Evaluation of the electron beam spot size in electron beam melting for additive manufacturing

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Abstract

Since electron beam (EB) is the main additive manufacturing (AM) tool in electron beam melting (EBM), EB spot size plays a significant role in the parts quality, surface roughness as well as the microstructure and corresponding properties. So far, the research on measuring EB spot size has been mainly based on printing with/without powder single tracks on a metal plate such as stainless steel. However, this method, due to material thermal properties as well as the melting phenomena, cannot reveal the actual value for the EB spot size. This research is carried out to establish a simple methodology on measuring the EB spot size in a more accurate way at a low cost. To do so, a ceramic surface coating was applied to the surface of a copper starting plate and a stainless steel starting plate respectively. Afterwards, the EB applied the tracks onto the coated starting plate and regular metal starting plate. The analysis showed that the EB tracks on ceramic coated stainless steel plates could be the best replica for the electron beam among those materials tested in this work.

1 Introduction

In comparison to other powder-bed metallic AM processes, EBM offers improved advantages in the build rate, material purity and reduced thermal distortion [1]. As the monopolistic heat source during the entire process, electron beam (EB) plays a main role in determining the stability and the quality of the final product. One important factor demonstrating the EB quality is the corresponding EB spot diameter, which altered via a parameter called focus offset in a typical EBM machine. This parameter is in fact the current value used for regulating the focusing coils to adjust the concentration of the EB, affacting the EB spot size and the melt pool geometry [2]. This parameter is critical since it influences the input energy intensity and hence the formation of defects, such as porosity, cracking, balling and delamination, as well as the material microstructures [3][4]. In this study, a simple and low cost method has been studied to measure the EB spot size more accurately. This has been practiced via analysing the EB tracks on the coated metal plates with a thin layer of an insulating ceramic.

2 Material and Experiment Setup

In order to measure the EB size, EB was radiated to ground and polished 316L stainless steel and Cu-DHP plates with 150 mm×150 mm cross section. The thickness of the stainless steel plate and copper plate was 10 mm and 6 mm respectively. After that, a ceramic coating layer by 'ESAB jig and tool protector ceramic coating' was sprayed to the base plate which can resist to heat up to 1300˚C [5]. For the levelling purposes, each plate was laid on a stack of IN718 powder bed which had the thickness of 20 mm.

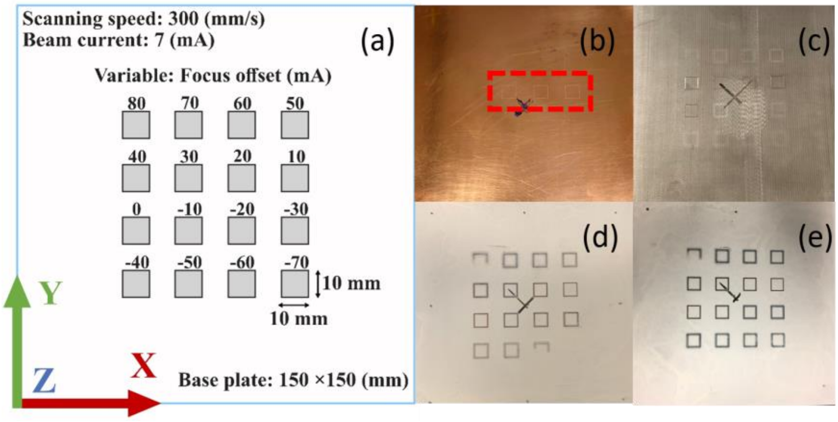

Figure 1. (a) Printing squares model layout and process parameter settings; Surface marking after the EB scanning (b) copper plate; (c) stainless steel plate; (d) copper plate with coating; (e) stainless steel plate with coating

An Arcam A2X EBM system (GE additive, Sweden) was used to perform the experiment. The EB tracks were applied at room temperature with various focus offsets, ranging from 80mA to -70 mA. (Figure 1). Four types of base plate were used, i) copper (Figure 1b), ii) ceramic coated copper (Figure 1 d), iii) stainless steel (Figure 1 c) and iv) ceramic coated stainless steel (Figure 1 e). In each case, a single contour square track with 10 mm length was made for 16 squares with various focus offsets. For all the squares, the scanning speed is 300 mm/s and the beam current is 7 mA. After creating EB tracks, each of the base plate was measured by a zygo NewView™ 7300 white light interferometor (Lambda Photometrics, UK&Ireland) and Nikon SMZ800 optical microscopy (Nikon metrology, USA). The surface profile measurement of the stainless steel and copper plate have been taken with WLI using 2.5X maganification. As shown in Figure 2, through the visualization and extraction of the surface profile function in mountains8^{TM} software, the EB re-consolidated geometery has been defined and analyzed for each square tracks with different focus offsets.

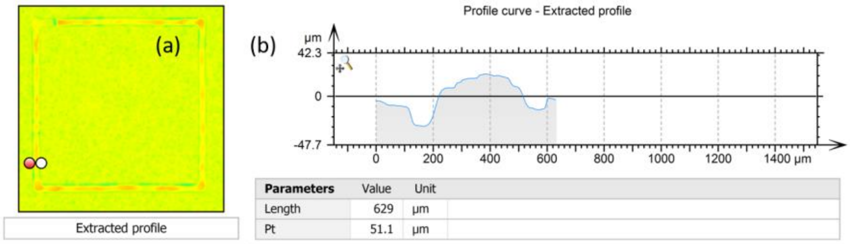

Figure 2. Stainless steel plate surface profile measurement from WLI when focus offset at 10 mA, a) Profile extraction; b) Profile extraction analysis

In addition, Figure 3 shows the example of data aquisition method applied by optical microscopy. Six points on each side has been selected and the dimension of the main EB track and also the EB affected zone have been measured by optical microscopy using both 1X and 10X magnification.

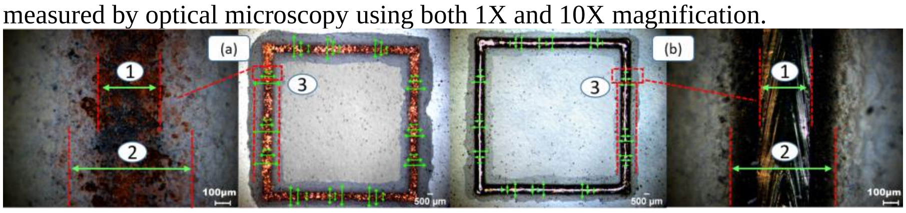

Figure 3. (1) Peak track width (PTW), (2) scanning track width (STW), and (3) full track width (FRW) viewed using optical microscopy in 1X and 10X magnification for (a) ceramic coated copper plate; and (b) ceramic coated stainless steel plate at focus offset of 10 mA

3 Results and Conclusion

From Figure **1**, there are only three squares visible on the copper plate being marked at the focus offset of 30 mA, 20 mA and 10mA which are located inside of the red dash line box. In comparison to the copper plate, almost all squares are visible for the naked eyes on the stainless steel plates, though their visibility could be so low that might not be detectable under optical microscopy. In contrast to regular plates, for the coated copper and coated stainless steel, all the squares are very clear except the last mark on the coated copper plate which is missing. The lowest number of visible tracks on copper demonstrates the minimum sensitivity of the copper plate to replicate the physical form of an EB. This can be attributed to the higher thermal conductivity of copper, being about

25 times more than stainless steel, dissipating the EB energy quickly. In contrast, all the tracks are well visible on the creamic coated stainless steel, demonstrating the maximum sensitivity of this material to detect EB.

Results of the measurement from WLI is based on the EB tracks on the copper and stainless steel plate. Thus, the dimension of the EB path width is mainly based on the melting pool size. As shown in Figure 2, the re-consolidated melt pool geometry has a near guassian distribution shape. Due to surface tension, there are also valleys located between the base plate and the peak track on both side which is the result of introducing the solid to the melt pool.

There are three different level of tracks observed in Figure 3 for tested materials. Peak track width (PTW), which had nearly all the ceramic coating evaporated, seems to be the result of the exposure to the highest level of energy intensity. In comparison, scanning track width (STW), with blackened ceramic coating appears to originate from exposure to lower level of energy intensity. At last, full track width (FTW), which cover the full scanning width has the minimum EB energy intensity.

The conclusion for this study can be given as:

- EB radiation effects varies with respect to the base material properties, mainly due to the thermal conductivity
- The EB tracks on the ceramic coated stainless steel could lead to the best replication to represent the EB profile in comparison with the tracks on other materials tested in this work

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