Comprehensive Investigation of Mechanical Properties of Fused Deposition Modelling

A dissertation presented in partial fulfilment of the requirements for the degree of

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PREFACE:

The author declares that this is his own work except where due acknowledgment has been given. It is being submitted for the PhD in Engineering, majoring in Mechatronics to the Massey University, New Zealand.

This thesis describes the research carried out by the author at the School of Engineering and Advance Technology, Massey University, Albany, New Zealand from June 2014 to May 2017, supervised by A/Prof J. Potgieter and Dr. K. Arif.

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Abstract

Fused depositing modelling (FDM) is a layer wise manufacturing method whereby parts are printed from the bottom up through the extrusion and deposition of a filament onto a print base. Various test methods exist for the determination of part mechanical properties. These include tensile, flexural, and impact testing and are conducted using a variety of standards including those of ASTM and ISO. Many researchers have investigated the effects of factors such as road width, raster orientation, layer height, and air gap on the mechanical properties of FDM parts. However, there are many unexplored factors that also impact on the properties of printed parts. For example, the printers used in characterisation studies are mostly commercially available or consumer market printers which allow only limited control over the print parameters and print with a limited set of materials. Similarly, the life of the printer can also affect the print quality but this has not been studied before.

Control over machines could be achieved by purchasing additional print profiles from the manufacturers or by open-sourcing legacy hardware through retrofitment with new electronics and software. The latter option is more economically viable as there are a large number of decommissioned legacy machines that have superior hardware cheaply/freely available. A retrofitted commercial 3D printer would allow control over print parameters and printing with materials outside the ones sold by the manufacturers. This can open new avenues to study the properties of the printed parts. In this work, a Stratasys Vantage X 3D printer has been retrofitted and made open-source through a combination of hardware, software, and firmware modifications. These modifications result in complete control by the user over all print variables along with the ability to use any feedstock including custom made feed stocks and ones that are locked by the manufacturer. The printing accuracy of the machine is evaluated by optical imaging of the printed samples and destructive testing in accordance with the ASTM D638 standard. .

To study the effect of the machine's life on the properties, a longitudinal study is designed in which two groups of parts (with 0° and 90° orientations) are printed at two different times during the course of this research. The temporal spacing between the parts is eighteen months. The parts are designed according to ASTM D638 standard and printed on identical printers using the same parameters on both occasions. The parts are subjected to tensile

testing for the mechanical characterization while scanning electron microscopy (SEM) is used for the examination of the sample's fracture and topographical surfaces.

A difference is discovered between the Young's moduli of old and new groups. The orthotropic nature of FDM parts becomes prevalent in the strain responses of samples with 0° samples experiencing the largest strain. Distinct differences exist between the diffusion levels of the chronological sample groups, with the original batch exhibiting greater diffusion resulting in almost indistinguishable layers and higher tensile strengths. Individual layers are easily observed in the newer sample groups. Topographical analysis of samples shows up to 0.1mm difference between the road widths with the older samples roads being the narrowest. Results from this research show that the age of the printer affects the mechanical properties of the parts with the older parts exhibiting greater strength compared to their new counterparts even though both were printer under identical conditions. Therefore, a significant difference exists between temporally spaced FDM parts.

To conclude, this research has successfully retrofitted an old FDM system which is capable of printing various materials through a choice of user parameters. The longitudinal study conducted to study the effect of the machine age on the printed parts purports that as the printing machines get older their print quality deteriorates and this factor should be considered by designers when designing parts for functional purposes.

List of Terms and Definitions

Print orientation: This refers to the inclination of the part with respect to the X, Y, and, Z axes with the X and Y -axis parallel to the build platform and the Z axis perpendicular to the platform in the direction of the build.

Raster angle: For the purposes of testing, it is the angle between the raster relative to the applied direction of the load. During the printing process, it is traditionally referenced to the angle of the raster relative to the X-axis on the build table.

Layer thickness: This is the thickness of the layer deposited by the nozzle.

Nozzle height: This is the height between the extrusion nozzle and the previously deposited layer or at the start of a print, the height between the nozzle and the print bed.

Road: This refers to a single strand of deposited material. The conglomeration of the roads makes up the raster pattern.

Raster width: This is the width of a single deposited road.

Raster gap (air gap): This refers to the gap between two adjacent roads on the same print layer.

Voids: These are spaces between two adjacent roads or layers where material would ideally exist but was not successfully filled.

Infill: This is a value usually represented as a percentage. It represents how much of a solid model should be filled in.

Number of shells (boundary layers): This is the number of outlines printed in each layer. The higher the number of shells, the greater the strength of the printed object.

Extruder temperature: This is the temperature at which the extruder operates during printing. This temperature setting is dependent on the material used.

Printing speed: This is the speed at which the printhead moves while it is extruding filament.

Extrusion rate: This is the speed at which filament is extruded.

Movement speed: This is the speed at which the printhead moves while it is not extruding the filament.

Fill pattern: This is the pattern used for the interior fill of a part. This is made up of linear roads at varying raster angles but can also be hexagonal, diamond and other patterns.

Printer age: The time between the printer being commissioned and the current date.

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