SIGNIFICANCE OF INTRA-BUILD DESIGN VARIABLES ON THE FRACTURE TOUGHNESS PROPERTIES OF ELECTRON BEAM MELTED TI6AL4V

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Abstract

Structurally reliable materials are essential for adopting additive manufacturing (AM) metals in safety-critical applications. Limited data on the damage-tolerance properties of metal AM materials exists, hindering the acceptance of AM metals in fracture-critical applications. A design of experiments (DOE) is used in this study to investigate the role of build space and part design parameters on the fracture toughness properties of Electron Beam Melted (EBM) Ti6Al4V. ASTM E399 tests were performed on over 100 compact tension (CT) samples in the as-built and machined conditions to obtain fracture toughness properties and evaluate the influence of part size and location within 80% of the build space. Results were comparable to wrought annealed titanium, with less than 10% variation in overall fracture toughness. Specimen location within the build envelope contributed to the observed variation, with an increase in properties with build height and specimens located in the center of the build envelope. The location-dependent properties result from changes in microstructure and porosity throughout the build space. While the experimental EBM Ti6Al4V fracture toughness properties are promising for future applications, it is crucial to consider the variation in properties due to build space location and design parameters when designing for consistency.

1. Introduction

Additive manufacturing (AM) is popular for its design freedom and flexibility, where complex designs are realized without additional cost, a solution not readily available with conventional fabrication technologies. There is a significant focus on research to push for certification of AM components; however, the need for durable and reliable components arises with industrialization, prompting the verification of the material and process. A thorough understanding of fracture resistance and the source of variation in properties is essential in manufacturing structural components. Limited data on the fracture critical properties of EBM metals currently exist, with notable inconsistency due to orientation, machine generation, and print process. Additionally, intra-build design parameters' contribution to fracture toughness has not been addressed. Therefore, this study investigates the influence and interaction of its location and geometry on the fracture toughness properties of EBM Ti6Al4V.

2. Results

The fracture toughness properties of EBM Ti6Al4V is evaluated in the untreated as-built and machined condition using 108 compact tension (CT) specimens under plane strain conditions per ASTM E399. Roughly 0.4 mm was removed from each surface to reduce surface roughness effects in the machined samples. The K_{Ic} design values with 95% confidence are 60 - 70 MPa√m in the as-built and 54 - 64 MPa√m in the machined condition, comparable to wrought annealed Grade 5 titanium [1]. The relationship between geometry and specimen location within the build envelope on fracture toughness is evaluated using a Design of Experiments (DOE), Fig 1(a). The relative impact of the parameters (thickness, radial distance, and height) and their interactions was analyzed using polynomial regressions. The model was significant ($p \leq 0.05$), with height and radial distance exhibiting the strongest trend, as shown in Fig. 1(b,c). Fracture toughness correlates with height, increasing in specimens printed near the top of the build envelope. Radial distance exhibits a negative trend, with a decrease in fracture toughness with an increase in radial distance. Microstructure analysis and X-Ray Computed Tomography (μCT) showed features such as α-lath thickness and defect diameter contributed to the variation in mechanical properties, as seen in Fig.1(d) [2].

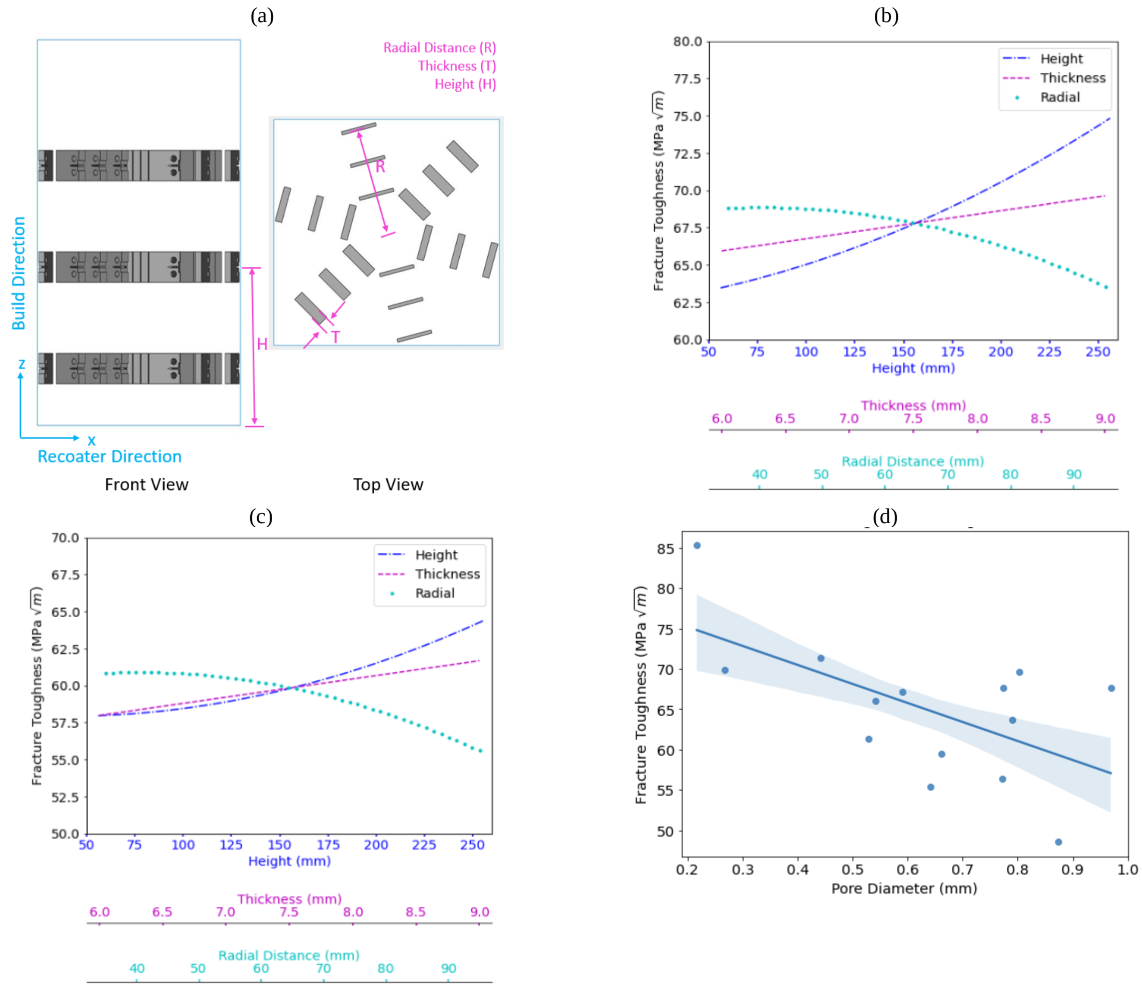

Fig.1 – (a) EBM build layout of ZX-oriented fracture toughness specimens, front and top views shown. The ZX-oriented (b) as-built and (c) machined fracture toughness relationship to height, thickness, and radial distance. (d) A negative trend in fracture toughness and respective largest internal pore exists.

3. Conclusions

An experimental evaluation of fracture toughness was conducted to obtain an EBM Ti6Al4V process-structure-property relationship. The EBM fracture toughness values measured roughly 60 MPa√m with less than 10% variation in overall properties, comparable to wrought annealed titanium. Process-induced microstructure and defect variation contributed to location-dependent fracture toughness properties. Additional testing is underway to investigate the influence of build space parameters on other orientations and material conditions.

Acknowledgments

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