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Influence of FDM Parameters on Fatigue Performance of 3-D Printed Material: A Review

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ABSTRACT

Additive Manufacturing (AM) is now a days fastest growing field and is being widely used by industries and research community. It enables rapid fabrication of physical prototype using CAD data. Out of various available AM processes, extrusion-based modelling also called Fused Deposition Modelling (FDM) contributes major share being cost effective and flexible. Apart from prototyping, most of the organized and unorganized industrial sectors are using FDM printed parts for end applications. FDM can built parts with customized critical shapes/ features with reasonable accuracy and cost in minimum time. When it comes to end application of 3-D printed products it is important to understand and predict mechanical behavior of FDM printed parts or material under static/ dynamic conditions.

Aim of this study is to carry out review of available research literature addressing the effect of FDM input parameters on mechanical behavior of 3-D printed polymer material. Specific focused area of this study is to critically review the research outcomes related to fatigue behavior of 3-D printed material. Several experimental researches have been carried out to study the influence of FDM parameters on mechanical and fatigue properties of 3-D printed polymer and components. Input parameters considered in theses studies are raster orientation, build orientation, layer height and bead width and air gap between filaments. Overview and analysis of currently available data in research literature is presented in this paper and it also includes various methodologies adopted by researchers to measure output parameters specially related to fatigue behavior.

Key words: Additive manufacturing, Polylactic acid, Fatigue performance, Raster angle

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INTRODUCTION

3D printing or additive manufacturing is a process of making three layered strong articles from a computerized record. The making of a 3D printed object is accomplished utilizing added substance processes. In an added substance process an article is made by setting down progressive layers of material until the item is made. Every one of these layers should be visible as a meagerly cut cross-part of the object.3D printing is something contrary to subtractive assembling which is removing/emptying out a piece of metal or plastic with for example a processing machine.3D printing empowers you to create complex shapes utilizing less material than customary assembling techniques.

Fused Deposition Modelling (FDM), otherwise called Fused Filament Fabrication (FFF), is an added substance producing process that falls inside the class of material expulsion. In FDM, an article is worked by specifically storing liquefied material in a foreordained way, layer by layer. The materials utilized are thermoplastic polymers, which arrive in a fiber structure. FDM is the most generally utilized 3D printing innovation. It involves the biggest introduced base of

3D printers worldwide and is frequently the main 3D printing innovation that individuals experience. This article presents the fundamental standards and the vital attributes of the innovation, fully intent on assisting engineers with getting the most ideal outcomes from FDM printing.

In the new reality, created out of complexity and opportunities, industrial 3D printing continues to evolve to help companies stay resilient and agile. The 3D printing industry has been on a stable growth trajectory over the last decade. Mostly, this growth has been associated with the changing perception of 3D printing, which entered 2020 as a maturing manufacturing solution. Investment in industrial 3D printing has been booming, with hundreds of millions of dollars poured into the industry. At the same time, more companies have started to explore promising applications, ranging from footwear to implants and rocket engine parts.

This paper comprises of the research in the field of 3D printing to study deeply the fatigue behaviour of the 3D printed materials

Deep research has been performed to find out the factors affecting the fatigue properties of 3D printed materials and the way these properties change according to the changing parameters.

LITERATURE REVIEW

P1: A review of the fatigue behavior of 3D printed polymers.
By: Lauren Safai, Juan Cuellar, et al.
Parameters considered: Raster Orientation, material and their properties.
Conclusion – For extrusion-based printing, it was found that printing with 45/45-degree raster orientation had the best fatigue life, while it was inclusive as to if ABS or PLA was the most fatigue resistant material.
In selective laser sintering, the printing orientation did not have an impact on the fatigue life of the specimen.
Understanding the mechanical properties of 3D printed polymers could aid in predicting and preventing fatigue failure.

P2: Effects of part build orientation on fatigue behavior of FDM- processed PLA material.
By: Mst Faujjia Afrose, S.H. Masood et al.
Parameters considered- Build orientation.
Conclusion – Build orientation affects stress values under different loadings.
PLA specimen built in 45-orientation displayed best capacity to store strain energy compared to those built in other two orientations.

P3: The effect of raster orientation on the static and fatigue properties of filament deposited ABS polymer.
By: Natalie S.F. Jap, Garth M. Pearce et al.
Parameters considered: Raster orientation.
Conclusion- for a given stress level, the raster orientation has a great impact on the fatigue life of the component. Evaluation of the models for a constant stress, say 16 Mpa shows the -45/+45 raster specimen to have more than twice the fatigue life of the equivalent 0/90-degree raster orientation.

P4: Damage tolerance-based methodology for fatigue lifetime estimation of a structural component produced by material extrusion -based additive manufacturing.
By: Florian Arbeiter, Lukas Travnicek et al.
Parameters considered- FRM (Flow rate multiplier).
Conclusion: Different values for the flow rate multiplier (FRM) lead to variations in the printing quality and therefore the total fatigue lifetime of a component.

P5: Effects of printing parameters on the Fatigue behavior of 3D- printed ABS under dynamic thermo-mechanical loads.
By: Feiyang He and Muhammad Khan
Parameters considered: Build orientation, nozzle size, layer thickness, environmental temperature.
Conclusion- The environmental temperature has the greatest influence on the fatigue performance, followed by the build orientation and nozzle size.

A combination of the following parameters provides the longest fatigue life among the tested values: X building orientation, 0.8mm nozzle size, and 0.15mm thick layer.
Higher temperature reduces the fatigue life possibly due to more active molecular movement.
Both a layer nozzle size and thicker layer height decreases the beams micro void space and quantity per unit area in the potential crack path and lead to a higher fatigue resistance.
Printing void defects fundamentally affect the fatigue life of FDM structure.

P6: Fatigue analysis of FDM Materials
By: John Lee and Adam Huang
Parameters considered – FDM dog bone UNI EN ISO 527-1 were tested at 100,80,60 and 40 percent nominal values of the ultimate strengths of 9 different print orientations.
Conclusion- according to available literature the orientation pf the raster angle +45/-45 degree yields a longer fatigue life in PLA and ABS-based printed materials.
FDM uses different thermoplastic materials since the significant variation in their physical properties tends to change the fatigue nature.
Polymeric materials are viscoelastic and typical FDM parameters and fatigue process involve varying temperatures.

P7: Fatigue behavior of FDM-3D printed polymers, polymeric composites and architected cellular materials.
By: Vigneshwaran Shanmugam, Oisik Das et al.
Parameters considered: 3D printed polymeric materials fatigue properties.
Conclusion: the orientation of the raster angle of +45◦/− 45◦ yields a longer fatigue life in PLA and ABS-based printed materials.
Polymeric materials are viscoelastic and typical FDM and fatigue process involve varying temperatures. High environmental temperatures would reduce the fatigue life of polymeric materials.

P8: Fatigue Characteristics of 3D Printed Acrylonitrile Butadiene Styrene (ABS).
By: M. M. Padzi, M. M. Bazin, W. M. W. Muhamad
Parameters considered: Fatigue properties of 3D printed materials.
Conclusion: fatigue life was determined by the tensile strength value. Ultimate tensile strength (UTS) value of the molding specimen (48.5 MPa) was higher compared to 3D printing specimen (17.8 MPa) where it causes the fatigue life of molding specimen was higher than 3D printed specimen.
3D printed component might not suitable for high strength industrial application. However, within the context of production, 3D printed components may be grown in low volume, customized design components and for low strength application. Moreover, the technology of 3D printing could produce a complex design of a product that could not be brought about by the molding method.

P9: FDM process parameters influence over the mechanical properties of polymer Specimens.
By: Diana Popescu, Aurelian Zapciu
Parameters considered: Tensile stress, compression stress, flexural stress, impact stress.
Conclusion: The mechanical behavior of FDM parts is determined by the filament bonding, all process parameters affecting, directly or indirectly, this thermally driven process. Among the mechanical properties, tensile strength is evaluated the most. It is reported that smaller values for layer thickness and raster width improve the tensile strength. Also, mechanical properties are improved by setting a negative raster to raster air gap. Mechanical properties optimization should not be performed by focusing solely on establishing settings of process parameters, instead the complex combination of polymer/3D printer/manufacturing conditions have to be considered.

P10: The impact of print orientation and raster pattern on fracture toughness in additively manufactured ABS.
By: Tait D. McLouth⁎, Joseph V. Severino et al.
Parameters considered: Part orientation, fracture toughness.
Conclusion: Print and raster orientation in FDM CT samples were shown significantly impact fracture toughness. Samples printed in the ZXY and XYZ directions contained half or more of their filaments in a direction that was orthogonal to the crack plane, which resulted in a significant obstacle to crack propagation and a fracture toughness that

reached 1.97 MPa”m1/2 for the ZXY orientation. The XZY orientation did not have any filaments aligned orthogonally to the crack plane. Instead, it relied upon weak interfilament bonding to resist crack propagation, resulting in a low fracture toughness of 1.28 MPa*m ½. The raster pattern utilized had a significant impact on samples when it aligned filaments orthogonally to the crack plane, as was the case for the ZXY +45/-45’ samples. When filaments adjacent to the crack tip were loaded along their axes the plastic zone was larger than when loading occurred in an interfilament manner. Ultimately it is the alignment of extruded filaments in strong configurations that changes the mechanical properties; the more filaments aligned orthogonally to the crack plane, the higher the fracture toughness. This research provides useful information and insight to future designers by highlighting the effect that filament orientation with respect to the crack font can have on crack stability. The analysis of specific raster patterns and sample orientations provides a wide range of potential configurations for samples that may be relevant when considering these new materials for space hardware

P11: Flexural Fatigue Properties of Polycarbonate Fused-deposition Modelling Specimens.
By: Josep M. Puigoriol-Forcada, et al.
Parameters considered: Built orientation, raster angle, layer thickness.
Conclusion: Good correlation between the simulated and experimental model shows that FEA is a proper validation method to predict the failure of FDM components. Voids can be created between filaments during the manufacturing process, this can be avoided by changing the manufacturing path.

P12: Influence of Processing and Orientation Print Effects on the Mechanical and Thermal Behavior of 3D-Printed ULTEM® 9085 Material
By: R. J. Zaldivar, D. B. Witkin et al.
Parameters considered: print orientation, mechanical and thermal properties, and the strain field behavior of ULTEM® 9085.
Conclusion: The tensile strength, failure strain and modulus of ULTEM® 9085 3-D printed dogbone specimens were shown to significantly vary as a function of build orientation. The tensile strength of these 3D FDM parts varied from 46 - 85% of reported values for injection molded (IM) ULTEM® parts. Build orientations with a higher fraction of extruded polymeric fibers oriented along the load direction exhibit improved strength utilization of the part, while those that were offset exhibit reductions in mechanical performance with increased scatter. The failure strains for FDM parts also ranged from 2-7% and were also considerably lower than the failure strains typically attained for IM ULTEM® parts (75%).

P13: Natural Frequency prediction of FDM manufactured parts using ANN approach
By: Fahraz Ali, Boppanna V. Chowdary
Parameters considered: Raster angle, air gap, build orientation, no. of contours.
Conclusion: the raster angle has the greatest impact on natural frequency. A decrease in raster angle results in higher natural frequency with an apparent increase occurring from 45 degrees to 0 degrees. This observation can be attributed to an increase in the stiffness of the specimens with a lower raster angle thus resulting in greater natural frequency. The specimens built with 0 degrees raster angle have all raster perpendicularly aligned to the bending axis hence offering more resistance and therefore characterized with having greater stiffness.

P14: Optimizing process parameters of fused deposition modeling by Taguchi method for the fabrication of lattice structures.
By: Guoying Dong, Grace Wijaya et al.
Parameters considered: process parameters.
Conclusion: The optimal values for inclined struts are 255◦ C nozzle temperature, 1200 mm/min print speed, 50% fan speed and 0.1 mm layer height. However, for horizontal struts, the optimum is 245◦ C nozzle temperature, 600 mm/min print speed, 0% fan speed and 0.2 mm layer height.

P15: Numerical modelling and simulation of fatigue damage in carbon fibre reinforced plastics at different stress ratios.
By: M. Broda, G. Justb et al.
Parameters considered: Stress ratio, fatigue damage.

Conclusion: With the help of the conducted experimental investigation of the damage response in cross-ply laminates under different stress ratios, the predictive capability of the FDM for constant cyclic loading was assessed.

P16: Mechanical characterization of 3D-printed polymers.
By: John Ryan C. Dizona, Alejandro H. Espera Jr. etnt.
Parameters considered: different mechanical tests such as tensile, bending, compression, fatigue, impact and others. Properties at cryogenic temperatures.
Conclusion: 3D-printed materials have large anisotropy especially for the FDM- and SLS-printed parts. The effects of post-processing on the mechanical properties are also significant especially in the case of SLA parts.

P17: Quantitative analysis of surface profile in fused deposition modeling
By: Yu-an Jin, Hui Li, Yong He, Jian-Zhong Fu
Parameters considered: layer thickness
Conclusion: Results from the experiments validate the feasibility and effectiveness of the proposed surface profile models and indicate that good quality top surface can be achieved by coordinating the speed of filament driving motor and the axis driving motors synchronously, and the quality of side surface can be guaranteed by adjusting the stratification angle and the layer thickness appropriately.

P18: Tensile and fatigue behavior of layered acrylonitrile butadiene styrene.
By: Sophia Ziemian, Maryvivian Okwara, Constance Wilkens Ziemian
Parameters considered: raster orientation
Conclusion: Tension tests indicate that the ultimate and yield strengths are the largest for the 0° raster orientation, followed by the 45/45, 45 and 90° orientations in descending order. The mean ultimate tensile stress for the 0° specimens is 93 per cent of the injection molded ABS, while the mean UTS for the 90°specimens is the smallest at only 34 per cent of the injection molded parts. Tension – tension fatigue tests also demonstrate anisotropic behavior on the basis of raster orientations. The 45/45°specimens had the longest fatigue life at each normalized stress level, followed by the 0, 45 and 90° orientations in descending order.

P19: On the strain-life fatigue parameters of additive manufactured plastic materials through used filament fabrication process.
By: Soran Hassani Fard, Seyed M. Hashemi
Parameters considered: Raster orientation, fatigue strength.
Conclusion: those with weaker fatigue strength, no transition fatigue life (Nt) was observed, and the fatigue life prediction was performed by the elastic part of the Coffin-Monson equation the 45o raster orientation for PLA 3D printed parts is recommended for fatigue design. The 90oraster orientation, however, showed the weakest fatigue strength beyond Nt.

CONCLUSION

The purpose of this literature review was to interpret various papers and see whether the trends in data could lead to any conclusions about how different printing parameters affect the fatigue behavior of 3D printed PLA material.

After the review, the major factors that affect the fatigue properties of 3D printed PLA material were found to be raster angle and build orientation. The raster angle of 45° orientation provided the best fatigue life. X building orientation also give better fatigue performance.

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