The XIV Finnish Mechanics Days 2022May 19–20, 2022,
Lappeenranta, Finland

Case studies on the mechanical performance of 3D printed steel and its correlation with the microstructural features

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ABSTRACT

Additive manufacturing of metals nowadays plays a crucial role in the production of intricate components with complicated external and internal features in many demanding applications. Such applications are required in numerous sophisticated industries such as aerospace, marine, and automotive. These industries require high-performance parts for use in harsh conditions, such as high-frequency mechanical loads, high temperatures, severe pressure fluctuations, and corrosive media. Among the various additive manufacturing techniques developed for metals, 3D printing of metals using laser, also known as laser powder bed fusion, is one of the most widely used techniques in the industry. This popularity is due to the ability of this method to maintain sustainable production, with a shortened supply chain, fewer manufacturing steps, and less material waste compared to conventional manufacturing methods. However, metal additive manufacturing, including processing with laser powder bed fusion technology, still suffers from some drawbacks that prevent this technology from reaching its full potential for industrial and construction applications. These drawbacks include inhomogeneity and anisotropy in the physical (e.g., microstructure, thermal conductivity, and electrical resistivity) and mechanical (e.g., strength and ductility) properties of the additively manufactured metals.

Furthermore, defects such as porosity and lack of fusion are known to be inevitable in additively manufactured metals. Therefore, it is expected that the behavior of additively manufactured metals, including those produced by laser powder bed fusion, in different service environments and the response of these materials to mechanical stresses will differ from those of conventional metals. Consequently, further research is needed to address these issues and facilitate the use of additively manufactured metals in actual applications.

On this basis, two grades of steel, the most commonly used alloy class in the industry, were selected for this study to evaluate the mechanical properties of the selected metals and to investigate the correlations between the mechanical properties and the microstructural characteristics. The steels studied were 316L stainless steel, an austenitic metal, and CX stainless tool steel, a martensitic precipitation hardening metal. These steels were processed using the laser powder bed fusion method as a commonly used additive manufacturing technique for fabricating metallic components. First, the microstructural characteristics of these materials were studied in detail using optical microscopy, scanning electron microscopy, and electron backscatter diffraction. Subsequently, the mechanical properties of the investigated materials were analyzed and compared using hardness measurements, uniaxial quasi-static tensile tests, Charpy tests, and high cycle fatigue tests. Fracture surface analyses were then carried out to investigate the failure mechanisms associated with the materials. Finally, this study also investigates the effectiveness of some post-processing treatments such as machining, polishing, high-frequency mechanical impact treatment (for 316L), and annealing and aging (for CX) to improve the mechanical performance of the materials. In conclusion, compared to their conventional counterparts, these additively manufactured steels showed promising results in the performed mechanical tests, and the correlations between the microstructural features and mechanical properties were addressed.

Keywords: metal additive manufacturing, 3D printing, microstructure, strength, fatigue, fracture.