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4-D Printing of NiTi Shape Memory Alloys

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INTRODUCTION

Nickel-Titanium (NiTi) shape memory alloys (SMA) have been broadly employed to biomedical and aerospace industry due to its functional properties, namely shape memory effect (SME) and superelasticity (SE). Usually, NiTi is thermo-mechanically processed from cast ingots, thereafter forming into rods, bars, sheets and wires. For this purpose, the material must follow a complex combination of working conditions. However, intrinsic problems such as high reactivity and strength configure an additional challenge to their processing. Nonetheless, in the last decade additive manufacturing (AM) has shown be capable of overcoming such difficulties, once it enables the manufacturing of complex SMA parts of maintaining its desired functional properties [1].

In AM, powder-based processes have skyrocketed and, according to recent reviews, selective laser melting (SLM) is the main technique used for the processing of SMA. On the other hand, SLM and related powder-based processes still present two critical limitations: impurity pick-up (C, O and N) and part size limitation. One alternative to mitigate the aforementioned problems is found on the electron beam freeform fabrication (EBF3) technique. EBF3 uses electron beam as energy source and wires as feedstock, additively fabricating medium-to-large near net shape parts. In addition, since processing takes place in a vacuum chamber, the level of contamination is reduced. In reason of its versatility, this cutting-edge technology has gained importance achieving increasingly more acceptance for industrial applications. To the best of authors' knowledge, there are currently no scientific work addressing the EBF3 fabrication of SMA. The present work addresses the first results on EBF3 of SMAs by studying NiTi alloys.

BASIC CONCEPTS

Shape Memory Alloys - Functional properties

Shape memory alloys (SMAs) are intermetallic alloys with shape memory effect (SME) and superelasticity (SE), both resulting from reversible martensitic transformations, causing reorientation of the lattice thus enabling the memory effects (Fig.1). SME is defined as the ability of a material to recover its previous shape after being deformed, when heated, prompting the occurrence of phase transformation; it also allows the material to transform thermal energy into mechanical work. In the case of SE, the alloy can be bent or stretched to great extent when austenite is mechanically loaded, returning to its original shape once the load is released.

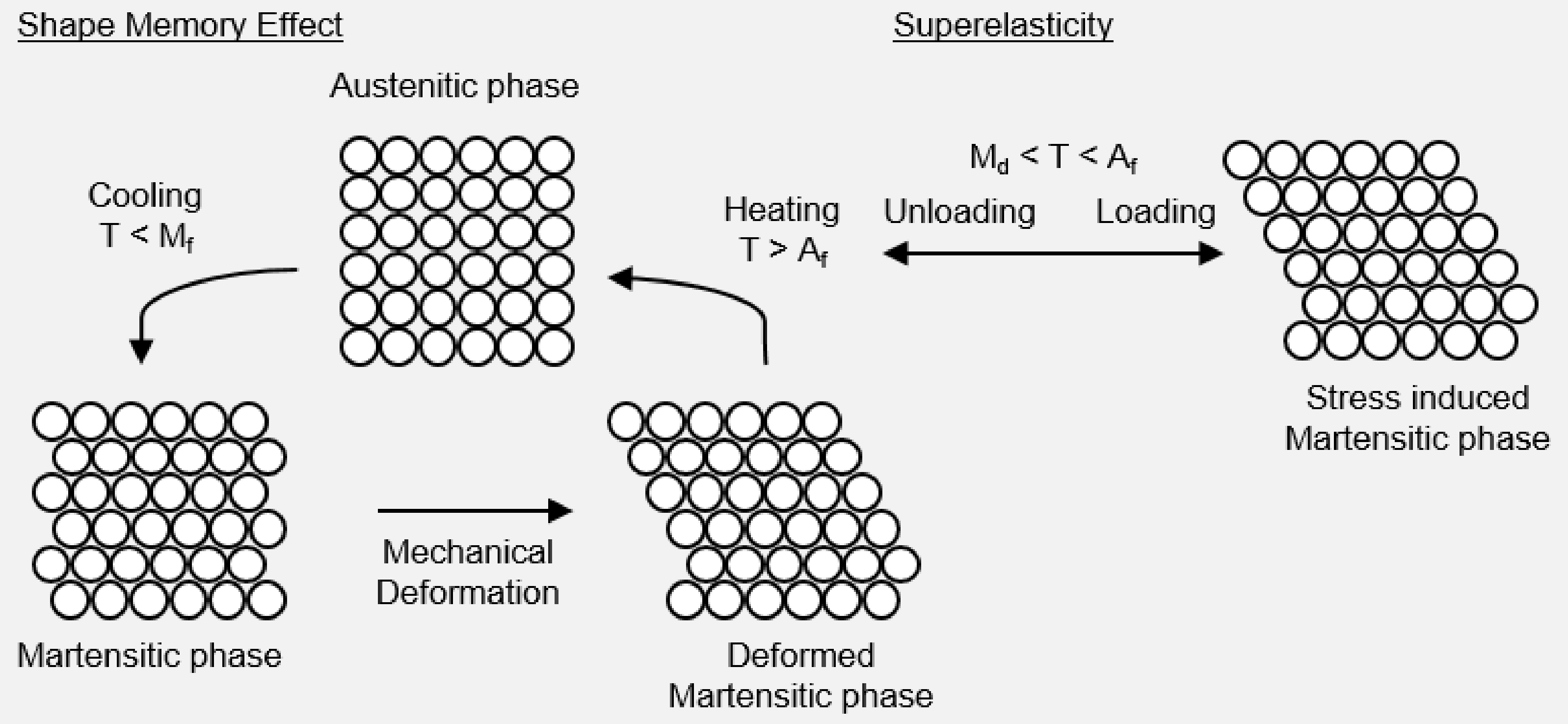

Figure 1: Shape Memory Effect and Superelasticity in atomic scale

Electron Beam Freeform Fabrication – EBF3

EBF3 process basically works by feeding and melting a wire into a molten pool, which is created and sustained by a focused electron beam in a high vacuum chamber (Fig.2). Gradually, either the substrate or the printing head, is translated, whereby the molten metal is deposited layer by layer until the part reaches the near-net shape. After the processing is completed, if necessary the part undergoes heat treatments – such as annealing – and/or machining aiming to achieve final shape.

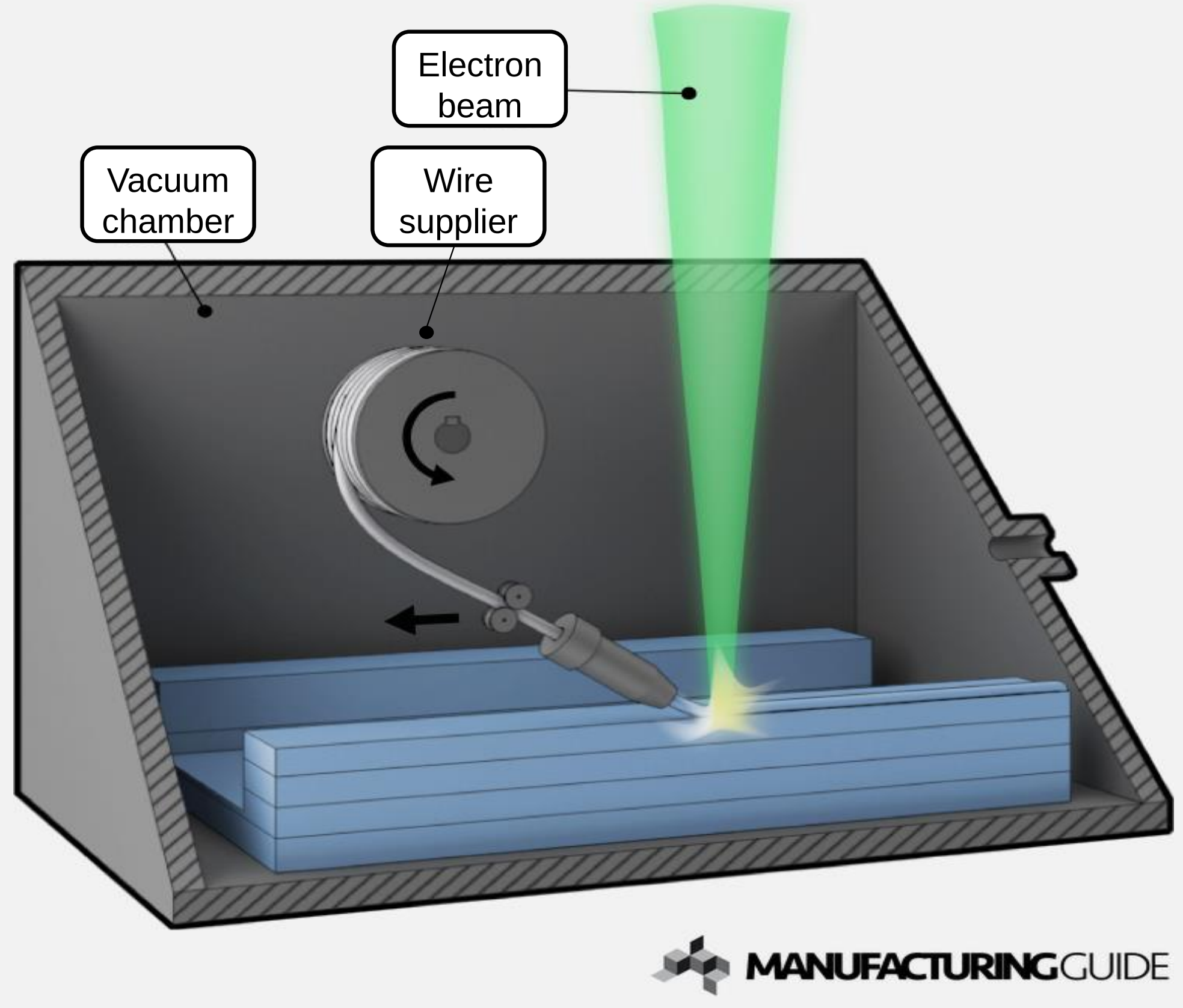

Figure 2: Schematic of the Electron beam Freeform Fabrication (EBF3) process.

PRELIMINARY RESULTS

Deposition of NiTi by the EBF3 process

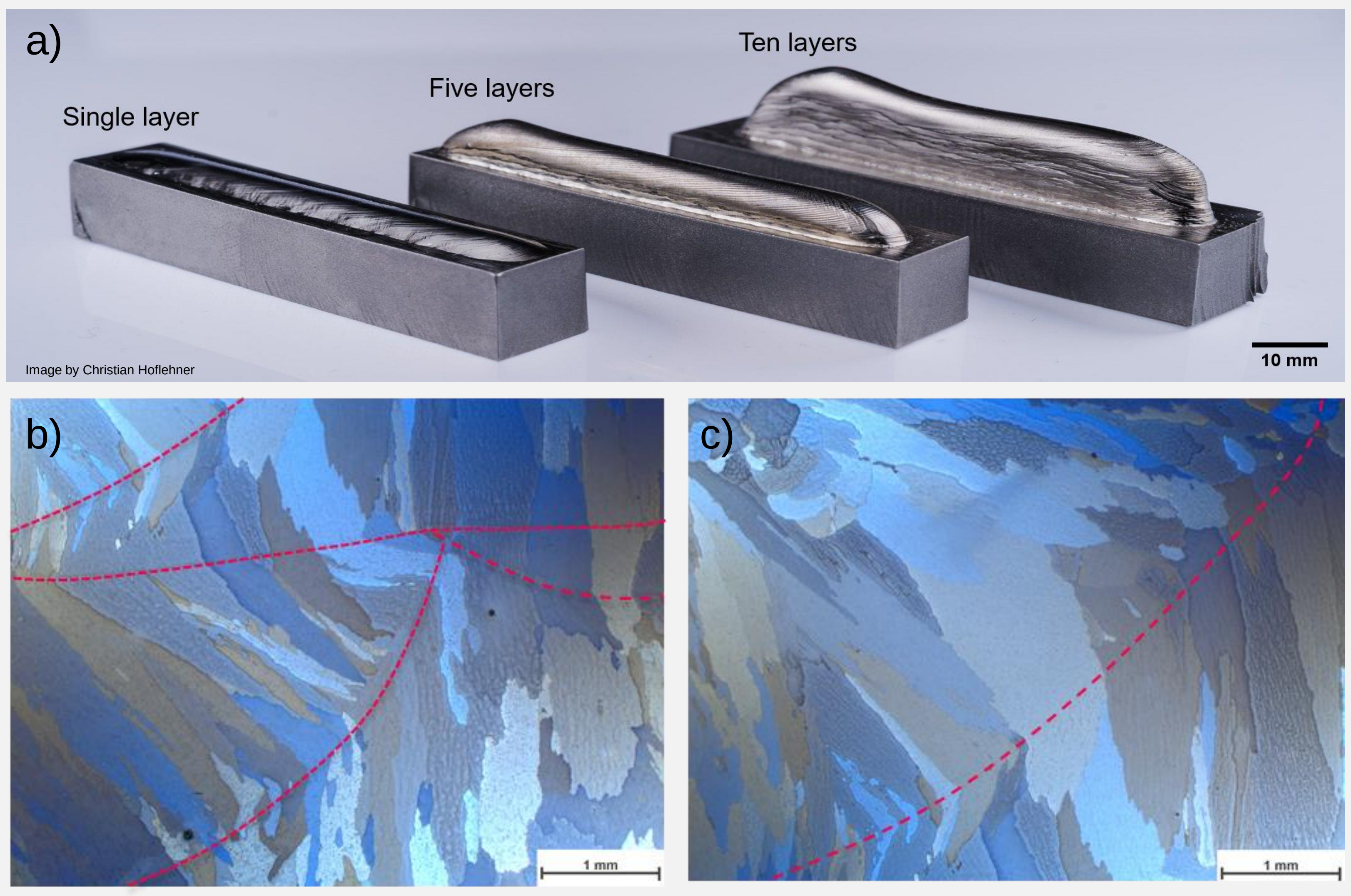

Figure 3: Single, five and ten layers deposition (a) and respective microstructure of transversal section for ten layers deposition (b and c) – the red lines represent the deposition lines, indicating different material deposition levels.

Figure 3a shows the stability of the build produced by EBF3. This shows the feasibility of EBF3 for NiTi alloys, indicating the potential of the technique for the fabrication of SMA structures. Concerning build microstructural morphology, one can note elongated grains resulting of preferential zones of heat extraction (Figures 3b and 3c). The preferential grain orientation in [001] is a result of the adopted material layer deposition. Once this texture direction favours the functional properties of NiTi, further investigations must be carried out determine how the fabrication parameters influences [001] texture.

X-ray diffraction (XRD) and differential scanning calorimetry (DSC)

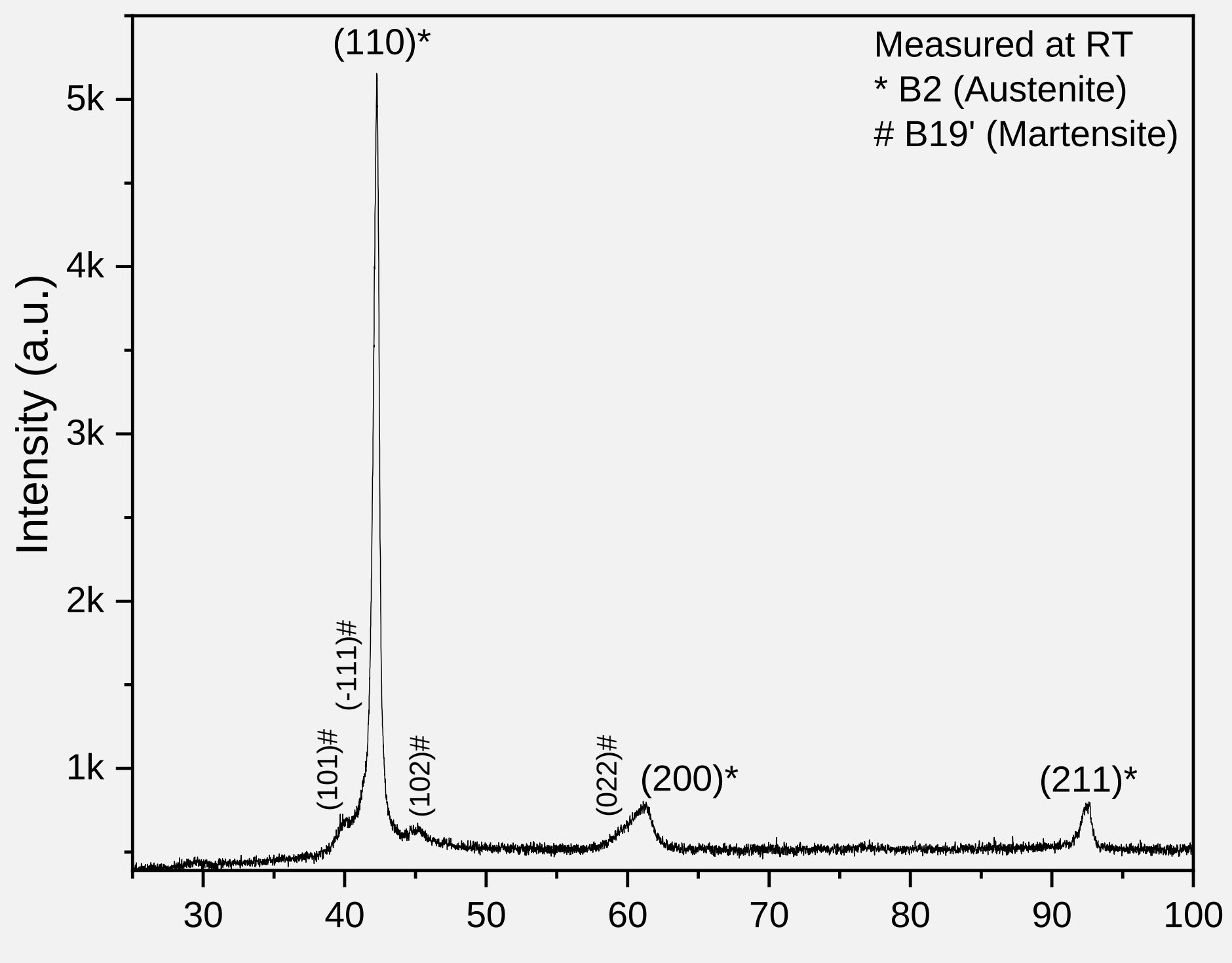

Figure 4: XRD of the fabricated part

The material in the as-fabricated condition presented mostly the austenitic phase and residues of martensite (Fig.4). Despite the absence of Ni_3Ti or Ni_4Ti_3 peaks, process cooling rate may favor their precipitation. Further investigation must be carried out to confirm this fact, once it can impact directly the transformation temperature.

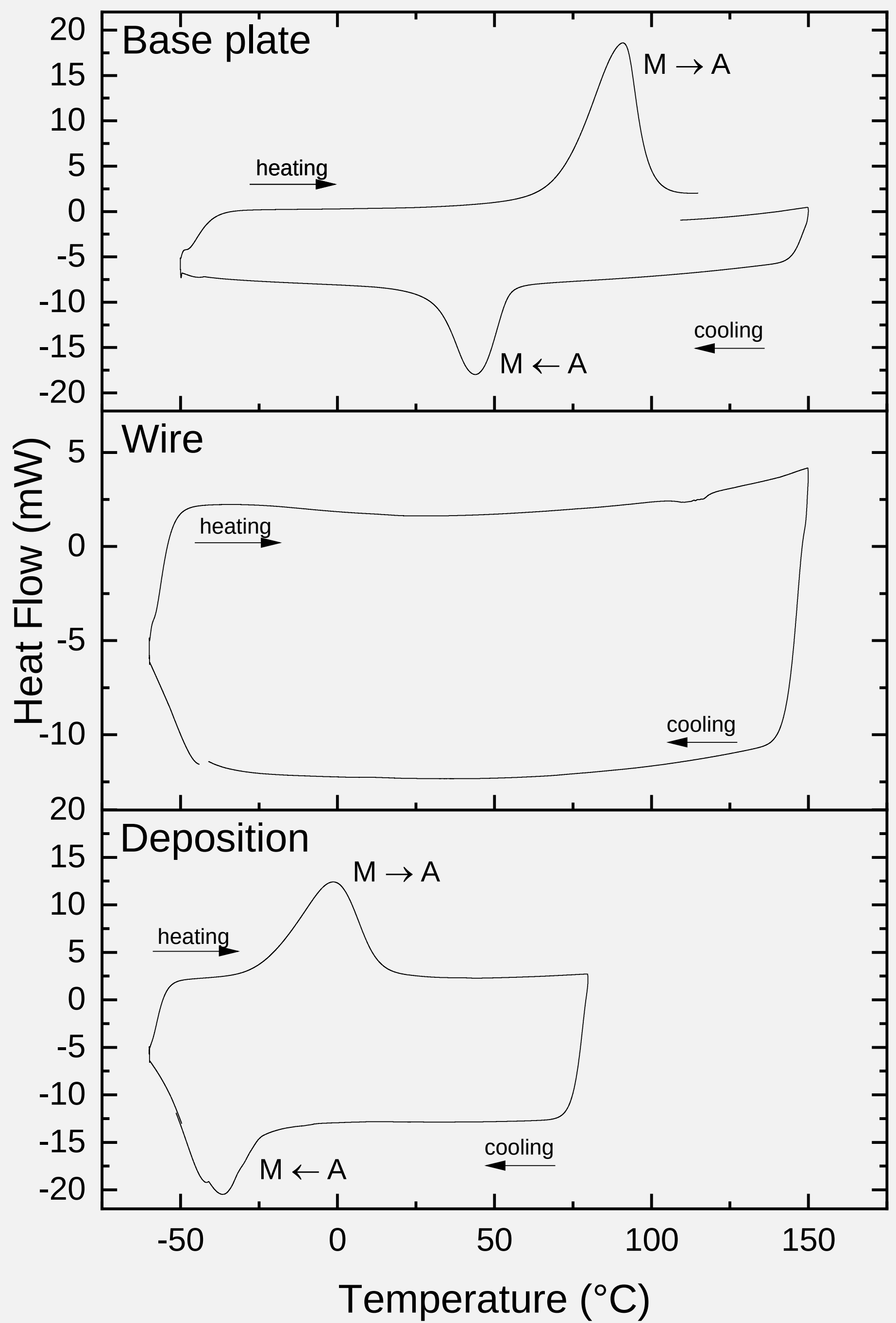

Figure 5: DSC plate, wire and part

Based on the DSC results (Fig. 5), it may be stated that the as-fabricated material is superelastic at room temperature due to 1) the predominance of the B2 austenitic phase and 2) austenitic final temperature (A_f) of 20 °C. In addition, the phase transformations observed indicates that EBF3 keeps the functional properties of NiTi wire base material. Based on the structural stability and the clear austenitic-martensitic transformation observed, one can concluded that EBF3 processing is a feasible technology for the processing of NiTi SMAs.

REFERENCES

[1] M. Elahinia, N. Shayesteh Moghaddam, M. Taheri Andani, A. Amerinatanzi, B. A. Bimber, and R. F. Hamilton, "Fabrication of NiTi through additive manufacturing: A review," *Prog. Mater. Sci.*, vol. 83, pp. 630–663, Oct. 2016.

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