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Effect of overlap distance on the microstructure and mechanical properties of *in situ* welded parts built by electron beam melting process

Pan Wang [a, *], Mui Ling Sharon Nai [a, **], Wai Jack Sin [a], Shenglu Lu [a], Baicheng Zhang [a], Jiaming Bai [a, b], Jie Song [a], Jun Wei [a, ***]

[a] *Singapore Institute of Manufacturing Technology, 73 Nanyang Drive, 637662, Singapore*
[b] *Department of Mechanical and Energy Engineering, South University of Science and Technology of China, No. 1088, Xueyuan Road, Shenzhen, Guangdong, 518055, China*

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A B S T R A C T

Electron Beam Melting (EBM), one of the powder bed-based additive manufacturing processes that is able to produce complex geometrical metal parts directly, has many application possibilities in various fields. However, an issue has been raised when we apply the EBM technology to fabricate medium volume components. Lack of energy when the scanning line is longer than 100 mm results in the lack-of-fusion pores, which degrades the mechanical properties of the printed part dramatically. Therefore, we propose an *in situ* welding process to overcome the issue. In order to further understand the microstructure and mechanical properties resulting from the *in situ* welded process with various overlap distances, we evaluate a series of overlap distances and successfully fabricate a big plate with dimensions of $200 \times 200 \times 4\ mm^3$. It is suggested that the defects and microstructure vary according to the overlap distance. Optimized overlap distances are 0.25–0.75 mm for Ti-6Al-4V. Within this range, no microstructural variation is observed which results in constant microhardness and superior mechanical properties of the EBM-built component. An overlap distance $\geq$1.5 mm results in microstructure coarsening and mechanical property degradation in the overlap zone. Furthermore, the localized deformation mechanism is discussed based on the findings of the tensile properties and digital image correlation analysis.

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1. Introduction

Additive manufacturing (AM) or more commonly known as 3D printing, is an emerging technology in the manufacturing industry. Unlike conventional manufacturing processes, such as milling, turning, and drilling which fabricate parts by removing material, AM, by its name is a process that builds parts by adding material layer by layer [1]. Although AM has been introduced for around three decades, it still attracts a lot of attention as there are more and more AM systems with different capabilities being invented and used in the market [2]. Among all the AM systems, electron beam melting (EBM) is one of the few which can fabricate metal parts directly without a stress relieving treatment [2]. The capability of printing metal components with complex geometry and high accuracy is one of the main attractions of EBM [1,3–5].

Ti alloys are considered as promising metals for the aerospace industry [6], biomedical implant [7–9] and chemical engineering [10]. Among these Ti alloys, numerous high-performance Ti alloys are formed based on the ternary Ti-Al-V system [10,11]. Traditionally, the Ti alloy parts are mainly produced in the cast or wrought forms with subsequent hot working and machining [6]. However, the poor machinability often increases the cost of complex geometry parts, thus limiting the application of Ti alloys. In order to lower the cost of the final parts, Ti-6Al-4V, a widespread Ti alloy [10], is selected for the EBM fabrication [1,5,12,13].

In the past few years, the microstructure of EBM-built Ti-6Al-4V parts has been widely discussed by understanding the phase transformation during the EBM process and by comparing the type

* Corresponding author.
** Corresponding author.
*** Corresponding author.
E-mail addresses: wangp@SIMTech.a-star.edu.sg (P. Wang), mlnai@simtech.a-star.edu.sg (M.L.S. Nai), jwei@SIMTech.a-star.edu.sg (J. Wei).

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of microstructure of the part followed by the prior β grain morphology and distribution of α′, α phase, and β phase [12,14–19]. The mechanical properties of a nearly full dense part fabricated by EBM are strongly related to its microstructure and are distributed over a wide range [16,20–25]. Fortunately, with the optimized processing parameters, the EBM-built parts give better mechanical properties than the wrought counterparts [5,16]. As such, this allows EBM-built Ti-6Al-4V components to be applied in many applications, such as biomedical implants, marine, aerospace, etc. [13,26–29]. However, these reported EBM components were relatively small in volume. Recently, some efforts have been taken to further explore the application of EBM technology for the fabrication of the medium volume components [5,30]. However, when the scanning line is longer than 100 mm, the lack-of-fusion pores are

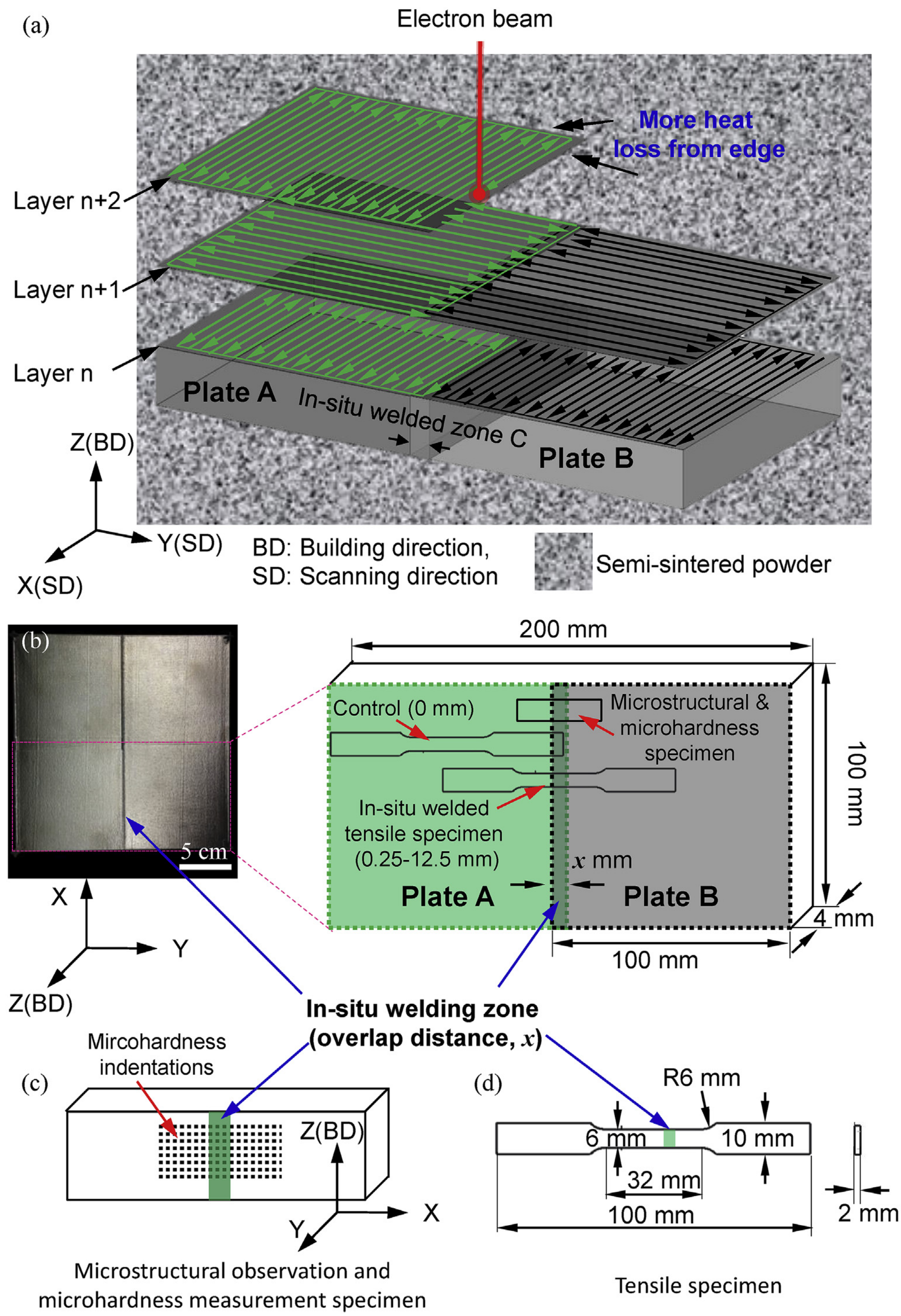

Fig. 1. (a) Concept of *in situ* welding during EBM process. The arrows on the plate A and plate B indicate the scanning lines. (b) Picture of the EBM-built plate with a dimension of 200 mm × 200 mm × 4 mm and illustrated locations of the tensile test and hardnesses measurement specimens cut from. (c) Schematic of the specimen for microstructural observation and microhardness measurement. The black dots show the location of the hardness measurement. (d) Schematic and dimensions of an ASTM E8 tensile test specimen cut from plate, as shown in (b).

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