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# Optimizing Lightweight Stainless Steel 316L Structures via Material Extrusion Additive Manufacturing (MEAM)

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## Abstract

While extensive studies in Material Extrusion Additive Manufacturing (MEAM) primarily focus on the fabrication and optimization of dense parts, research on lightweight structures remains limited. This is despite the significant potential of additive manufacturing (AM) to revolutionize the design and production of optimized, weight-efficient components, which are crucial for applications in industries such as aerospace, automotive, and biomedical engineering.

This study investigates the mechanical performance of lightweight 316L stainless steel structures fabricated using a MEAM process, leveraging a cost-effective and accessible approach to metal additive manufacturing. A single infill pattern "grid" was selected, with two key variations: (i) changing the infill density while using a single wall and (ii) varying the number of walls while fixing the infill density. The primary objective was to assess whether, for parts of equivalent mass, prioritizing wall count or infill density yields superior mechanical performance, offering insights into the structural optimization of lightweight components. Unlike topology optimization, which requires redesigning parts from scratch, this approach offers the advantage of leveraging existing industrial part libraries without requiring complete reconceptualization.

Mechanical testing was conducted using three-point bending tests, providing macro-scale analysis of force-displacement curves to evaluate stiffness, strength, and failure behavior. At the meso-scale, detailed deformation analysis was performed using digital image correlation (DIC) with the DISFlow algorithm, capturing localized strain.

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The results indicate that, for components of equivalent mass, increasing the wall count consistently results in superior mechanical properties compared to increasing the infill density. These findings emphasize the importance of wall-dominated designs for lightweight structures where bending loads are significant. The DIC results also highlighted the limitations of existing modeling approaches for lattice structures, underscoring the need for the development of new, efficient computational models capable of rapidly and accurately predicting the mechanical behavior of additively manufactured architectures. Finally, a significant finding of this study was the establishment of a link between the local second moment of area and crack initiation, demonstrating how local geometric parameters influence mechanical performance and failure mechanisms in lattice structures.