be considered natural thermomechanical actuators.

In this context, this paper aims to manufacture and characterize SMA mesh actuators, made of NiTi, through a melting conformation process called *Plasma Skull Push Pull (PSPP)* (De Araujo et al, 2009). In this technique, the material is molten by a rotating plasma torch and then injected into a metallic mold. In this paper, the mold was obtained by lost-wax casting technique with a mesh-shaped cavity. This is called a precision casting process (Adabo, 2006).

In order to verify the presence of typical solid-phase transformations of SMA, chemical composition, and carry out the thermomechanical characterization of the manufactured NiTi meshes, there were used the following techniques: Differential Scanning Calorimetry (DSC) and tensile tests.

2. MATERIALS AND METHODS

2.1 Manufacturing process

The SMA used for the manufacturing process of the meshes had chemical compositions of 54.7%Ni-Ti. Due to the complexity of the mesh's geometry, one chose to use lost-wax casting. In this process, one uses a product-based geometry for molding it, in order to obtain the final product.

For preparation of the mesh-based geometry, one used a squared wax commercialized by *Talmax*. To ensure the complete mold filling at the time of casting and injection, it was used tubes with diameter of 3mm diameter in the injection system, with angles of at least 30°.

The ceramic preparation process consists in homogenizing 135 g of a crude powder coating with a solution of 13,5ml distilled water and 27ml of curing solution, pouring this mixture into a silicone mold. After 40 minutes of curing process, the mold was heat-treated over a temperature range of 25 to 1000°C, at 30°C/min. The process sequence can be seen in Figure 1.

Figure 1. Process sequence for preparation of ceramic molds made through lost-wax.

To manufacture the SMA meshes, the metals which constitute the alloy (Ni and Ti) were molten into a machine that uses a plasma melting process followed by injection molding, called *Plasma Skull Push Pull (PSPP)* (De Araújo et al., 2009). The melting process sequence is shown in Fig. (2), in a simplified manner.

Figure 2. Melting process sequence used for manufacturing of SMA meshes.

The meshes obtained through this process were cleaned, cut and polished aiming further characterization techniques described later.

2.2 Heat Treatment and Rolling

The NiTi meshes were heat treated at 750°C for 30 minutes. This treatment was used to stabilize the transformations temperatures and to eliminate any effect from the casting process. Subsequently, the meshes were rolled for 10 turns. After each rolling, the meshes were subjected to a reheating at 750°C and immediately removed from the oven and rolled, until achieving a final thickness of 0.50mm. Figure 3 shows the result of this rolling process up to the final thickness.

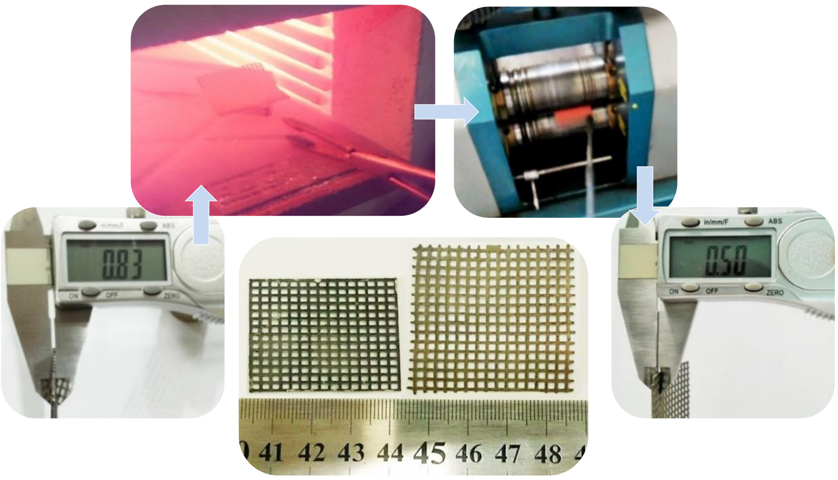

Figure 3. Hot rolling of SMA meshes obtained from *PSPP*.

2.3 Differential Scanning Calorimetry (DSC)

The DSC tests were carried out over a temperature range of -70 to 100°C, starting from the highest to the lowest temperature (cooling), with subsequent return (heating). The heating/cooling rate was 5°C/min.

2.4 Mechanical tests

The tensile tests were performed using the setup shown in Figure 4.

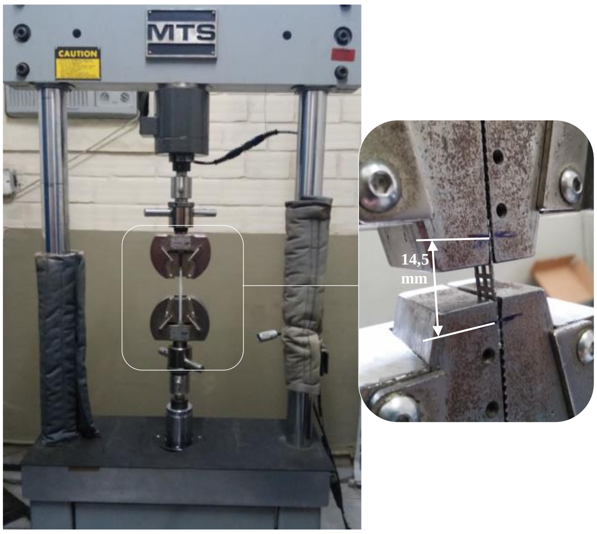

Figure 4. Setup for mechanical tests of SMA meshes.

Previously, there were carried out cycling tests, where the specimens were subjected to 50 cycles of loading/unloading. During loading, the deformation was limited to 2% of the effective length, at a rate of 0.001mm/s for both test stages. After this mechanical stabilization, one started a set of uniaxial tensile tests, consisting in loading the mesh, through displacement control, up to 2, 3 and 4% and unloading it, through force control, down to 1N, at 0.001mm/s.

3. RESULTS

3.1 Transformation Temperatures

The transformation temperatures at different points of 3 NiTi meshes were determined from DSC thermograms as shown in Figure 5.

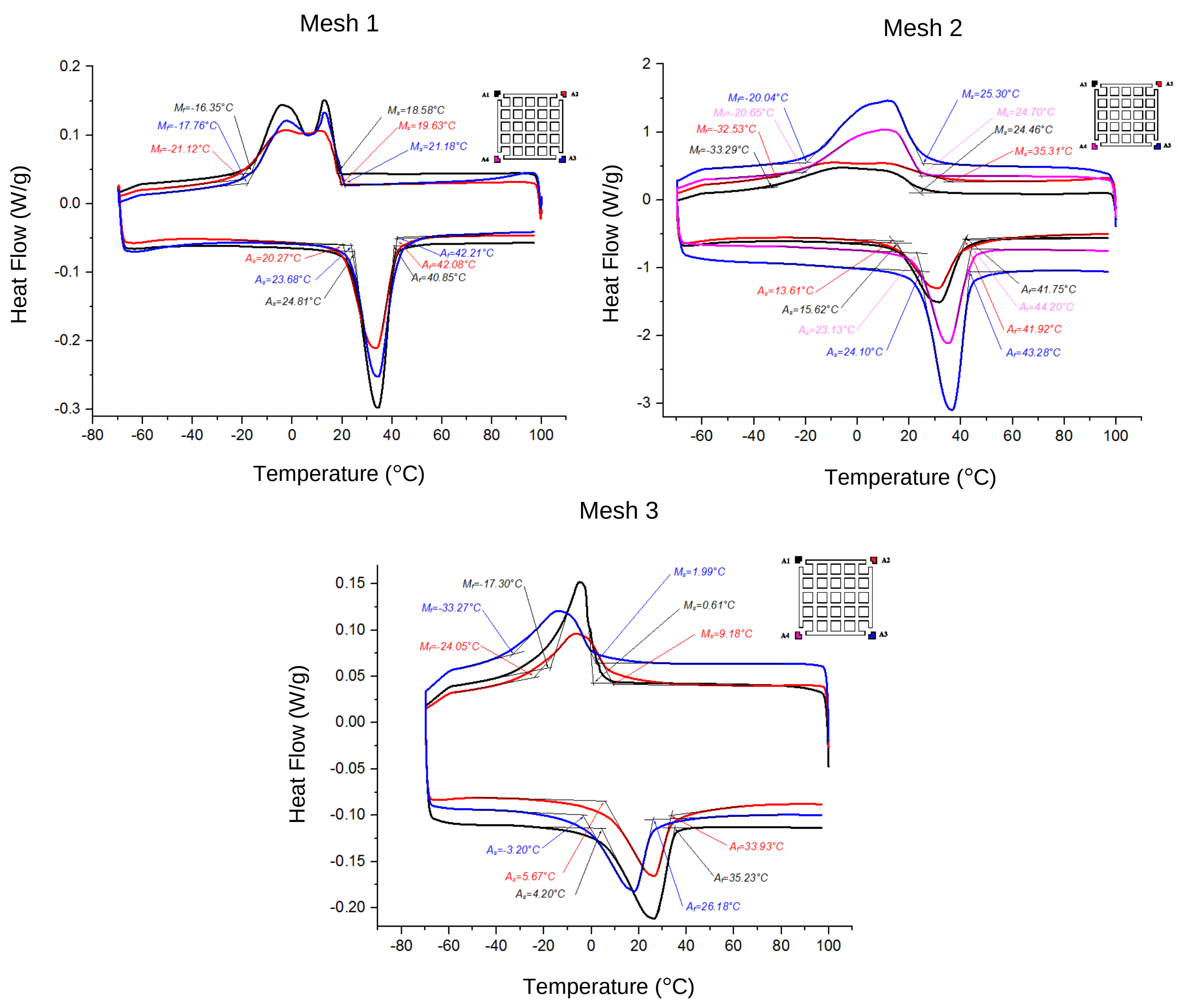

Figure 5. DSC results for NiTi meshes.

The transformation temperatures were extracted from the DCS curves and can be summarized in Tab. 3. From the analyses of those temperatures one could verify that, at room temperature (25ºC), the meshes would not be at a superelastic condition and, because of that, before carrying out tensile tests, it was necessary to heat up the specimens above Af and then cool them down to room temperature, which is higher than Ms.

	Edge	Ms (°C)	Mf (°C)	As (°C)	Af (°C)
Mesh 1	**A1**	18.58	-16.35	24.81	40.85
	A2	19.63	-21.12	20.27	42.08
	A3	21.18	-17.76	23.68	42.21
	Average	**19.80**	**-18.41**	**22.92**	**41.71**
	Standard Deviation	**1.31**	**2.45**	**2.36**	**0.75**
Mesh 2	**A1**	25.3	-20.04	13.61	41.75
	A2	24.7	-20.65	15.62	44.2
	A3	24.46	-32.53	23.13	41.92
	Average	**19.37**	**-18.05**	**20.58**	**42.10**
	Standard Deviation	**0.59**	**8.83**	**6.73**	**0.12**
Mesh 3	**A1**	1.99	-17.3	-3.2	33.93
	A2	0.61	-33.27	5.67	35.23
	A3	9.18	-24.05	4.2	26.18
	Average	**3.93**	**-24.87**	**2.22**	**31.78**
	Standard Deviation	**4.60**	**8.02**	**4.75**	**4.89**

Table 1. Transformation temperatures of NiTi Meshes.

3.2 Tensile tests

The results for mechanical cycling are presented in Figure 6. One can observe that the evolution of cycling leads to the stabilization on the mechanical behavior of the mesh, characterized by a slight reduction on the maximum force value and the presence of a residual strain.

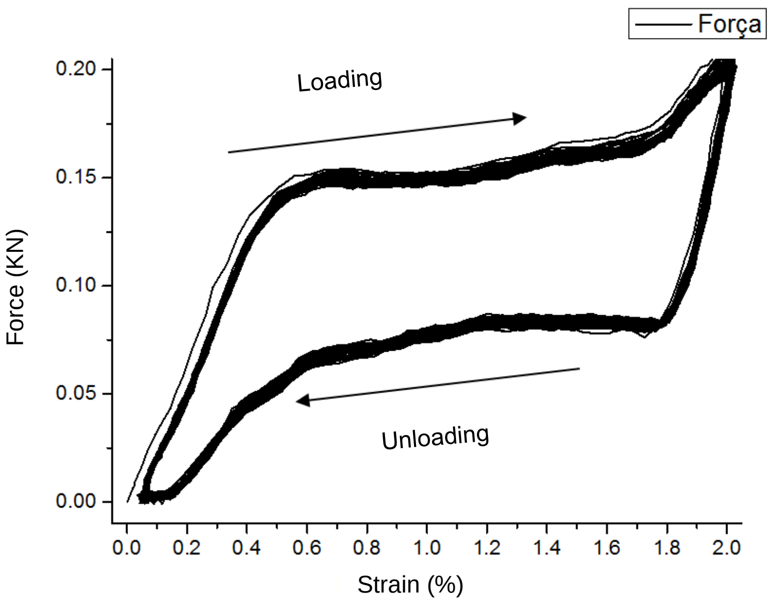

Figure 6. Mechanical behavior of a NiTi mesh, after 50 cycles.

After this cycling, tensile tests were conducted at room temperature, at strain levels ranging from 2% to 4%, considering the effective length of the SMA mesh. The most illustrative results were obtained from tests on the mesh 1, shown in Figure 7.

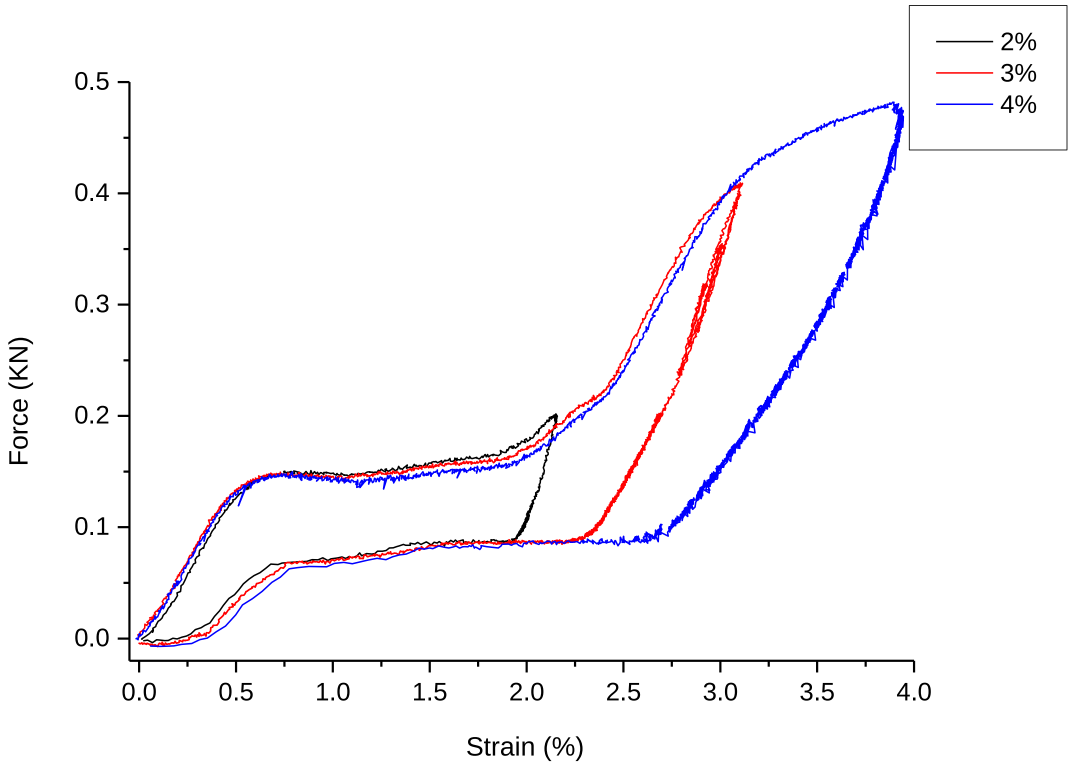

Figure 7. Superelastic behavior at different strain levels (2, 3 and 4%).

From these tests, it is verified that the phenomena of superelasticity clearly appears on the curves, confirming the results extracted from DSC curves. The curve shows the total recovery from the imposed strain on the mesh which has shown to be stable when deformed up to 4%, without breakage.

4. CONCLUSIONS

The present study has shown that is possible to manufacture SMA meshes from the NiTi system by a specific plasma melting, called PSPP, combined with ceramic mold obtained from the lost-wax technique. Such a precision casting technique offers opportunities for future projects of mechanical components from NiTi SMA, which further increases the potential applications of these components.

The mechanical properties shown by tensile tests show that the SMA meshes have developed mechanical properties of superelasticity (up to 4%) without breakage, which is an advantage when compared to strain levels of meshes manufactured with conventional titanium alloys, making this a highly competitive product in this segment.

The meshes manufactured in this work presented a reversible martensitic transformation temperatures ranging between 0°C and 45°C, showing further potential relevance and application of SMA to the development of mechanical components with diverse application possibilities.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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