EVALUATION OF STRENGTH CHARACTERISTICS FOR NON-COMBUSTIBLE MAGNESIUM ALLOY PRODUCTS FABRICATED BY LASER POWDER BED FUSION UNDER AS-BUILT CONDITION

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Abstract

It is difficult to evaluate fracture toughness according to ASTM standards for non-combustible magnesium alloy fabricated by Laser Powder Bed Fusion (LPBF) in as-built conditions. The reason is its microstructure duality between inner and outer surfaces. The microstructure duality can be eliminated by heat treatment. However, heat treatment reduces the strength of the material by around 11%. Therefore, heat treatment was not performed. In addition, the greatest advantage of LPBF is maximized when it can be used immediately without post-processing. Therefore in this study, the as-built condition was targeted. In the case of non-combustible Mg products, the mechanical properties of the inner and outer microstructures have a non-negligible difference. The difference is expected to affect the fracture behavior, so it is important to consider the difference in microstructure in strength evaluation. Therefore, this paper explains why ASTM standards are difficult to apply to non-combustible magnesium products fabricated by LPBF in as-built conditions with their microstructure differences. Furthermore, the alternative methods for measuring the fracture toughness of metals fabricated by the LPBF in as-built conditions with these characteristics are introduced and discussed.

1. Introduction

The ASTM standards can be used to determine the fracture toughness of metallic materials. Several studies measuring the fracture toughness of components fabricated by LPBF have been performed by making an oversized component and subsequently mechanically shaping the component to the recommended geometry indicated in the ASTM standards. However, the component's microstructure in as-built conditions differs between the inner and outer surfaces due to differences in cooling rates. In addition, the influence of the inherent different microstructure distribution between LPBF products' inner and outer surfaces cannot be analyzed due to the machining process. For this purpose, several non-combustible Mg alloy CT specimens were fabricated and followed by machining without mechanically removing the microstructure duality. Subsequently, the specimens were tested according to the ASTM E399 standard procedure to determine fracture toughness. Before the test, the CT specimens fractured when the pre-crack was introduced during the procedure. Furthermore, fractography results showed a transition from stable crack growth to unstable fracture during pre-crack formation by fatigue loading, where the outer microstructure transitions into the inner microstructure. These results showed that the microstructure influences crack growth and unstable fracture. However, the pre-crack length required by ASTM exceeds the range of the outer microstructure. Therefore, it is difficult to measure the fracture toughness considering the outer microstructure with a specimen with pre-crack. Therefore, in this study, the difficulty of measuring fracture toughness according to ASTM standards is introduced, and a method for evaluating mechanical strength considering the influence of microstructure was devised.

2. Method

The specimen was printed using EOS M 100. The notch was built at the same time when printing, and the rest was mechanically machined using an Electrical Discharge Machine (EDM) and a milling machine. Then, tensile tests were conducted using SHIMADZU servo-hydraulic testing machines. After the test, the fracture surface was analyzed through Scanning Electron Microscopy (SEM) observation.

3. Results

The following results were obtained through microstructure observation through SEM images.

a. Regardless of internal defects, cracks always initiate from the outer surface microstructure.
b. Cracks originating from the outer surface microstructure cause an unstable fracture when they reach the point where the outer microstructure transitions into the inner microstructure.
c. As mentioned in the Introduction, the unstable fracture that occurred during the fatigue cracks introduction is a phenomenon caused by different crack extension patterns during static and fatigue loading.

4. Conclusions

The microstructure's duality affects the material's mechanical strength. In addition, the microstructure must be considered in explaining the fracture behavior of magnesium alloy in as-built conditions manufactured with LPBD, and the duality of the microstructure makes it difficult to apply the ASTM standard. Therefore, finally, an alternative method was suggested.

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