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Anisotropy in the impact toughness of selective laser melted Ti–6Al–4V alloy

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ABSTRACT

Apparent anisotropies have been found in the mechanical properties of selective laser melted Ti–6Al–4V alloy. This study investigated the influences of the vertical and horizontal building directions on the impact toughness of selective laser melted Ti–6Al–4V, and a mechanism for the anisotropy in toughness is proposed. Disc-shaped building defects were clearly observed, even though the relative density was as high as 99.5%. The directionality of these defects reduces the load-bearing cross-section of a vertical specimen relative to that of a horizontal specimen; consequently, the impact energy of a horizontal specimen is 96% higher than that of a vertical specimen.

1. Introduction

Selective laser melting (SLM) is a novel free-form and nearly net-shaped technique of producing various metallic materials with complicated shapes and controlled porosity [1–5]. The metal powders are repeatedly packed in the powder bed and are melted by a high-power scanning laser beam layer-by-layer. Among the SLM metallic materials, Ti alloys, particularly Ti–6Al–4V, have been extensively studied due to their versatility [1–9]. However, compared with conventional processes, the SLM technique still has several drawbacks, such as the expense of SLM apparatuses, high cost of raw powders, low productivity, and anisotropic properties [9–18]. Furthermore, numerous studies have examined the influences of the building direction on the mechanical properties of as-built SLM Ti–6Al–4V and indicated that the microstructural anisotropy significantly affects the various mechanical properties [10–15].

Vilaro et al. [10] studied the tensile properties of SLM Ti–6Al–4V alloys built in the longitudinal and transverse directions. The greatest lengths of the specimens built in the longitudinal and transverse directions were parallel and perpendicular to the building substrate, respectively. They found that the ultimate tensile strengths (UTS) of these two directions were comparable, and that the ductilities of these two directions were quite different. The ductilities of the longitudinal and transverse directions are 7.6% and 1.7%, respectively. Qiu et al. [12] and Ahuja et al. [15] also found that the building direction plays an important role on elongation, but does not apparently affect the UTS. Besides the tensile properties, impact toughness is also very important for structural materials because it dominates the mechanical properties and fracture behaviors under unexpected loading with a high strain rate. However, the role of the building direction on the impact properties has rarely been studied. Only Yasa et al. [18] demonstrated that the building axis does not obviously affect the toughness. The main objective of this study was thus to identify the correlation between the building direction and impact toughness of SLM Ti–6Al–4V alloy.

2. Material and methods

To understand the relationship between the building direction and impact energy, SLM Ti–6Al–4V specimens were built in the vertical and horizontal orientations using an SLM machine (SLM 250 HL, SLM Solutions GmbH, Lübeck, Germany) under a protective atmosphere of Ar, as shown in Fig. 1. A layer thickness of 50 μm and a hatching distance of 120 μm were applied. The raw powder used was a spherical Ti–6Al–4V prealloyed powder produced by plasma atomization, and the median size of the powder was 34 μm, as determined by a laser light scattering particle analyzer (Mastersizer 3000E, Malvern Instruments LTD.,

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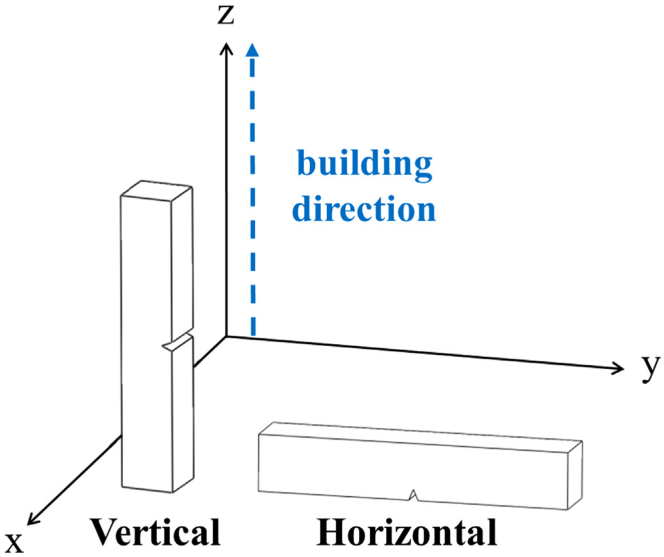

Fig. 1. Schematic of the SLM Ti–6Al–4V impact specimens built in the vertical and horizontal orientations.

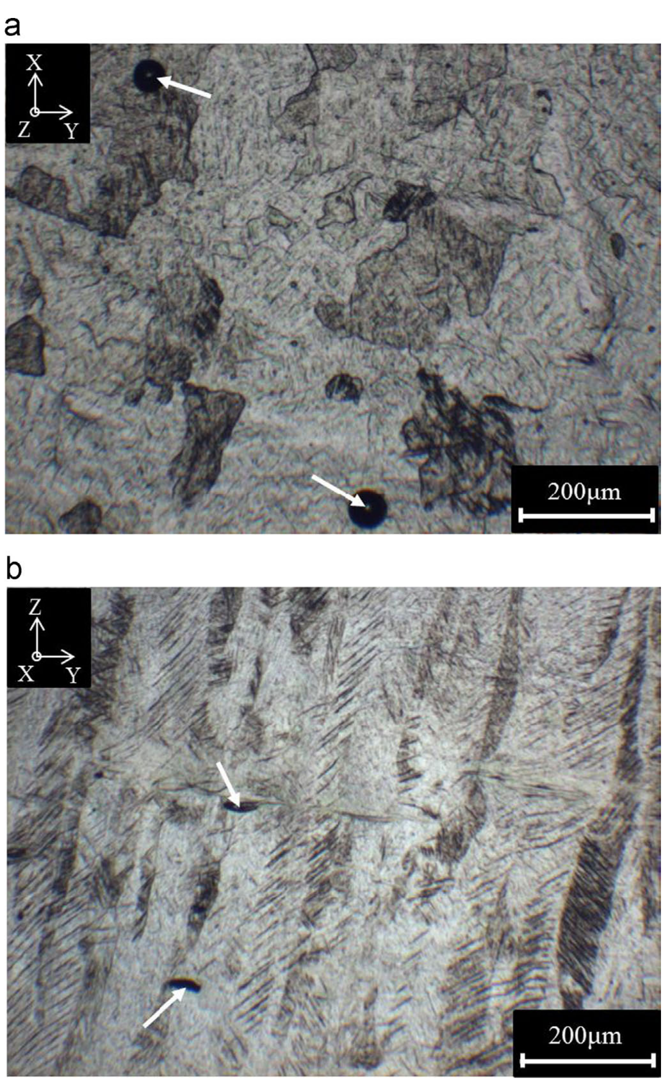

Fig. 2. The microstructures of SLM Ti–6Al–4V specimen built in the vertical direction. (a) *xy* plane, (b) *yz* plane.

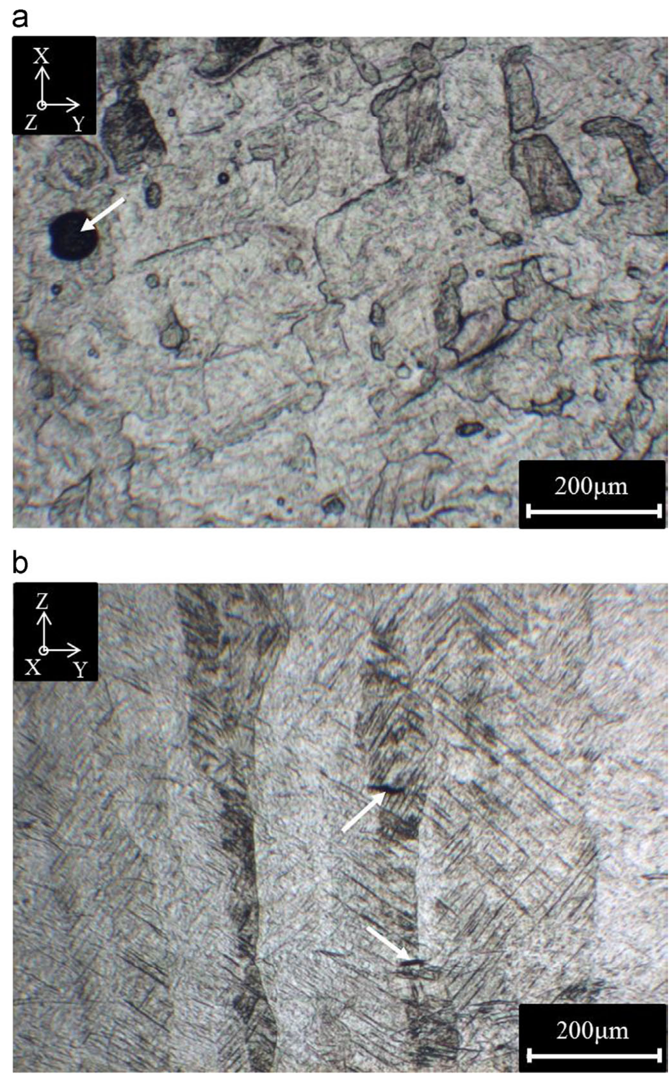

Fig. 3. The microstructures of SLM Ti–6Al–4V specimen built in the horizontal direction. (a) *xy* plane, (b) *yz* plane.

Worcestershire, UK). The dimensions of impact specimens with a 45° notch were $55\times10\times10\ mm^3$, and the size of the notch was 2 mm, as per ASTM standard E23-12c. The longest edges of the vertical and horizontal specimens were parallel and perpendicular to the building orientation, namely the z axis, respectively. The vertical and horizontal specimens were designated as V and H, respectively, in this study. To study the anisotropy of as-built SLM Ti–6Al–4V alloy, no specimen investigated in this study was heat-treated in any way.

Archimedes' method was used to determine the relative densities and the porosities of SLM Ti–6Al–4V specimens. The theoretical density of Ti–6Al–4V is $4.43\ g/cm^3$. The metallographic specimens were sampled, ground, polished, and chemically etched with an etchant of 5% HF, 5% HNO_3, and 90% distilled water. An optical microscope (OM) and a scanning electron microscope (SEM, JSM-6510, JEOL, Tokyo, Japan) were used to observe the cross-section microstructures of the *xy* and *yz* planes. A Charpy impact tester made by Shimadzu Corporation was used to estimate the impact energies of the specimens, and the impact fracture surface was examined by SEM. Furthermore, the impact fracture path was analyzed under an OM to clarify the roles of the microstructural constituents in the fracture [19,20].