Electron beam freeform fabrication of Ni-rich NiTi shape memory alloy

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Introduction

Recently, Shape Memory Alloys (SMA) have been fabricated by wire-based electron beam additive manufacturing technique for the first time[1]. However, the state-of-the-art study has not investigated the effect of processing parameters on the bead/stack geometry, layer features, and compositional variations. The current work addresses these knowledge gaps by means of Box-Behnken Design (BBD) of experiments. Based on these findings, a suitable combination of deposition parameters can be devised for Ni51Ti (at.%) additively manufactured multi-track structure, for future mechanical assessment.

Shape Memory Alloys

Shape memory alloys (SMAs) are intermetallic alloys with the ability of recover its previous shape after being deformed. The alloy can be bent or stretched to great extent, returning to its original shape once the load is released (superelasticity) or when the material is heated (superelastic effect).

Electron Beam Freeform Fabrication – *EBF3*

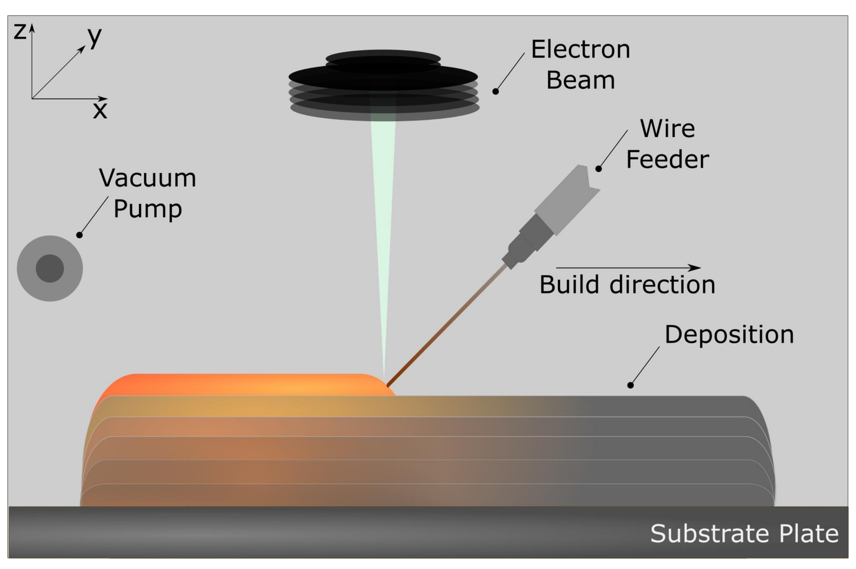

Figure 1: Schematic of the EBF3 process. The wire is inserted into a melting pool, which is created and sustained by a focused electron beam. The molten metal is deposited layer by layer until the part reaches the near-net shape

Experimental Procedures

Table 1 shows the range of EBF3 parameters used in the BBD study.

Table 1. BBD factors and respective variation levels

Factors	Symbol	Levels
Current (mA)	I_S	20, 22.5, and 25
Welding speed (mm/s)	W_s	9, 10.5, and 12
Feeding speed (m/min)	F_s	2.4, 2,85, and 3.3

The energy per volume of the beam can be calculated according to the following equation:

$$E_V = \frac{U_B * I_S * 4 * 60}{d_{wire}^2 * \pi * F_s * 1000} = \frac{E}{V} \quad [\mathrm{J/mm^3}]$$

where U_B, I_S, d^2_{wire} and F_S corresponds to accelerating voltage (90 kV), beam current (mA), wire diameter (1.2 mm), and feeding speed (m/min).

The following responses were taking into account:

- Aspect ratio (height/width ratio) (-)
- Dilution (%)
- Martensitic starting temperature, M_s (°C)

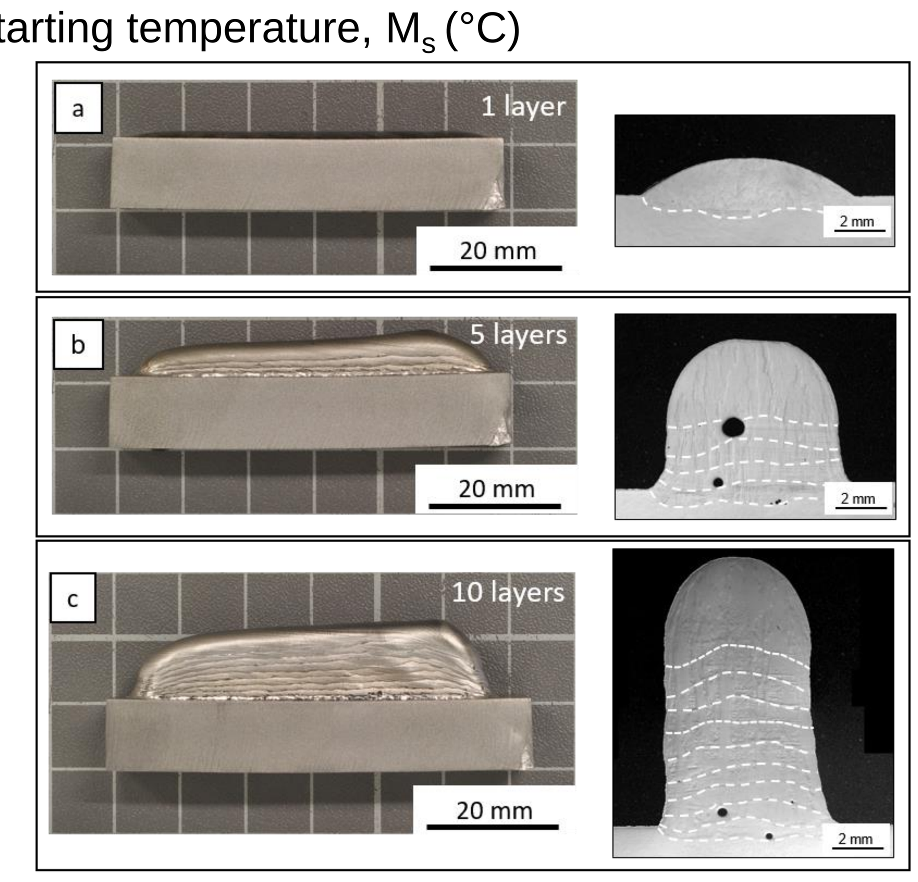

Figure 2: Macro and cross-section light optical image of a) one, b) five and c) ten layer deposition for 22.5 mA, 10.5 mm/s, and 2.85 m/min.

Results

Statistical Analysis

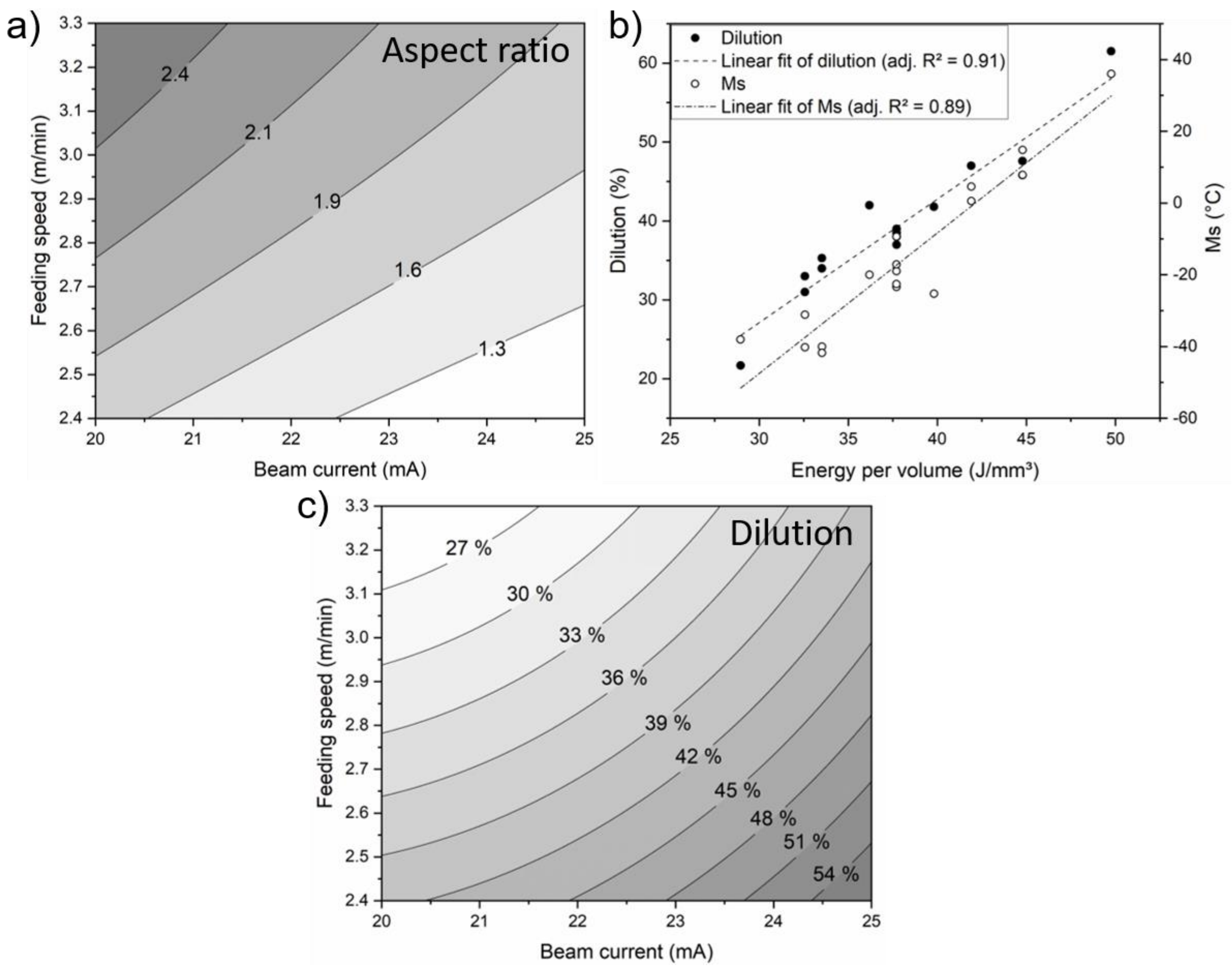

Figure 3: Contour plot of two-way interaction for a) aspect ratio, b) relationship between energy density, dilution, and M_S, and c) contour plot of two-way interaction for dilution

Following conclusions can be drawn from Figure 3:

- The aspect ratio increases as more material is melted using less energy
- There is a strong linear correlation between Dilution and M_s
- For higher energies and lower material feedings, higher dilutions are attained, whereby higher amounts of Ni-evaporation and higher M_s are seen

Selection of suitable processing parameters

Based on high aspect ratio, low dilution and M_s, surface regularity, and deposition homogeneity.

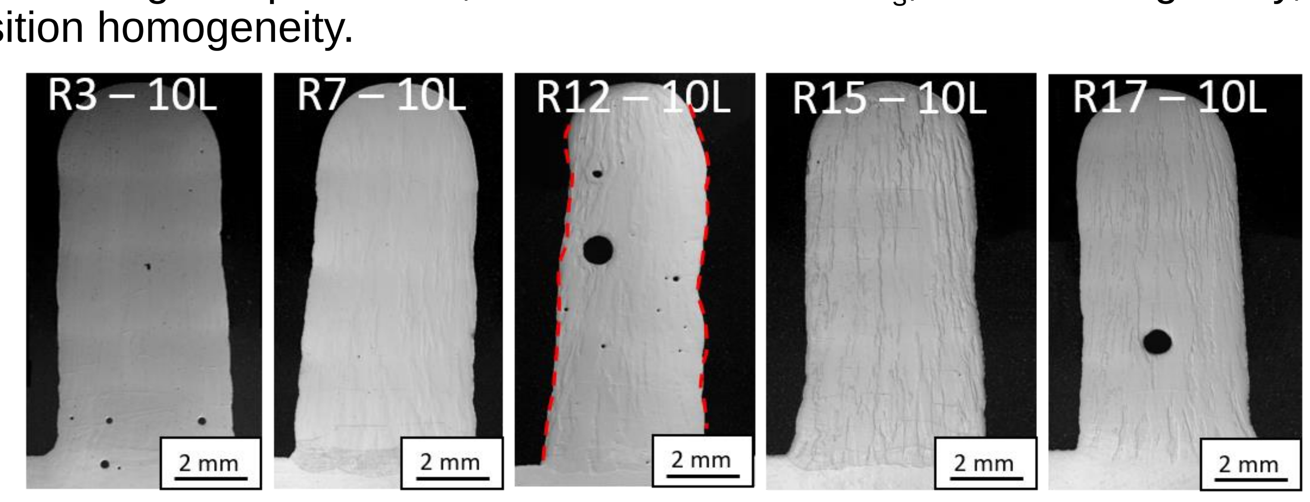

Figure 4: Analysis of surface regularity of ten-layers suitable running orders, where R12 presented an irregular surface.

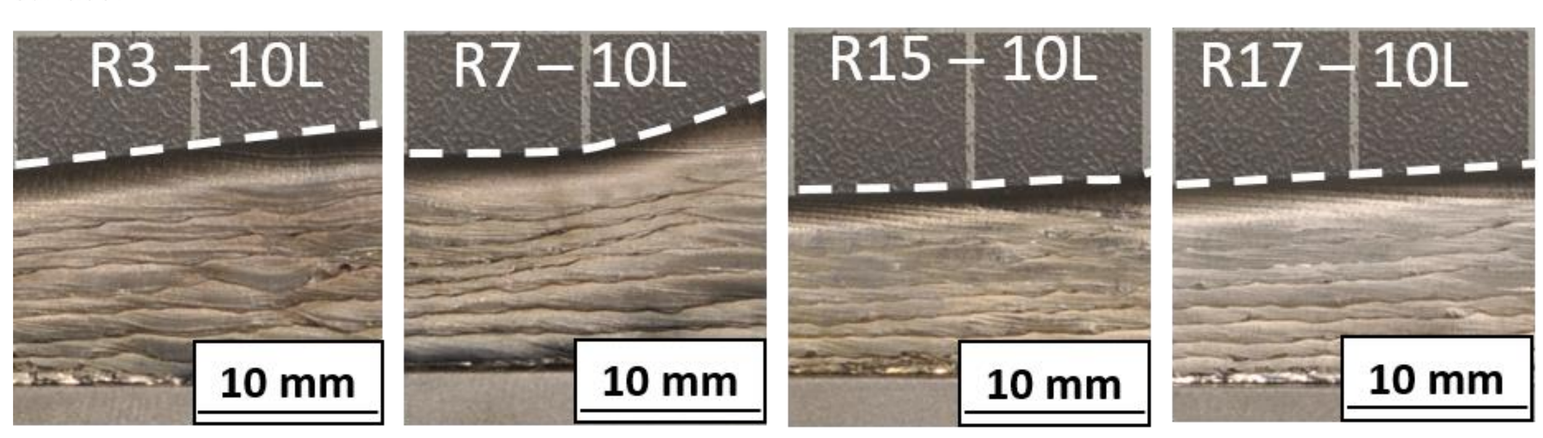

Figure 5: Humping effect based selection: R3 and R7 were eliminated.

BBD's R17 condition (I_S= 22.5 mA, W_s= 12 mm/sec, and F_s= 3.3 m/min) was selected due to its lower dilution and higher deposition rates. Martensite ↔ austenite phase transformation is present according to differential scanning calorimetry (DSC), thereby proving the existence of the functional properties.

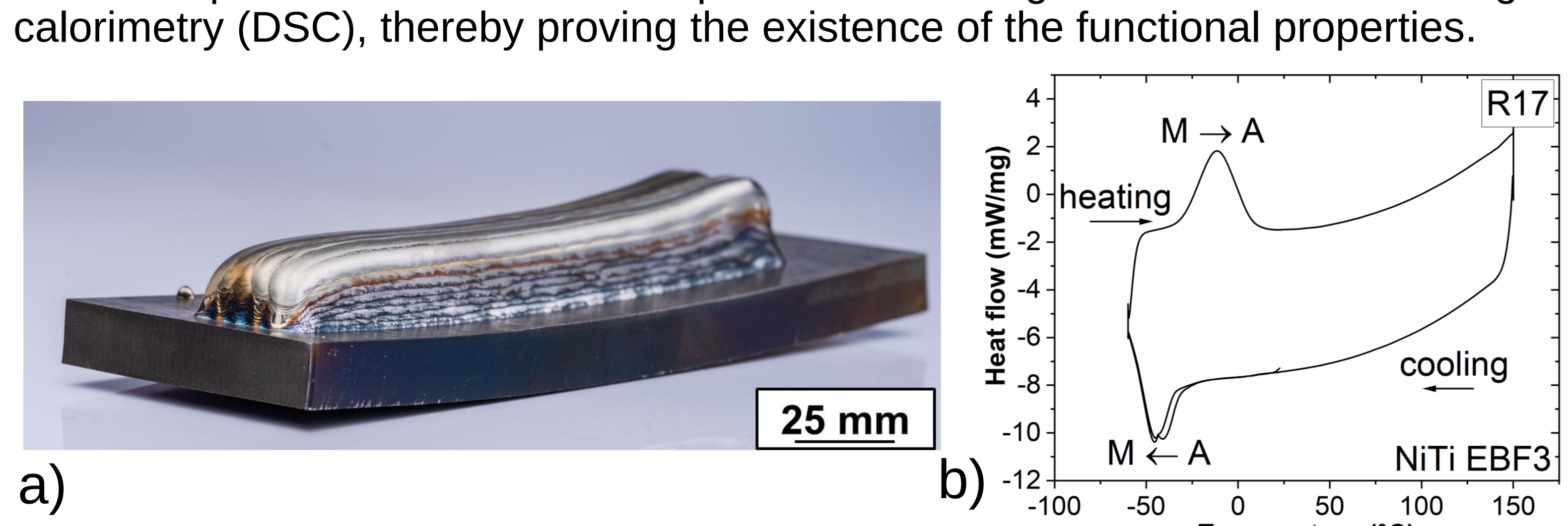

Figure 6: a) Multi-track deposition considered R17 processing parameters and b) DSC profile.

References
[1] J. Dutkiewicz, Ł. Rogal, D. Kalita, and M. We, "Superelastic Effect in NiTi Alloys Manufactured Using Electron Beam and Focused Laser Rapid Manufacturing Methods," no. Ref. 10, 2020

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