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Abstract

Characterising material properties for fused filament fabrication of spinal orthoses

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Thoracic-lumbar-sacral orthoses (TLSO) are the current gold-standard for conservatively managing Adolescent Idiopathic Scoliosis. The advancement of virtual workflows and additive manufacturing provide opportunities to rapidly fabricate these orthoses. Fused filament fabrication (FFF) is a 3D printing technique that aims at reducing manufacturing time and improving fit. FFF print parameters and filament material properties have a highly complex relationship. Although previous studies have investigated this relationship, this research is significant as it must balance ideal print parameter for optimised mechanical performance with quality and comfort requirements of TLSO. This study aims to recommend FFF filament and parameter combinations for the application of 3D-prinitng spinal orthoses. Mechanical testing was conducted to determine the tensile, flexural, and flexural fatigue properties of both FFF filament (PETG, ASA and two PLA-composites: PLA-1, PLA-2) and machined, traditional materials (PP and PE). The sample dimensions and testing protocol were derived from ISO/ASTM standards for tensile, flexural and fatigue testing. This study considered extrusion temperature, extrusion speed, print speed and layer height as critical parameters for improving performance. A three-factor-three-level Taguchi orthogonal array was used to optimize the experimental design. Five repeats of each test were completed resulting in a sample size of 540 samples. Mechanical behaviour of the traditional, machined TLSO material were used as a benchmark to define an ideal range for static tensile and flexural properties of the FFF materials. The printability of the FFF specimens was determined using a scoring system that rated the surface quality, dimensional accuracy and repeatability of each filament and parameter combination. FFF specimens that achieved high printability scores, as well as static tensile and flexural properties within the ideal range were included in the fatigue testing. Fatigue tests were completed on the traditional, machine TLSO materials to define the ideal range and all specimens were underwent 2500 cycles at 1Hz to examine fit-for-purpose.

Flexural Fatigue

PETG	No samples ruptured before 2500 cycles
PLA-1	Some samples ruptured before 2500 cycles
PLA-2	Samples mostly ruptured before 2500 cycles

The PLA-1 filament comprised of a high percentage of PLA, a brittle a material. The PLA-2 filament comprised of a higher percentage of calcium carbonate and acrylic. Specimens that ruptured before 2500 cycles failed due to the cyclic strain exceeding the limits of the outer fibres of the specimen. PETG is more ductile than PLA and the fatigue specimens had good durability for the desired 2500 cycles. Selecting suitable material filament/print parameter combinations that balance mechanical performance, printability and patient satisfaction is a current challenge for 3D-printing TLSO. This research has utilised the complex relationship of application-specific 3D-print parameters to achieve suitable mechanics from FFF filament.

AUTHOR'S STATEMENT

Conflict of interest: R. Chalmers, S. Suresh, M-L. Wille and J.P. Little have no conflicts of interest to disclose.

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