INVESTIGATION OF MECHANICAL BEHAVIOR AND PROPERTIES PREDICTION MODELLING OF COPPER-FILLED FILAMENT FOR 3D PRINTING

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

“Fused Deposition Modelling” (FDM) merupakan salah satu teknologi pencetakan 3D dengan kos penghasilan yang terendah bagi pemprosesan termoplastik dan komposit. FDM digunakan secara menyeluruh di dalam pembuatan komponen oleh kerana kemampuannya untuk memproses binaan kompleks yang berdimensi tinggi dengan kos yang terendah. Walau bagaimanapun, teknologi FDM mempunyai suhu kerja yang terhad dan bahan-bahan seperti logam tidak dapat dicairkan untuk proses pencetakan. Justeru, bahan termoplastik seperti PLA sering digunakan dalam FDM disebabkan ianya mempunyai suhu lebur yang rendah. Namun, kelemahan termoplastik yang dicetak melalui FDM adalah kekurangan dalam kekuatan mekanikal dan sifat seperti kekonduksian terma dan elektrik untuk mencetak bahagian yang berfungsi. Masalah-masalah ini telah membawa kepada pengembangan filamen komposit baru untuk teknik FDM. Dalam kajian ini, spesimen asid polilaktik berisi tembaga dengan komposisi 25%, 50% dan 80% telah dicetak dengan corak yang berbeza (Rectilinear, Grid, Concentric, Octagram-spiral, dan Honeycomb) dengan mesin cetak 3D WANHAO dengan kelajuan cetakan 30 mm/s, diameter muncung 0.4mm, ketinggian lapisan 0.3mm, suhu penyemperit 210 ℃ dan suhu tapak cetakan 60 ℃ untuk mengkaji sifat mekaniknya. Corak pencetakan telah ditetapkan pada isipadu ketumpatan isian 50% untuk semua spesimen ujian. Geometri spesimen ujian dibuat berdasarkan standard ASTM dengan menggunakan pencetak FDM berkos rendah. Persekitaran percetakan dikawal pada 20 ℃ hingga 25 ℃ dan 70% hingga kelembapan relatif 80%. Sifat mekanikal yang dikaji ialah sifat tegangan dan sifat mampatan. Keputusan ujian mekanikal kemudian dikaji dengan menggunakan metodologi permukaan tindak balas untuk mengenal pasti parameter penting yang mempengaruhi sifat mekanikal dan set parameter yang optimum untuk sifat mekanikal yang dikehendaki dicadangkan. Model matematik sifat-sifat mekanik juga diperkenalkan menggunakan metodologi permukaan tindak balas yang boleh digunakan untuk meramalkan sifat-sifat mekanik yang dikehendaki dengan komposisi tembaga yang berbeza-beza dan corak isian. Daripada ujian tegangan, kekuatan tegangan muktamad (UTS), modulus Young dan kekuatan hasil (0.2% offset) diperolehi. Kekuatan tegangan muktamad (UTS) tertinggi 25.20 MPa dicapai oleh spesimen komposisi Cu 25 wt.% dengan corak isian Concentric. Modulus Young yang paling tinggi dicapai oleh spesimen Cu 80 wt.% dengan corak isian Concentric pada 329.3 MPa. Kekuatan hasil tertinggi (0.2% offset dicapai oleh spesimen komposisi Cu 25 wt.% dengan corak infill Concentric pada 12.81 MPa. Model yang dibuat untuk modulus Young, kekuatan UTS dan kekuatan hasil (0.2 % offset) mempunyai ralat hanya 0.76%, 0.42% dan 0.19%. Kekuatan mampatan tertinggi dicapai oleh corak isian Grid dengan 25.94 MPa bagi komposisi 25 wt.% Cu. Modulus mampatan tertinggi dicapai oleh corak isian Grid dengan 555.3 MPa untuk komposisi 80 wt.% Cu. Model dicipta untuk kekuatan mampatan dan modulus mampatan mempunyai ralat hanya 0.43% dan 2.57%. Maka, kekuatan tegangan tertinggi dapat dicapai melalui penggunaan komposisi Cu 25 wt.% dan corak isian Concentric manakala komposisi yang sama dengan corak isian Grid dapat memberi kekuatan mampatan tertinggi.

ABSTRACT

Fused Deposition Modelling (FDM) technology is among the lowest-cost 3D printing technology for processing thermoplastic and composite materials. FDM has been highly used in additive manufacturing due to its ability to process complex parts with accurate dimensions and lowest cost possible. However, FDM technology has a limited working temperature and is unable to melt substances like metals for printing purposes. Thus, thermoplastics materials such as PLA are used in FDM due to their relatively low melting temperature. However, the drawback of these thermoplastic printed through FDM is the lack of mechanical strength and properties such as thermal and electrical conductivity to print functional parts. These problems have led to the development of new composite filament for FDM technique. In this research, 25 wt.%, 50 wt.%, and 80 wt.% of copper reinforced polylactic acid (PLA) specimens have been printed with different infill patterns (Rectilinear, Grid, Concentric, Octagram-spiral, and Honeycomb) using WANHAO 3D printer with printing speed of 30 mm/s, nozzle diameter of 0.4mm, layer height of 0.3mm and extruder temperature at 210 ℃ with print bed temperature of 60 ℃ to study its mechanical properties. The 3D printer was calibrated prior to beginning of test specimens. The infill patterns were set constant at 50 % infill density for all test specimens. The geometry of test specimens was fabricated according to ASTM standards using a low-cost FDM printer. The printing environment is controlled at 20 ℃ to 25 ℃ and 70% to 80% relative humidity. The mechanical properties include tensile properties, and compression properties were investigated. The results of the mechanical tests were then studied using response surface methodology to identify significant parameters that affect the mechanical behaviour and the optimum set of parameters for desired mechanical properties was then proposed. Mathematical models of the mechanical properties were also introduced using response surface methodology, which can be used to predict desired mechanical properties with varying copper composition and infill pattern. From the tensile test, ultimate tensile strength (UTS), Young's modulus and yield strength (0.2 % offset) were obtained. The highest ultimate tensile strength (UTS) is achieved by the 25 wt.% Cu composition specimens with Concentric infill pattern recording 25.20 MPa. The highest young's modulus is achieved by the 80 wt.% Cu composition specimens with Concentric infill pattern recording 329.3 MPa. The highest yield strength (0.2% offset is achieved by the 25 wt.% Cu composition specimens with Concentric infill pattern recording 12.81 MPa. The model created for young's modulus, UTS, and Yield strength has an error of just 0.76%, 0.42%, and 0.19%, respectively. The highest compressive strength is achieved by the Grid infill pattern with 25.94 MPa for 25 wt.% Cu. The highest compressive modulus is achieved by the Grid infill pattern with 555.3 MPa for 80 wt.% Cu. The model created for compressive strength and compressive modulus has an error of just 0.43% and 2.57%. Hence, the Concentric infill pattern with 80 wt.% Cu can provide maximum tensile strength while Grid infill pattern with 25 wt.% Cu can provide maximum compressive strength.

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