INFLUENCE OF THE CONTOUR PARAMETER IN MICROSTRUCTURE DUALITY AND FRACTURE INITIATION IN NON-COMBUSTIBLE MAGNESIUM ALLOYS FABRICATED BY LASER POWDER BED FUSION

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Abstract
Non-combustible Mg alloy components fabricated by laser powder bed fusion in as-built conditions have an average ultimate tensile strength (UTS) of 320 MPa, a significantly larger value than its casting counterparts, which present an average UTS of 200 MPa. In addition, it was determined that stable crack extension always starts at the outer surface due to the coarsened microstructure regions present in the area. Therefore, this paper will use fracture mechanics to predict the UTS value by determining the size of the coarsened microstructure region and considering it as a surface crack with the $\sqrt{area}$ parameter. Then, by using a fixed fracture toughness (K_{IC}) value, the UTS will be predicted. Furthermore, a processing parameter known as contour, which is used for remelting the outer surface of the specimen, can also smoothen the microstructure and potentially increase the UTS value. Results showed that the $\sqrt{area}$ of the surface crack responsible for fracture was 730 μm for the no-contour specimen and 630 μm for a contour specimen. Subsequently, using Murakami's theory, the predicted UTS is 320 MPa for a no-contour specimen and 345 MPa for a contour specimen. Finally, tensile testing was performed to confirm the prediction, showing similar results with an average deviation of 2.9%.

1. Introduction
Metallic components fabricated by laser powder bed fusion (LPBF) have gained considerable attention throughout recent years due to their high shape flexibility. However, the reliability of the mechanical properties has always been an issue because two specimens made in the same production bulk with the same processing parameters could present different UTS values. Additionally, a common fracture mechanism for LPBF products has not been determined yet, partly due to the critical defect responsible for the fracture not being identified. Particularly in as-built specimens, it has been determined that fracture always starts from the outer surface under static load, although large defects could be present in the specimen. A previous study by the authors argued that this phenomenon could be attributed to microstructural differences between the outer and inner surfaces. It is well known that due to heat transfer and phase change phenomena, LPBF products have a sequence of melt pool distributions where two types of microstructures can be observed: a coarsened microstructure at the melt pool boundaries and a refined microstructure at the melt pool center. Nevertheless, large and irregular bundles of coarsened microstructure are present on the outer surface of the specimens. These regions of coarsened microstructure at the outer surface enable a stable crack propagation that is suddenly interrupted once the microstructure distribution stabilizes. The authors have suggested that the length of the stable crack propagation until its interruption could be considered as a surface crack, where its size represented in the $\sqrt{area}$ parameter is a critical factor that predicts the tensile strength before the load is applied using its relation to fracture toughness (K_{IC}) in accordance to Murakami's theory, thus increasing the reliability of LPBF products. In addition, if the microstructure at the outer surface is responsible for fracture, a processing parameter that remelts the outer surface to reduce roughness, known as the contour parameter applied during the LPBF process, could smoothen it, therefore having a considerable impact on the resulting mechanical properties. This paper describes the fracture process that LPBF products under as-built conditions go through, determines the critical defect responsible for fracture, and quantitatively evaluates its size to predict the UTS value. Finally,

a comparison between the strength prediction of a specimen with and without the contour parameter is analyzed.

2. Results

Microstructure observation of a specimen with and without contour was performed, and subsequential quantitative analyses and strength prediction for each case are described below:

a. Use statistics of extremes to quantitatively measure the coarsened microstructure at the outer surface and determine the surface crack's *area* parameter.
b. Use Murakami's theory to predict the strength value using the fixed K_{IC} reference value.
c. Perform tensile testing and compare the obtained results with the ones predicted for the specimens with and without the contour parameter.

Microstructure observations were performed before tensile testing. Considering a fixed K_{IC} value of 10 MPa√m and measuring the coarsened microstructure at the outer surface using statistics of extremes, the $\sqrt{area}$ parameter was approximately 730 μm for the no-contour specimen and approximately 630 μm for a contour specimen. The specimen without the contour parameter shows a considerably larger and more irregular distribution of coarsened microstructure at the outer surface compared to the specimen where the contour parameter is applied. As a result, in accordance with Murakami's theory ($K_{IC} = 0.65\sigma_C\sqrt{\pi\sqrt{area}}$), the predicted strength is approximately 320 MPa for a no-contour specimen and approximately 345 MPa for a contour specimen. The tensile test results are similar to the expected results, with an average deviation of 2.9%.

3. Conclusions

- The critical defect responsible for fracture in LPBF products is the large, irregular, coarsened microstructure located at the outer surface of the specimens.
- The contour parameter remelts the metallic component's outer surface, reducing the critical defect's size. As a result, the predicted strength in accordance with Murakami's theory is increased.

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