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Effect of Manufacturing Process Parameters on the Static Properties of 316L Stainless Steel Produced by Fused Filament Fabrication

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Recent advances in additive manufacturing (AM) of metals revolutionised the production of metal parts, enabling complex geometries and creating customised and geometrically complex mechanical parts which would otherwise be almost impossible to achieve.

This study deals with a specific class of AM methods for the production of metals, fused filament fabrication (FFF). The FFF process embeds three fundamental steps: printing, debinding, and sintering.

The printing step consists of a metal filament, containing metal particles evenly infused within a polymeric binder, being extruded during the process. The filament is heated to its melting point and then deposited through the extruder layer-by-layer to create a three-dimensional object. After printing, the parts undergo debinding, to remove the polymeric binder, leaving behind a porous structure that is then densified through a process called sintering.

This manufacturing technique introduces unique types of defects, residual stress and anisotropic mechanical properties. These features inevitably affect the mechanical properties of the manufactured material and make it highly unpredictable. Therefore, careful analysis of such characteristics and advancing the understanding of their effect on the material structural response is essential for making this technology viable in practical engineering applications.

This study focused on FFF manufactured 316L stainless steel. 316L stainless steel, due to its many qualities like high corrosion resistance, biocompatibility and high strength, finds applications in a wide range of industries. Combined with the fact that it is one of the first metallic materials available for production using FFF technology, 316L stainless steel presents an intriguing subject for study.

FFF 3D printing technology allows the customisation of a large number of manufacturing process parameters. The goal of this experiment was to unravel the importance that processing parameters have on the tensile mechanical properties of the manufactured 316L specimens. The following parameters were considered: nozzle temperature, print bed temperature, layer thickness, print speed, layer orientation and infill percentage. Levels for each of the parameters were chosen based on their recommended range of values. Due to the large number of parameters and a mixed number of levels in the experiment, the experiment was set up using a D-optimal design of the experiment (DOE). This approach reduced the required measurements and samples to a manageable amount.

Miniaturized samples were fabricated and mechanically tested using a DEBEN Microtest tensile testing system, capable of applying up to 5 kN force with a precision down to 1 mN.

Given the limitation in the size of the sample and whole testing setup, Digital Image Correlation (DIC) was employed to evaluate the engineering strain during the tensile tests. Camera and lens were carefully selected according to the considered sample size to obtain good quality photos and reduce noise in the measured strain. Finally, to improve the accuracy of the DIC measuring system, the spackle pattern was applied on a lightly polished surface of the sample using the airbrush and black paint.

Post-processing analysis of the tensile behaviour of each configuration allowed the extraction of: Young's modulus, yield strength, ultimate tensile strength, strain at break and toughness.

The measured data was analysed to determine the influence of each manufacturing parameter and its levels on the material's mechanical properties. Statistical analysis, specifically the ANOVA method, was used to quantify the effect of each parameter and their levels on the analyses mechanical characteristics extracted from the tensile tests. This approach provided a clear understanding of how manufacturing parameters dictate the final material static performance, enabling the optimisation of printing parameters for enhanced mechanical properties.

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