# 激光选区熔化成形 NiTi 合金的相变行为和力学性能研究

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与传统加工方法相比，激光选区熔化技术(SLM，Selective Laser Melting)可以成形形状复杂、几何精度高、杂质含量少的 NiTi 合金。因此，本文采用 SLM 技术制备 NiTi 合金，研究了工艺参数对合金微观结构、相变行为、力学性能和形状记忆效应的影响规律。结果表明：SLM 成形的 NiTi 合金的相变行为和力学-功能特性均与能量密度密切相关。在 54J/mm$^3$–100 J/mm$^3$ 能量密度范围内，成形的 NiTi 合金的致密度能超过 99.9%；相比于激光功率(140W–180W)和扫描间距(50μm–110μm)，扫描速度(500mm/s–1400mm/s)对致密度和微观组织的影响更为显著。SLM 成形的 NiTi 合金均由 B2 奥氏体和 B19'马氏体相组成，相变温度随着扫描速度的增加先下降后上升，由于成形过程中氧对 Ti 原子的吸附作用，合金原子比发生变化，导致马氏体相变温度基本都处于 0℃以下。通过工艺优化，本文制造的 NiTi 合金抗拉强度、屈服强度和延伸率为 408MPa、376MPa 和 8%。在压缩试验中，应变为 6.1%和 12.8%时，形状记忆率分别为 89%和 77%。与铸造工艺相比，SLM 成形的 NiTi 合金具有更高、形状回复率、可控的相变温度和硬度。

**关键词：**激光选区熔化成形技术；NiTi 合金；微观组织；力学性能；形状记忆效应

Compared with traditional thermomechanical processing methods, selective laser melting (SLM) is capable of manufacturing NiTi alloy parts with complex shapes, high geometric accuracy and low impurity content. Therefore, the NiTi alloy parts were prepared by SLM technology in this work. The effects of SLM process parameters on the microstructure, phase transformation behavior, mechanical properties and shape memory effect of NiTi alloy were also investigated. The results showed that the phase transformation behavior, mechanical and functional properties of NiTi alloy formed by SLM were closely related to the energy density. The relative density of the SLMed NiTi samples can exceed 99.9% in the range of 54–100 J/mm$^3$. Compared with laser power (140–180W) and scanning distance (50–110μm), scanning speed (500–1400mm/s) has a more significant effect on the relative density and microstructure of the samples. All the SLMed NiTi samples were composed of B2 austenite and B19' martensite phase under various energy densities. The transformation temperature first decreases and then increases with the scanning speed. The atomic ratio of NiTi samples was changed due to the adsorption of oxygen on Ti atoms during the SLM process, resulting in the martensite transformation temperature below 0℃. Through process optimization, the tensile strength, yield strength and elongation of the SLMed NiTi alloy were 408 MPa, 376 MPa and 8%, respectively. The shape memory recovery ratio was 89% and 77% under the pre-strain of 6.1% and 12.8% in the compression test, respectively. Compared with the cast counterpart, the SLMed NiTi alloy possessed a better shape memory effect, controllable martensitic transformation temperature, and higher hardness.
Keywords: Selective laser melting; NiTi alloy; Microstructure; Mechanical Property; Shape memory effect