Advances in micro-laser-melting of the shape-memory alloy NiTi

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Abstract

Shape memory alloys (SMA) can be reversed to their original shape after a finite deformation, as the crystal transformation is fully reversible. For processing of SMAs at high purity, selective laser melting was used. As an example, Nitinol actuators with a cross section of 100 µm x 360 µm and a length between 14 mm and 24 mm were fabricated. The advantages of the chosen laser sintering process were shown. Furthermore NiTi SMAs could be qualified as actuators for medical applications.

1 Introduction

The application of shape memory alloys (SMA) has been suggested for various devices like micropumps, microvalves, microgrippers, and microactuators [1, 2, 3]. They are typically fabricated at high purity and good mixture by vacuum arc melting or induction melting [4]. A new possibility of fabrication is the application of a rapid prototyping process, which allows the production of well defined, complex structures. In this process a laser beam selectively melts the metallic particles on a predefined contour for producing the actuator. The precision of the fabricated form depends on particle size and laser beam diameter [5]. Especially Nitinol SMA is suitable as material for medical devices due to its biocompatibility [6]. Thus, the application of the produced Nitinol actuators can be found in biomedical engineering for cochlear implants.

2 Experimental

The experimental work was carried out at a semiautomatic working experimental laser melting station, depicted in figure 1b. It is based on a SPI 25 W fibre laser source with a wavelength of 1,070 nm and a process chamber (glove box) on a machine base. The laser radiation is guided by an optical fibre from the laser source to a 2D laser scanning system by Scanlab. The laser beam is focused by an f-theta lens in the working plane. The part geometry was designed with the scanning system software SAM light® and transferred afterwards to the control unit of the laser scanning system. The principle of the laser melting process is depicted in figure 1a. The structures were built up on square Nitinol sheet metals with a size of 9 cm^2.

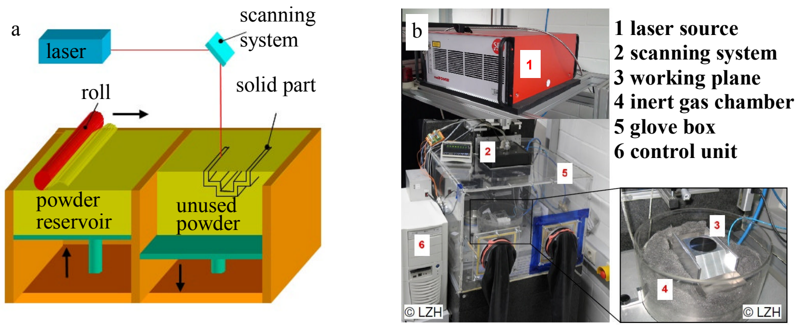

Figure 1: Principle of laser melting (a); experimental setup (b)

The powder was deposited in a manual procedure with a fine-meshed sieve on a substrate holder. The nominal layer thickness was 60 µm. To even the powder layer surface, a ceramic roll was used. In a subsequent process, the laser beam illuminates and melts the material on a predefined contour. The treated Nitinol powder particles are spherically shaped with a range of the particle size between 25 and 45 µm (Fig. 2a). As shown in figure 2b, a single actuator consists of 6 layers of molten Nitinol. Each single actuator consists of a linear part of about 5 mm length and a curved segment varied from b = 14.3 mm to b = 18.8 mm (Fig 2c). The linear part is intended for fixing the actuator with regard to additional force measuring.

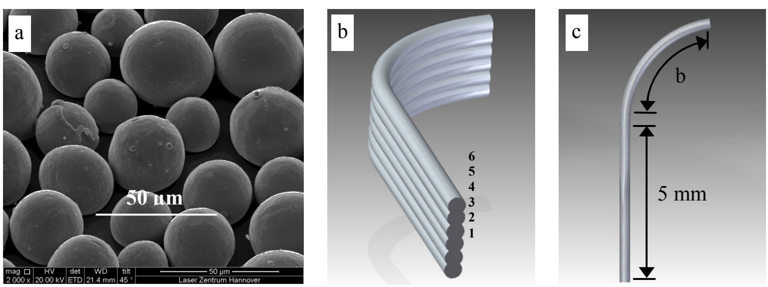

Figure 2: SEM micrograph of powder particles (a); the actuators 6 layer structure (b); geometrical specifications of an actuator (c)

The process strategy to built up the actuators with high resolution is based on a one vector scanning contour in longitudinal direction which allows a minimum width of approx. 60 µm.

3 Results of fabrication

The initial layers 1 and 2 (Fig. 2b) are processed in a single scan step strategy with a laser power of 7.5 Watt in order to achieve lower bonding forces between the initial layers and the substrate. Single scan step strategy means that an area of the powder layer is illuminated once. Due to heat conduction and multiple beam reflections at the powder particles, it is necessary to generate the initial layers with reduced laser energy input. It allows for an easier separation after processing of the finished actuators from the substrates. Layers 3 to 6 are produced with full laser power of 25 Watt to get a continuous and completely molten line. The used triple scan step strategy leads to very accurate and clean melting structures. These process variants ensure a sufficient mechanical stability of the actuators. On a single substrate, seven actuators with increasing curvature radius at the tip were built up as shown in figure 3a. The actuators are located in the centre of the substrate. The outer area of the substrate is intended to be unused. Due to pillow-shape effect in this area the powder layer is thinner there than in the centre of the substrate. Figure 3b shows an SEM micrograph of the laser-molten layer structure of an actuator. To draw conclusions on the phase transformation behaviour of the material before and after the process, differential scanning calorimetry (DSC) measurements were carried out. The sample itself and a reference sample are heated up in order to compare their heat flows. Figure 3c shows the results of DSC measurements of the powder material used as well as of a laser-molten actuator, respectively. The phase-transformation temperature of the powder has decreased from approx. 80 °C to approx. 60 °C as a result of the laser melting process.

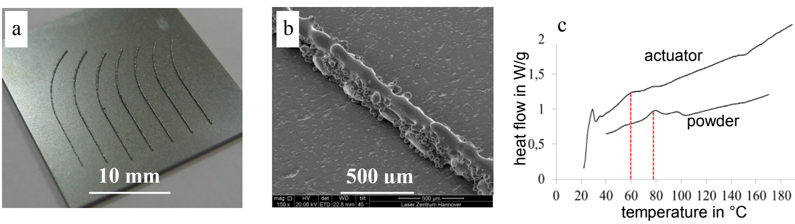

Figure 3: Finished NiTi actuators on substrate (a); SEM micrograph of laser-molten structures (b); results of differential scanning calorimetry (DSC) measurements (c)

4 Conclusions

In the range of the evaluated process parameters, the actuators could be produced without reject. After laser melting the shape memory effect could be kept for all finished samples. The microstructure proved a good alloying of the molten metal layers. Furthermore, samples were analyzed by differential scanning calorimetry. It could be shown, that the phase transformation temperature is directly influenced by the laser process. This dependency has to be analyzed in more detail in further investigations. Direct laser melting is a good alternative to conventional fabrication technologies for individually producing shape memory alloys.

Acknowledgements

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