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Realizing a full volume component by in-situ welding during electron beam melting process

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ABSTRACT

As one of the powder-bed-fusion additive manufacturing processes, electron beam melting (EBM) is able to produce metal parts directly. Many small volume components with high quality have been fabricated using the EBM technology. However, there are only few reports on the EBM fabrication of medium-sized components. One of the reasons is the lack of energy issue when the scan length is too long, which results in the generation of lack of fusion pores. This, in turn, drastically degrades the mechanical properties of the EBM printed parts. Here, we firstly report an in-situ welding process to overcome the lack of energy issue caused by the long scan length during EBM process. After the investigation of the corresponding microstructure, microhardness and tensile properties, it is revealed that the in-situ welding zone is fully joined and the mechanical properties of the in-situ welded part are comparable to that of the wrought counterpart. This implies that medium-sized components can be successfully fabricated using the EBM, with no compromise on the mechanical properties.

1. Introduction

Electron beam melting (EBM) is one of the few additive manufacturing (AM) technologies which can fabricate metal parts directly without post-processing. The capability of printing metal components with complex geometry and high accuracy is one of the main attractions of EBM [1–7]. Over the past few years, several researchers have devoted their efforts to characterize the microstructure [8–11] and mechanical properties of the EBM-built parts with/without heat treatments [4,8,12–17]. Although the mechanical properties of the EBM-built parts are able to compare to those of their wrought counterparts [8,10,18], these reported EBM-built components were relatively small in size [2,3,19–21]. The maximum size of these reported components in x–y cross-section is Φ100 mm. There is lack of reports on medium-sized components, which is defined as one having a scan length ranging from 100 mm to 200 mm, fabricated by EBM. This is partly due to the lack of energy when the scan distance is longer than a certain distance, such as 100 mm, which results in the generation of lack of fusion pores [22]. With the increase in scan distance, the extra energy from the previous neighbor scan line drops sharply, resulting in a varied and unstable melt pool. In order to maintain a stable and equal-sized melt pool regardless of the scan length, the scan length dependency of these parameters, such as beam current and scanning speed, are implemented in EBM control software [22,23]. The longer the scan length, the higher the beam current and scanning speed. However, there is a maximum limitation of beam current, for example, 50 mA for Arcam A2X system. A lack of energy appears, which causes lack of fusion pores, once the required beam current exceeds the maximum value. The presence of these lack of fusion pores degrades the mechanical properties of the printed part significantly and limits the further application of the medium-sized components [22–24]. Recently, some efforts have been taken to further explore the application of the EBM technology in the medium-sized components [18,24].

One of the possible approaches is to fabricate the part as a hybrid component, whereby the large section which requires a long scan length can be replaced by cast or wrought forms. Recently, the effort of building a Ti-6Al-4V impeller on a wrought plate was reported [24]. Although the direct fabrication of a complex 3D part on top of the wrought plate made of the same building material has been proven, the degradation of mechanical properties in the substrate during fabrication due to the long duration of annealing limits the applications of this approach [24]. It is thus necessary to consider the total building time that also acts as the annealing time of the cast or wrought substrate. The long annealing duration coarsens the microstructure, and this in turn,

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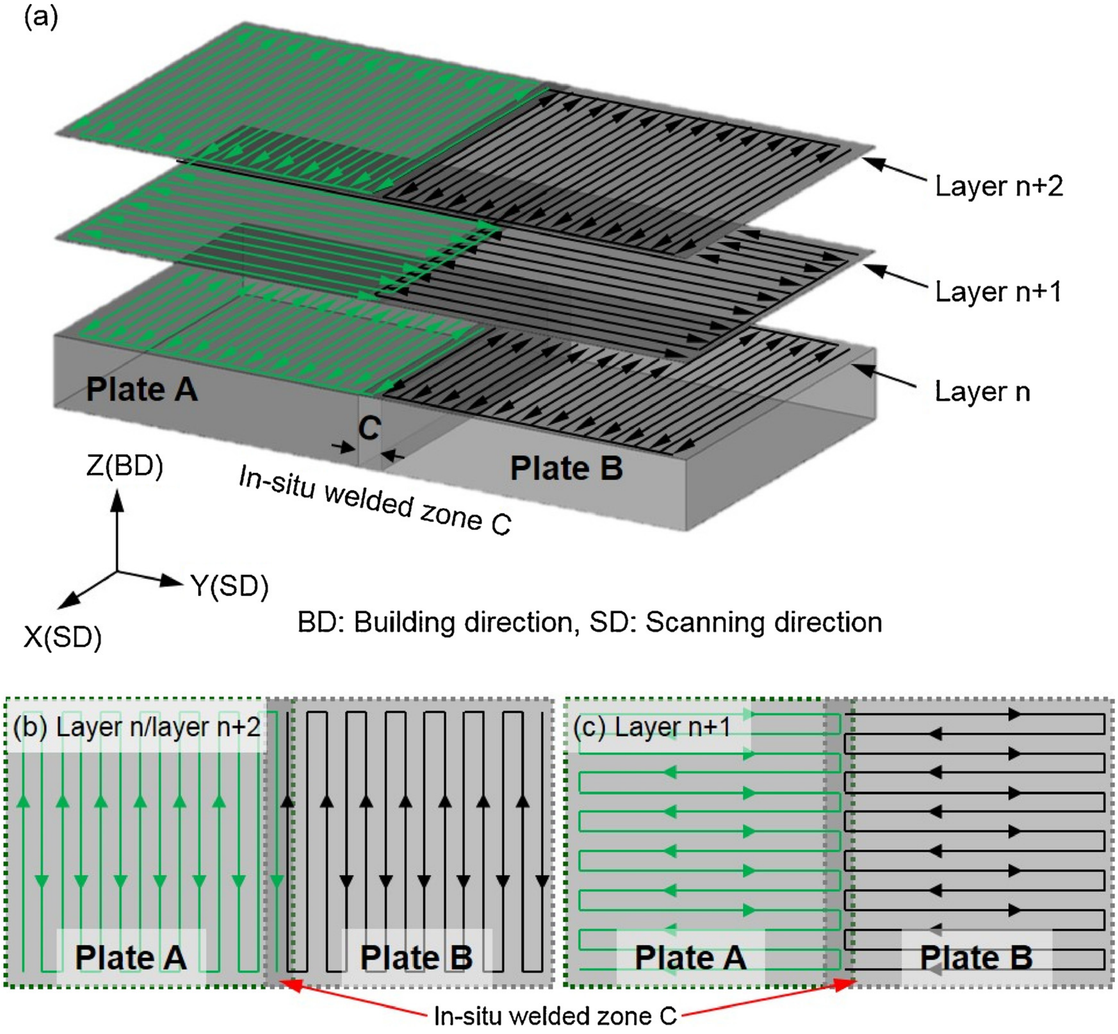

Fig. 1. (a) Concept of in-situ welding during EBM process. Top view of (b) layer n/layer n + 2 and (c) layer n + 1. The arrows on the plate A and plate B indicate the scanning lines.

significantly degrades the mechanical properties [25,26]. Therefore, a subsequent heat treatment has to be implemented to recover the mechanical properties [27].

Another possible approach is to split the medium-sized component into several portions and weld them after the EBM process. This is suitable for components of relatively simple geometry which are limited by the welding profiles. This approach also introduces additional residual stress and dimensional inaccuracies [28,29]. As widely known, one of the main advantages of the metal AM process is to realize the direct fabrication of complex geometrical components [3,5,18,30]. In order to leverage on this unique capability, it is necessary to explore new approaches to fabricate the component as a single piece. Although it is not desirable to apply the welding process after additive manufacturing, the concept of the welding process can be utilized during the EBM process to facilitate the direct fabrication of medium-sized components with complex geometry. Moreover, some similar function, such as ‘striped’ or ‘island’ scanning strategies have been implemented on selective laser melting that is another powder bed fusion AM technology. Recently, the success of these scanning strategies [31–34] encourages us to make the in-situ welding concept possible. Therefore, the present paper will prove the proposed concept by in-situ welding two plates during the EBM process. The microstructure and microhardness across the in-situ welding profile were characterized, and the tensile properties against standard samples were also evaluated.

2. Experimental procedure

2.1. Concept of in-situ welding during EBM process

The present study tried to utilize the layer-by-layer fusion manner of EBM process to weld two parts at each sliced layer during EBM process. The lower layer thickness for the EBM process (ranged from 25 to 90 μm [6]) was expected to minimize the heat affect zone as compared to the conventional welding process. Moreover, the preheating manner (~730 °C for Ti-6Al-4V) of the EBM process was also expected to further remove the microstructural difference between the welded zone, heat affect zone and base materials. As illustrated in Fig. 1, two three-dimensional files, named plate A and plate B, were “welded” together with an overlap zone. During the preparation of the EBM process, plate A and plate B were selected as two different print jobs, although both of them used the same process parameters. Thereafter, the Arcam EBM system would recognize them as two separate print jobs. During each printing layer, the plate A was printed firstly, and subsequently, the plate B (Fig. 1a) was printed. This process was repeated until the final object was completed. During the EBM process, the bidirectional scanning was changed with a 90° rotation at each layer (Fig. 1b and c). In this case, the plate A and plate B were “welded” for every single layer. Finally, a fully fused part with a combination of plate A and plate B was obtained by the EBM process.