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ORIGINAL CONTRIBUTION

Strength and Surface Characteristics of FDM-Based 3D Printed PLA Parts for Multiple Infill Design Patterns

Pushpendra Yadav[1] · Ankit Sahai[1] · Rahul Swarup Sharma[1]

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Abstract Fused Deposition Modeling (FDM) based 3D printers are gaining popularity as cost-effective printers that are changing the life of millions with their capability to manufacture products in the fields of engineering, medical and education. This paper examines the variation in the compressive strength of FDM processed Polylactic acid (PLA) parts for different infill design patterns. The work is performed on 6 infill designs i.e., Hilbert curve, honeycomb, line, rectilinear, Archimedean curve and octagram spiral and compressive strengths are compared for infill densities varying from 20 till 80% in step of 20. It is observed that the Hilbert curve design exhibits maximum compressive strength of 121.35 MPa which is much higher than other designs rectilinear (78.88 MPa), line (73.84 MPa), honeycomb (62.56 MPa), Archimedean (70.07 MPa), octagram spiral (60.01 MPa). Also, with increase in infill density, compressive strength increases for all the considered infill design patterns. The fabricated parts are also investigated for surface roughness values for best 3 compression strengths with different combinations of infill densities. The surface roughness increases with increase in infill densities for rectilinear and hilbert curve but decreases for line pattern. Rectilinear pattern exhibits lowest roughness value as compared to hilbert curve and line design patterns.

Keywords Fused deposition modeling · 3D printing · Compressive strength · Surface roughness

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Introduction

Present world is witnessing the amazing technological growth in the field of Additive Manufacturing (AM) and 3D printing [1]. This field is gaining popularity not only in the area of manufacturing but also in biomedical [2], tissue engineering [3, 4], educational systems [5, 6], etc. Also, with customers demanding more and more customized products, manufacturing technologies are experiencing exponential shift in their designing of products and manufacturing in quick time with improved quality [7]. In comparison with numerous AM technologies that are available commercially i.e., selective laser melting (SLM), binder jetting (BJ), laminated object technology (LOM), selective laser sintering (SLS), fused-deposition modeling (FDM) and stereolithography (SLA), FDM is most popular and cost-effective technique to print 3D models and prototypes [8]. Through this technology, plastics such as polycarbonate (PC), polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), PEEK and even nano-composites are used as raw materials for producing 3D printed products. Moreover for sustainable development in 3D Printing, researchers are using natural fibers which are biodegradable with improved properties [9, 10].

Considerable research work has been done on fused deposition modeling (FDM) process parameters and their effects on mechanical properties. In many studies, researchers considered FDM process variables such as layer thickness [11, 12], width, and distance between filaments, nozzle temperature; build orientation [13–16] and material feed rate [17, 18]. The mechanical properties of 3D printed parts by FDM process are greatly enhanced by the bond between raster and layer and the amount and size of voids present in the structure. The quality of these bonds and the features of voids are the functions of various FDM

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ORIGINAL CONTRIBUTION

Flexural Strength and Surface Profiling of Carbon-Based PLA Parts by Additive Manufacturing

Pushpendra Yadav[1] · Ankit Sahai[1] · Rahul Swarup Sharma[1]

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Abstract Recent years have witnessed the exponential shift in the designing of products and manufacturing in quick time with improved quality through numerous Additive Manufacturing (AM) techniques. This paper examines the flexural properties of the carbon-based PLA composites through one of the most popular AM processes i.e. Fused Filament Fabrication. The specimens are prepared based on three input parameters i.e. layer thickness, LT (0.1, 0.15, 0.2 mm), feed rate, FR (20, 40, 60 mm/s) and raster orientation, RO (0°, 45°, 90°). The variation in flexural strength at each layer thickness is evaluated with combination of feed rates and raster orientations. The experiments reveal that flexural strength decreases on increasing the layer thickness and feed rate because of poor bond strength between the layers. The flexural strength increases by 48% (for 20 mm/sec FR) on varying raster orientation (RO) from 90° to 0° at 0.1 mm LT. Similarly, the flexural strength increases only by 10% (for 20 mm/sec FR) on varying RO from 90° to 0° at 0.15 mm LT. For 0.2 mm LT, the strength increases by only 6% on varying RO from 90° to 0° for 20 mm/sec FR. This indicates that mechanical anisotropy is reduced due to more evenly distribution of carbon fibres resulting in strong fibre-PLA bond. The best value of flexural strength at each layer thickness (113.189 MPa, 119.138 MPa and 106.12 MPa for 0.1, 0.15 and 0.2 mm, respectively) based on the considered parameter combinations is taken forward for analyzing the surface profile parameters. The best surface finish having roughness value R_a = 0.277 µm and high flexural strength, 119.138 MPa, is obtained having parameter combination of Layer Thickness = 0.15 mm, Feed Rate = 20 mm/s, Raster Orientation = 0°.

Keywords Additive manufacturing · Fused filament fabrication · Flexural strength · Surface roughness

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Introduction

The power of 3D printing or Additive Manufacturing is taking over the world with its existence being felt in almost all the domains of life be it manufacturing, biomedical, education, food processing, civil structures, etc. The main advantage is that this process can produce complex to complex parts without expensive tooling and with greater ease and affordable cost. In conventional subtractive process, more energy, time and cost are needed to remove the extra material and it multiples with increase in complexity of the part. Therefore, industrial units are finding out ways where the conventional method is now being replaced by the additive processes in which designers, scientists and manufacturers have freedom to work on complex designs, where we can place the material at the right place and can actually see it shaping up with layer by layer formation. This helps in reduction of energy and cost needed for removing the material, thereby increasing the manufacturing efficiency [1]. Since last decade, Additive Manufacturing has displayed immense potential in revolutionizing industries and manufacturing methods, but certain drawbacks are limiting its world wide acceptance especially in the field of manufacturing. The first being the mechanical properties of the polymers which are relatively low and therefore cannot be used as a functional

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ORIGINAL CONTRIBUTION

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Pushpendra Yadav[1] · Ankit Sahai[1] · Rahul Swarup Sharma[1]

Received: 19 May 2020 / Accepted: 2 October 2020 / Published online: 10 October 2020

Abstract Fused Deposition Modeling (FDM) based 3D printers are gaining popularity as cost-effective printers that are changing the life of millions with their capability to manufacture products in the fields of engineering, medical and education. This paper examines the variation in the compressive strength of FDM processed Polylactic acid (PLA) parts for different infill design patterns. The work is performed on 6 infill designs i.e., Hilbert curve, honeycomb, line, rectilinear, Archimedean curve and octagram spiral and compressive strengths are compared for infill densities varying from 20 till 80% in step of 20. It is observed that the Hilbert curve design exhibits maximum compressive strength of 121.35 MPa which is much higher than other designs rectilinear (78.88 MPa), line (73.84 MPa), honeycomb (62.56 MPa), Archimedean (70.07 MPa), octagram spiral (60.01 MPa). Also, with increase in infill density, compressive strength increases for all the considered infill design patterns. The fabricated parts are also investigated for surface roughness values for best 3 compression strengths with different combinations of infill densities. The surface roughness increases with increase in infill densities for rectilinear and hilbert curve but decreases for line pattern. Rectilinear pattern exhibits lowest roughness value as compared to hilbert curve and line design patterns.

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Considerable research work has been done on fused deposition modeling (FDM) process parameters and their effects on mechanical properties. In many studies, researchers considered FDM process variables such as layer thickness [11, 12], width, and distance between filaments, nozzle temperature; build orientation [13–16] and material feed rate [17, 18]. The mechanical properties of 3D printed parts by FDM process are greatly enhanced by the bond between raster and layer and the amount and size of voids present in the structure. The quality of these bonds and the features of voids are the functions of various FDM

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INTENSIFYING HANDS-ON LEARNING, EXPLORATION, AND INVENTORSHIP BY DESIGNING FUSED DEPOSITION MODELING THREE DIMENSIONAL PRINTER

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Introduction

3D printing is considered as the future of the technology in the world and is a manufacturing phenomenon that will revolutionize industries, factories and mass production in the coming years. 3D printing has shown excellent potential to reduce both the cycle time and cost of product development [1]. With the development of 3D printing, a large number of processes have been developed that allow the use of variety of materials and methods [2–6]. Among these technologies, one of the most commonly used is fused deposition modelling (FDM), a layer-by-layer additive manufacturing technique, based on material extrusion technology. The advantages of this technology are easy material change, low maintenance costs, supervision-free operation, compact size and low working temperature.

3D printers are a valuable addition to almost any learning space, with students ranging from the very young to adults. 3D printers can inspire learners to explore, brainstorm, and experiment with many different ideas [7]. There are no limitations for this evolving technology except the constraints of our 'Imagination'. Sometimes young kids are the biggest experts and they should be encouraged to keep thinking and learning, and keep advancing their knowledge. This work proposes hands-on learning method for high school and undergraduate students to learn and design their own 3D printers to turn their innovative ideas into reality.

Design and Development of 3D printers

Rapid Prototyping lab at Dayalbagh Educational Institute (DEI) allows the students a significantly deeper insight into the functioning of 3D-printing by

Chapter 36
Experimental Investigations for Effects of Raster Orientation and Infill Design on Mechanical Properties in Additive Manufacturing by Fused Deposition Modelling

Pushpendra Yadav, Ankit Sahai and Rahul Swarup Sharma

Abstract Manufacturing and designing of various functional components in the fields of engineering, automobile and aerospace are being done by additive manufacturing (AM) technology. These activities must be supported by the knowledge of process parameters that may influence mechanical properties of industrial products. Fused deposition modelling (FDM) is one of the most popular AM technologies in which the quality of part depends on selection of process variables. The present work focuses on two input process parameters, i.e. raster orientation and infill density and its effect on the mechanical properties of 3D-printed samples. The PLA samples were prepared in *XY* and *XZ* orientation with infill density of 20, 40, 60, 80 and 100%. The tensile testing is conducted to evaluate the effects of these process parameters on tensile strength, ultimate strength, etc. Further, fractography was performed and it is concluded that dimple size and distribution on fractured surface were affected by the infill density. Printing time was also checked and compared for specimens printed for different parameters, which shows printing time is least for *XY* orientation and maximum for *XZ* orientation. Printing time increases as the infill density increases from 20 to 100%.

Keywords 3D printing · FDM · Tensile testing · Infill density · Fractography

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Evaluating Mechanical Strength of Three Dimensional Printed PLA Parts by Free Form Fabrication

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Abstract

Additive Manufacturing (AM) or three dimensional printing is a new integrated manufacturing technology that has been gaining lot of attention for its ability to produce high quality parts quickly and in cost effective way. Among the several available techniques, extrusion based AM, namely, Fused Filament Fabrication (FFF) Figure1, is most widely used method for manufacturing functional parts for fields like education, engineering, medical, etc. But this needs to be supported by knowledge on how different combinations of process parameters impact the mechanical behaviour of the products. The present work focuses on the effect of some parameters on the mechanical properties of polylactic acid (PLA) based 3D printed parts. The study was conducted using input parameters like infill density (60% & 90%), annealing temperature (80 ^{0}C and 120 ^{0}C), and range of layer thickness from 0.2 mm to 0.4 mm. The prepared specimens were subjected to tensile testing for evaluating tensile strength, yield strength; etc based on different parameter combinations. It was observed that 90% infill density exhibits higher strength as compared to 60%. Also, increasing the annealing temperature results in minor increase of the strength but at the expense of ductility and mechanical strength is higher for low values of layer thickness. Scanning electron microscopy was also performed to analyze the behaviour of fractured surface of the tensile tested parts. The results show a strong dependence of mechanical properties on layer thickness and infill density.

Keywords: Additive Manufacturing, FFF, 3D Printing, Mechanical Properties;

1. Introduction

In the last few years, additive manufacturing (AM) or 3D printing has witnessed massive growth in industrial and education sector owing to its simple, cost effective and customized production process. This is possible due to its acceptability in variety of domains like manufacturing, healthcare, education, aerospace, defence, etc [1-6] and thus three-dimensional (3D) printing has come under the spotlight of being the next technological revolution in the world. Digital technologies right from the adoption of CNC machines to now have witnessed major acceleration especially since last decade because of the rising of 3D printing technologies.

Among the several mainstream techniques, extrusion-based AM, typically called fused deposition modeling (FDM) or free-form fabrication (FFF) is arguably the most versatile and widely used method. In extrusion AM, the material, which is typically provided as a spooled polymer filament, is fed to the print head where it is heated, melted, and forced through a nozzle. The print head assembly is mounted atop a gantry which typically moves the extrusion nozzle within the horizontal plane, while the build platform is moved vertically, Figure. 1.

3D printed parts through FDM have been more sensitive to processing parameters such as layer thickness or build orientation [7-10]. They are directly dependent on the final product quality. However, at low loads 3D printed products still fail due to brittle fracture and low mechanical property of FDM printed objects is a major weak point to be ahead of the competition in the field of digital manufacturing.

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