Strength reliability of metallic components fabricated by selective laser melting: Application on non-combustible Mg-products

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論 文 名　:　Strength reliability of metallic components fabricated by selective laser melting: Application on non-combustible Mg-products
(選択的レーザー溶融で製造された金属部品の強度信頼性：難燃性 Mg 合金製品への応用)

区　　分　:　甲

論 文 内 容 の 要 旨

Selective laser melting (SLM) has attracted the mechanical engineering community due to the products' excellent mechanical properties compared to their casting counterparts. Therefore, literature on the matter has focused on the variation of the mechanical properties depending on the laser sintering parameters, the scanning strategies, or the presence of defects. Also, post-processing, such as heat treatment techniques and mechanical machining, is often used to evaluate SLM products due to the intrinsic phase changes that enable residual stresses to form and the resulting high surface roughness. As a result, several studies reach different conclusions regarding why SLM products present the mechanical properties obtained during experimentation, particularly from a fracture mechanics perspective. Thus, this study focuses on increasing the SLM process's reliability by identifying the critical defect responsible for fracture and how it influences the mechanical properties, as well as how the mechanical properties change when this defect is directly affected by post-processing.

Strength at failure can be predicted using traditional fracture mechanics. However, one of the conditions required for that purpose is that the material must be homogeneous, an unattainable characteristic of SLM products in an as-built state due to the microstructure duality present in the form of melt pool formations that have coarse microstructure at its borders and refined microstructure at the center. Furthermore, the coarse microstructure is present in the form of large bundles at the outer surface of the SLM specimen due to the proximity of the metallic powder, which has a lower heat transfer coefficient, and as a result of this, a slow cooldown is induced when the scanning track starts to melt a single layer. These bundles at the outer surface enable a stable crack propagation that is suddenly interrupted when the bundle's region finishes, which induces large stress concentrations and then unstable fracture. Suppose the length of the stable crack propagation until it is interrupted is considered as an invisible surface crack responsible for the fracture. In that case, its $\sqrt{area}$ size, according to Murakami's theory, could be applied, and fracture toughness (K_{IC}) can be a useful tool to predict the strength and increase the reliability of SLM products.

Chapter 1 is the starting point of this dissertation. The background and the contents of previous research that has been performed and their conclusions are introduced, as well as the principal objective of this thesis. In addition, the reason why non-combustible Mg alloys were selected as the raw material for this study is explained.

Chapter 2 analyses the weakest region of round bar tensile test specimens. This chapter briefly explains

the formation mechanism of coarse microstructure and fine microstructure in SLM products, their distribution rate and their role in the fracture mechanism considering the defect responsible for fracture under as-built conditions. Here the hypothesis and its originality are presented as a basis for the subsequent chapters.

Chapter 3 is focused on verifying the hypothesis established in the previous chapter and analyzes the plastic strain distribution in a non-homogeneous microstructure. Also, the interaction of the microstructure duality between coarse and fine particles is discussed to propose the evaluation of the fracture mechanism quantitatively using Murakami's Theory by using the size of the defect to calculate fracture toughness.

Chapter 4 presents the quantitative evaluation of the fracture mechanism proposed in Chapter 2 using the method proposed in Chapter 3 with artificially introduced defects to predict the ultimate tensile strength (UTS) value of SLM products and increase the reliability of the process. In addition, the calculated fracture toughness for specimens in as-built conditions is compared to the results of specimens where a visible artificial defect is inserted.

Chapter 5 introduces the importance of a non-homogeneous microstructure compared to a homogeneous microstructure. Since traditional fracture mechanics needs a homogeneous material for engineering applications and purposes, it makes sense that the mechanical engineer would consider the homogenization of the SLM product via heat treatment. The impact of thermal post-processing on microstructure and the fracture mechanism is analyzed and discussed.

Chapter 6 discusses the true potential of SLM products by reducing the number of defects to a minimum. It considers plastic instability theory to calculate a critical UTS value with its correspondent critical defect size by using an Mg alloy as an example. This concept allows the mechanical engineer to realistically determine the maximum UTS of SLM products.

Chapter 7 evaluates the plastic zone's microstructure duality distribution before an unstable fracture occurs and its influence on the fracture process. As a result, a valid explanation for the variation of certain mechanical properties of SLM products, such as elongation, can be determined.

Chapter 8 includes the summary of this study and the conclusions relevant to the mechanical engineering community. In addition, the extension of the topics that could be researched in the future is proposed.