Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Review and preliminary design of 3-D printed ABS polymer torsion element with parametric internal structures

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ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Plastic molding
Fused deposition methods
The density of infill
The thickness of a print layer
Deposition parameters

ABSTRACT

Various components utilized in the automobile dashboard controls are manufactured from plastic by a conventional molding process. With the recent trend and continuously changing designs of the components due to frequently upgraded models, the conventional process of manufacture of these components proves costly owing to the high investment in molds. The technology which has taken attention for these demanding conditions is the Fused Deposition or 3-D printing technology in development and manufacture of plastic components for ready use direct assembly which bypasses the process of mold manufacture and then subsequent plastic molding which is many times involves a considerable amount of production time and high production cost. The strength of the components produced by the 3-D printing method is seen to be greatly influenced by the infill density, print quality, and layer thickness.

The depositing parameters have been studied in various studies but they failed to characterize the geometrical arrangement permutations through the addition of internal support structures to enhance the torsion strength of the components. The paper discusses a review of research work over the years proposes the first stage design and analysis of the plain component using Ansys workbench and also the manufacturing of these plain elements with various permutations of infill density, layer thickness, and print quality. The components thus produced will be tested and compared for optimal deposition parameters. By considering the gathered data, an optimization model that realizes the material usage, build time, strength characteristics, and their related variables will be presented and used to assist the components with optimal deposition parameters which will be further considered for design with internal support structures with the incorporation of varied parametric internal structure matrix.

1. Introduction

Presently it is seen that the need of the time is to develop high strength but low weight automotive components in the least possible lead time thus, the method proposed is very apt and suits the requirements of the industry wherein we can reduce the weight of the components and also will affect scale of production economy as low batch quantities and even single-unit production will be possible which otherwise is not possible by the conventional plastic molding methods. Additive manufacturing processes are used to develop physical true scale models from three-dimensional (3D) computer-aided design (CAD) data. A solid model created to scale using 3-d modeling tool is used as the input in the.stl format, which is cut and distributed into layers, and printing pathways are created for every layer. The construction of object is done layer by layer in a stacked format, with the strength provided using supporting structures for overhanging geometry and process-dependent undercuts provided to reduce the material usage. Fused deposition modeling (FDM) is a fabrication process that builds the geometry of parts from polymer elements that are extruded from a melted thermoplastic filament roll. The process of FDM through changes in the positing parameters have been already studied by several researchers; however, very few researchers worked on the strengthening methods that use the support structures in an internal manner using varied arrangements of geometry profiles internally and their effect on the strength of components has not been studied. With the advent of 3-D printing technology, the

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https://doi.org/10.1016/j.matpr.2022.09.173
2214-7853/

Please cite this article as: M.N. Vhatkar, G.V. Patil, I.G. Bhavi et al., Review and preliminary design of 3-D printed ABS polymer torsion element with parametric internal structures, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2022.09.173

rapid prototyping technology is at the center stage in the development and manufacture of plastic components for ready use direct assembly bypassing the process of mold manufacture and then subsequent plastic molding which is many times a considerable amount of production time and high production cost. Thus 3-d printing of such components used ABS polymer filaments is regular in the industry. But the present strength of the material being formidably low, so also the effect of deposition parameters on the strength components playing a critical role, further study in this area is needed to develop components for ready use in the automobile industry. The two prominent FDM manufacturing strategies are solid mode and shell mode can be applied depending upon the applications. The shell mold is used in places where the solid build strategy cannot be necessary or prove problematic. It is observed that for certain geometries with thick wall and thin wall blend the shell mode may not be applied. The conventional molding process is known to produce distortion in case of the junction of walls both thick and thin the FDM process offers a solution as per the research work carried out earlier regarding the wall thickness of varied permutations. However, in the case of the components with thin-walled geometry, the shell building mode cannot be advisable that leads to low stiffness making the prototype considerably unsuitable for the application. Research reveals that the mechanical strength using the method of internal support material has not been fully researched or studied yet. Hence, it is beneficial to use internal support structures with the incorporation of varied parametric internal structure matrix with known attributes and behavior that will propose provide the support desirable at the same time balancing the quantity of material used on both the model as well as support structure matrix. The research work previously done in this field is studied in the literature review and the gap in the research work is mentioned in the literature gap.

2. Literature reviewed

Joseph T. Belter et al. [1] the authors in this paper describe the strength augmentation techniques for components produced using fused deposition using thermoplastic materials. The techniques studied were proposed to retain the benefits of the process about the speed of production, the complexity of part geometry, and ease of manufacture. The authors used the method of placing cavity in the produced geometry in 3-d printing and filling them resins that offer high strength. The researchers through their work showed that the strength and stiffness of the components prepared by the said method were observed to be 25 percent to 45 percent over the components produced by the conventional methods.

Jibisha Blessie J P et al. [2] the authors in their study showed the effect of the process parameters of the FDM process on the rigidity of the components produced by the 3-d printing process. The printing pattern, infill densities were studied and examined by experimental design. The authors used Taguchi design with orthogonal L9 array for the study and the PLA (poly-lactic acid) material was used for the 3-d printing of the specimens.

Anil Kumar et al. [3] the authors in their paper have discussed the methods of printing hollow compounds with various shapes for application in turbine blades, disc brakes, and gears. The authors focus on the design development of the hollow turbine blades for gas turbines and compared the components produced by 3-d printing to the components to the solid compounds produced by conventional methods. The authors found the hollow compounds produced by the 3-d printing more advantageous in regards to the heat transfer ability and low material cost over the traditional turbine blades.

Andrei Danut Mazurchevici et al. [4] the authors in their paper review additive manufacturing or 3-d printing in comparison to

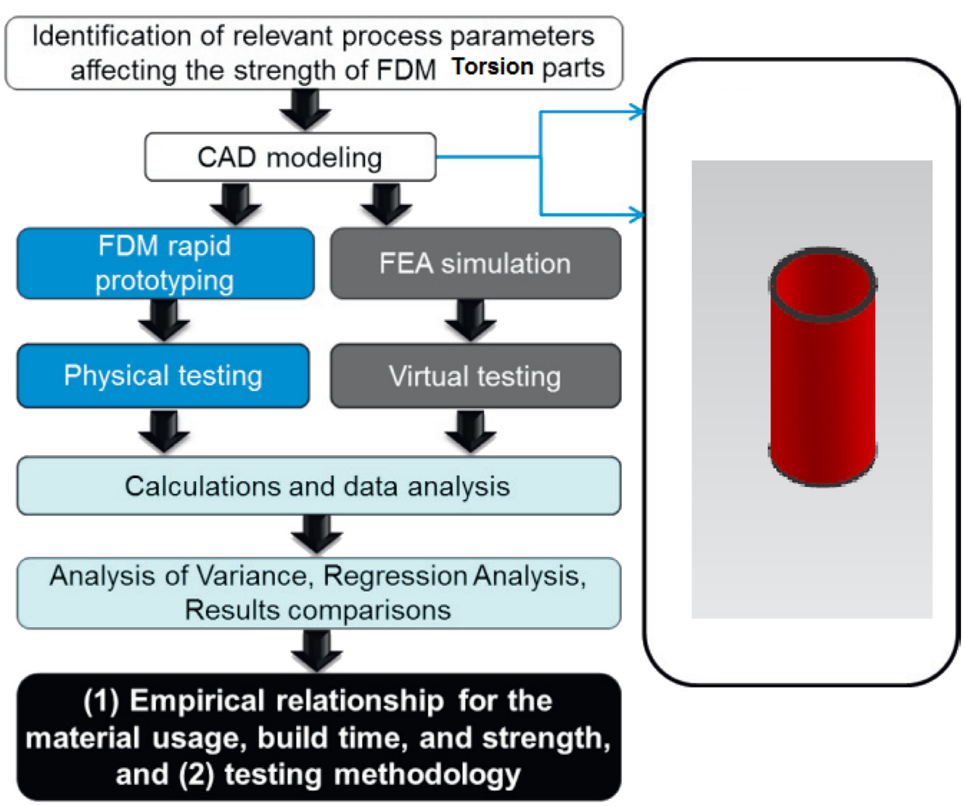

Fig. 1. Steps to be followed in methodology.

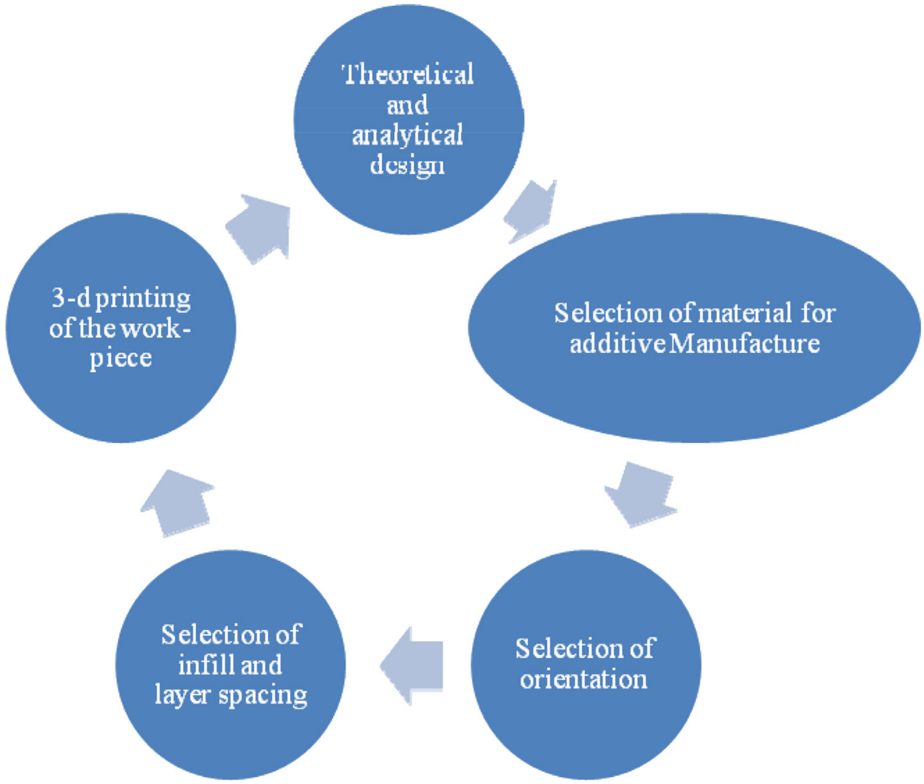

Fig. 2. Flow diagram of horizontal orientation (0 degrees) specimen.

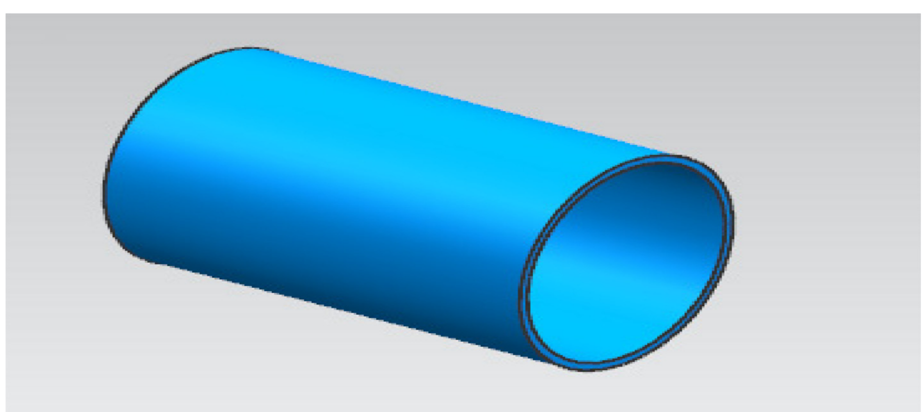

Fig. 3. 3-D CAD model of horizontal orientation (0 degrees) specimen.

the classic manufacturing methods like jetting, extrusion, powder bed fusion, etc. The authors in the paper summarize the FDM process with PLA as material for tensile and flexural testing of the specimens. The authors propose the benefits of the FDM process as regards the cost, product quality, functionality, and manufacturing time.

Samuel Clinton Daminabo et al. [5] the authors in their paper shed light on the prospective application of 3-d printing technology in the fields of health care, manufacturing, packaging, aerospace, and automotive industries. The authors state the advantages of the fused deposition method as regards the scalability, cost-effectiveness, and range of materials for the production of components.

Hugo I. Medellin Castillo et al. [6] authors in their paper discuss the design of additive manufacturing knowledge and its influence on the additive manufacturing industry. The research work about the operation principles, shortcomings, and advantages of the FDM process is categorized into four groups as to geometry, materials, quality, and sustainability respectively to provide aid to the designers and manufacturers through case studies.

Vinaykumar S Jatti et al. [7] the authors in their paper study the influence of the various process variables such as the layer thickness, infill percentage, extrusion temperature, printing speed, etc. on the mechanical properties of the FDM produced parts. The mechanical properties like the impact strength, flexural strength, and tensile strength were observed and studied with one variable at a time approach in their study.

Jonathan Mark Holman et al. [8] the authors studied the impact of the different fill patterns, infill densities, varying shell thickness, and materials of printing on the final strength of the functional 3-d

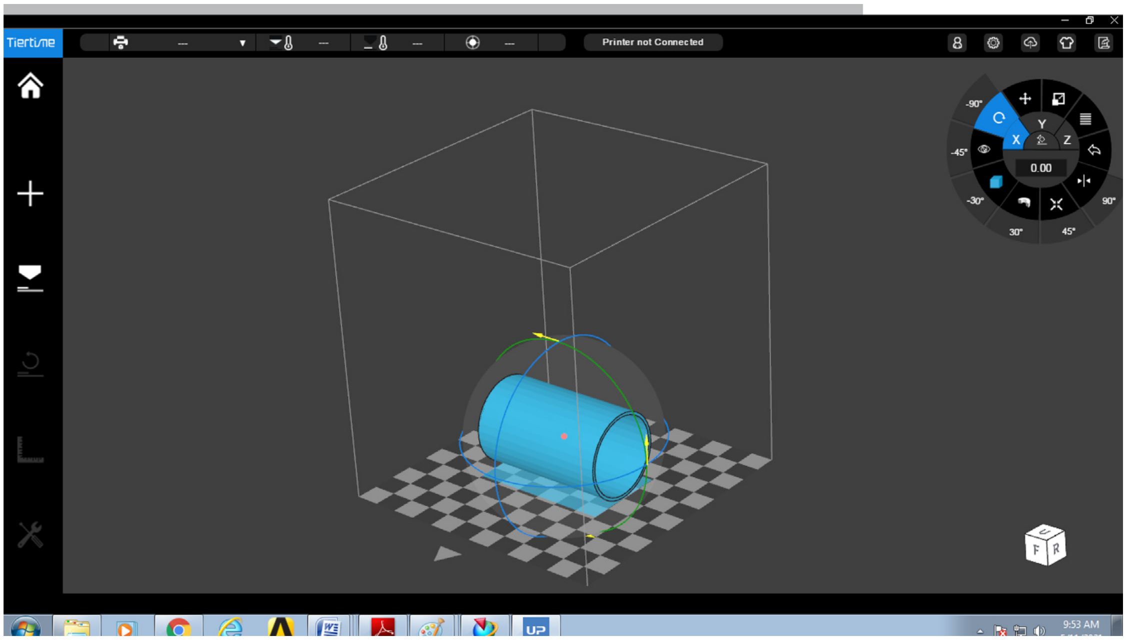

Fig. 4. GUI of UP-mini 3.0 to print the horizontal orientation (0 degrees) specimen.

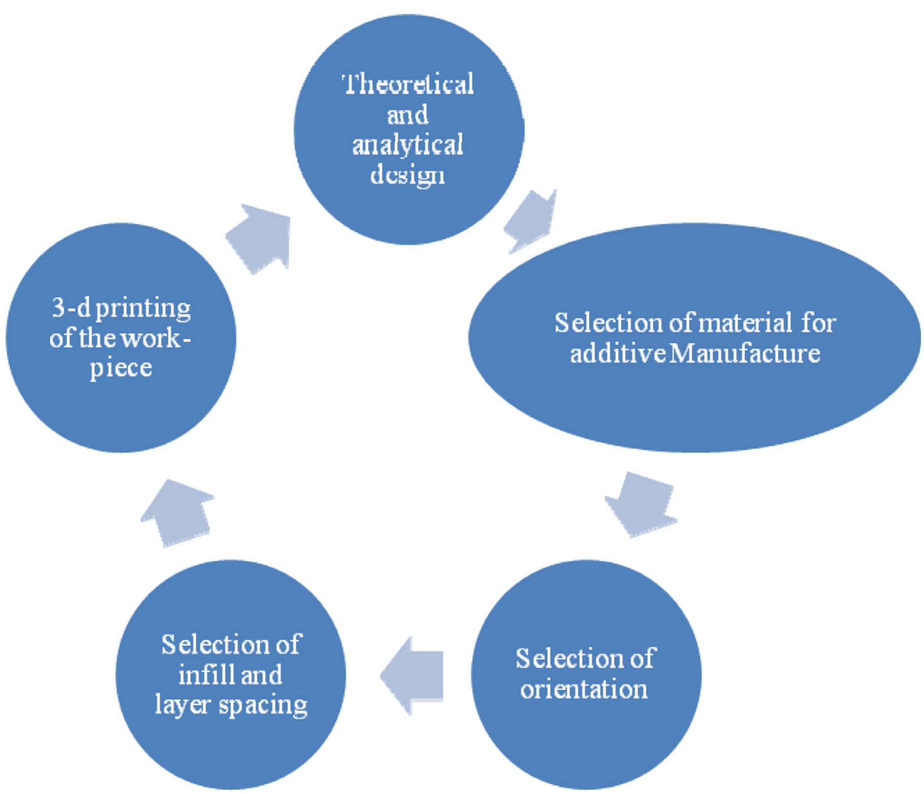

Fig. 5. Flow diagram vertical orientation (90 degrees) specimen.

printed components. The hollow shell components were converted to solid using the epoxy resin infill and thereby the comparisons of the solid printed and shell-resin components were done experimentally as well as through FEM simulation.

Salvador Caballero et al. [9] the authors focus on the application of the FDM-produced components as structural members in civil engineering applications for study under compressive, buckling, or crushing loads. The components were tested using the ASTMD695 method and the design improvements were made to enhance the capacity to handle axial loads for the components.

Carla M. Ferreira et al. [10] (2021) authors in this work studied the fatigue response of specimens to high cycle where in the specimens were prepared using ABS polymer. The shape of the specimens was solid cylinders and they were subjected to cyclic

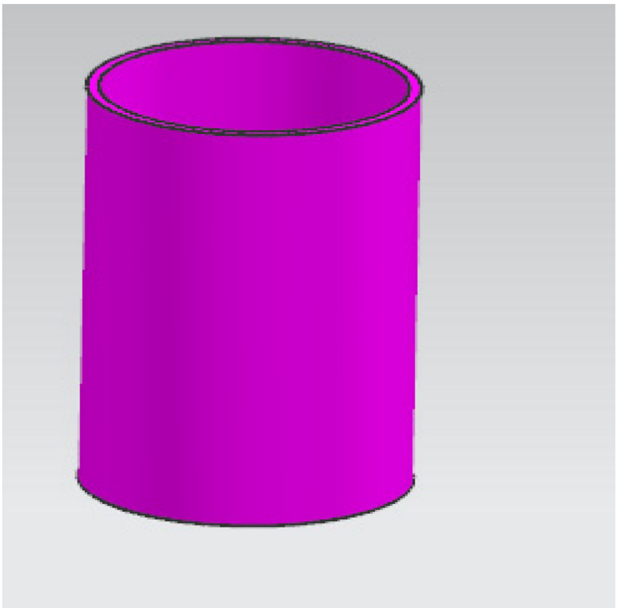

Fig. 6. 3-D CAD model of vertical orientation (90 degrees) specimen.

torsion and static loads. Different infill patterns and two or three contour variations were experimented. The authors carried out the design of experiment at seven levels and optimization was done through signal noise responses.

Mohammad Reza Khosravani et al. [11] (2022) the authors 3D-printed test coupons using poly-lactic acid material (PLA) to experimentally evaluate the effect of two printing parameters on the mechanical behavior of the specimens they used five different rater orientations. The specimens were subjected to series of tensile strength to evaluate the strength, modulus of elasticity.

Michal Korinek et al. [12] (2021) the authors in their research evaluated the mechanical behavior of the SS316L 3-d printed in vertical direction specimens. The nature of loading was monotonic and two loading paths namely tension and loading were considered. The experimental data was further used to carry out the finite element analysis of the specimens and comparison and co-relation was established in the printing parameters and strength of the specimens.

Nicholas Beattie et al. [13] (2021) the authors carried out the investigation of mechanical behavior and failure modes of 3-d printed FDM parts by changing print orientation. The specimens were prepared from ABS polymer and the tensile, torsion and bending results were documented, work showed effect of print orientation on the strength and facture of the specimens.

A Cerro et al. [14] (2021) the authors carried out design of experiment using Taguchi L16 array with three factors of printing and two levels of parameters for cylindrical parts with hexagonal heats using 3d- printing for application of part in water heater.

Nathan Ng et al. [15] (2021) the authors carried out research on print parameters of FFF 3-d printed part for custom torsional resistant parts to be applied to robotic mechanism and drive trains. The experimental evaluation of the torsion test and time each part lasts before failure was determined.

2.1. Literature gap identified

With the recent trend and continuously changing designs of the components due to frequently upgraded models, the conventional process of manufacture of these components proves costly owing to the high investment in moulds. The technology which has taken centre stage for these demanding conditions is the fused deposition or 3-d printing technology in the development and manufacture of plastic components for ready use direct assembly which bypasses the process of mould manufacture and then subsequent plastic moulding which is many times a considerable amount of production time and high production cost. The strength of the components produced by the 3-d printing method is seen to be greatly influenced by the infill density, thickness of the print layer, and print quality. The depositing parameters have been studied in various studies but they failed to characterize the geometrical arrangement permutations through the addition of internal support structures to enhance the torsion strength of the components.

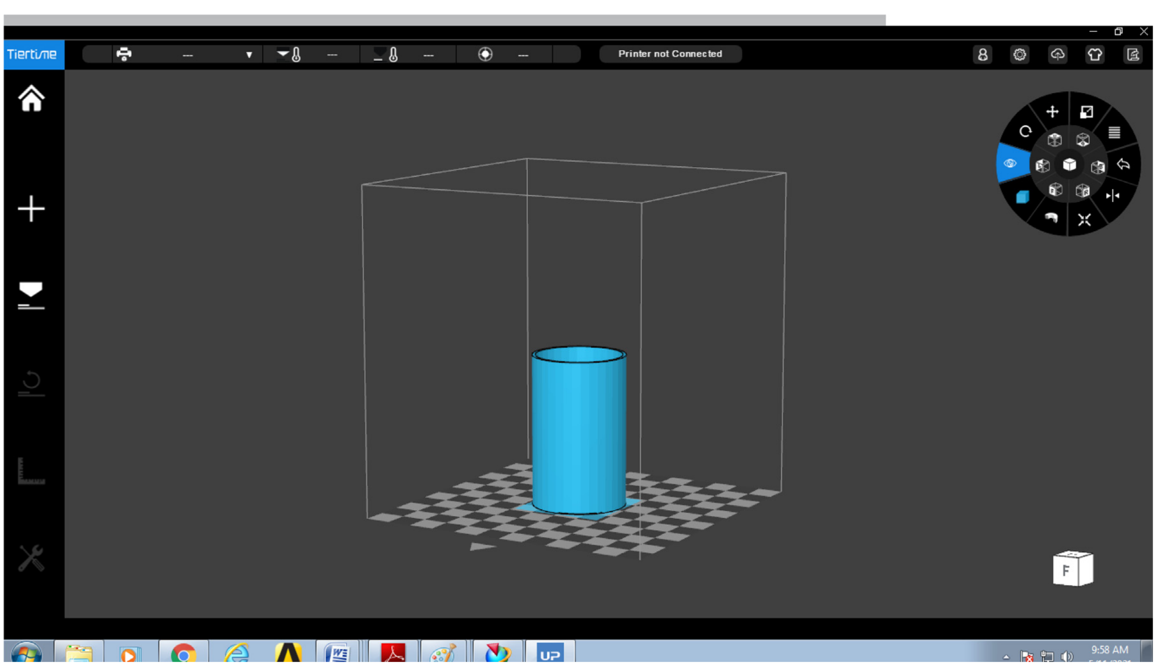

Fig. 7. GUI of UP-mini 3.0 to print the vertical orientation (90 degrees) specimen.

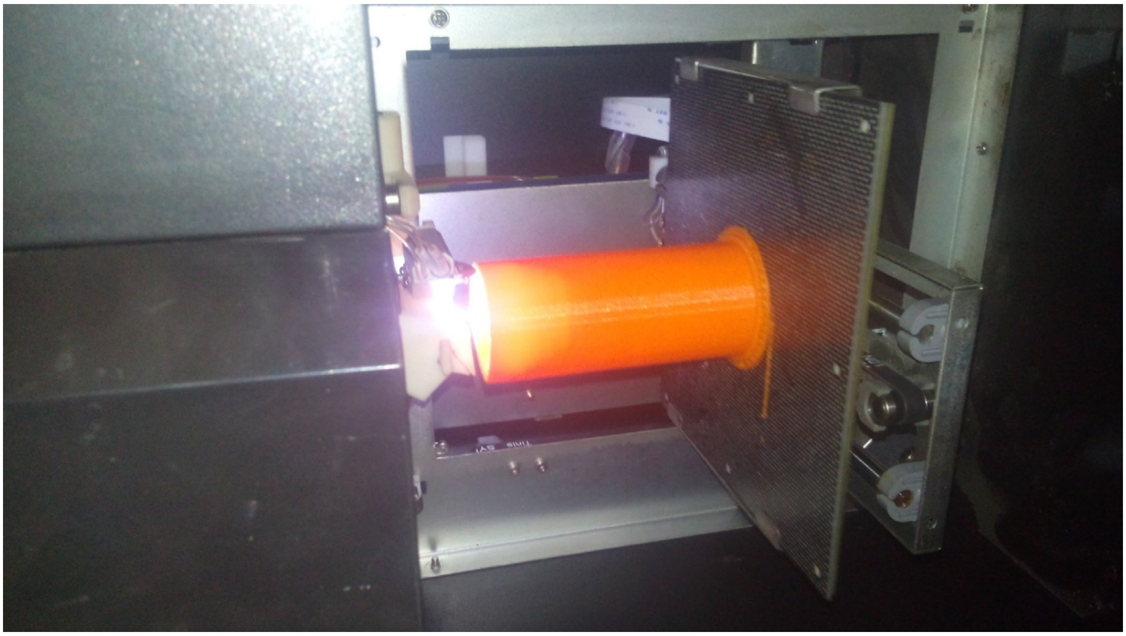

Fig. 8. Actual printing of specimen in 3-D printer.

Through the incorporation of reconfigurable internal support structures through a parametric matrix is likely to balance the strength of components produced using 3-d printing. Optimal material usage and build time can be attained by the use of this technique which needs to explore through further research.

2.2. Objectives

1. Study of effect of orientation of lay on the torsion strength of FDM produced hollow specimens.
2. Study of effect of print parameters on the torsion strength of FDM produced hollow specimens.

2.3. Hypothesis of research

a. The torsion strength of the 3-d printed hollow parts depends upon the orientation of print.

b. The torsion strength of the 3-d printed hollow parts depends upon the print parameters.

3. Methodology to be used (See Fig. 1)

3.1. Manufacturing of horizontal orientation (0 degree) specimen

In the manufacturing technique of horizontal orientation (0 degrees) specimen, we use the additive manufacture method for and the workflow is shown in the figure.(See Fig. 2)

Step1: 3-D modeling of horizontal orientation (0 degrees) specimen.

The 3-D modeling of horizontal orientation (0 degrees) specimen is done using UG-NX. (See Fig. 3)

Step 2: The stereolithography CAD file (.stl) is imported to UP-mini 3.0 software and the footplate is 3-D printed using ABS polymer.(See Fig. 4)

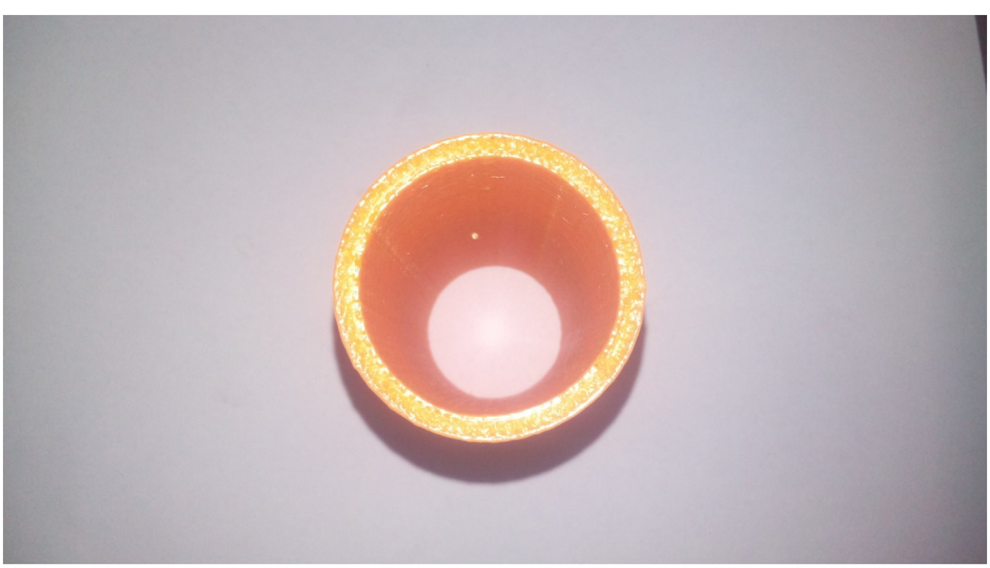

Fig. 9. Inside view of 3-D printed specimen.

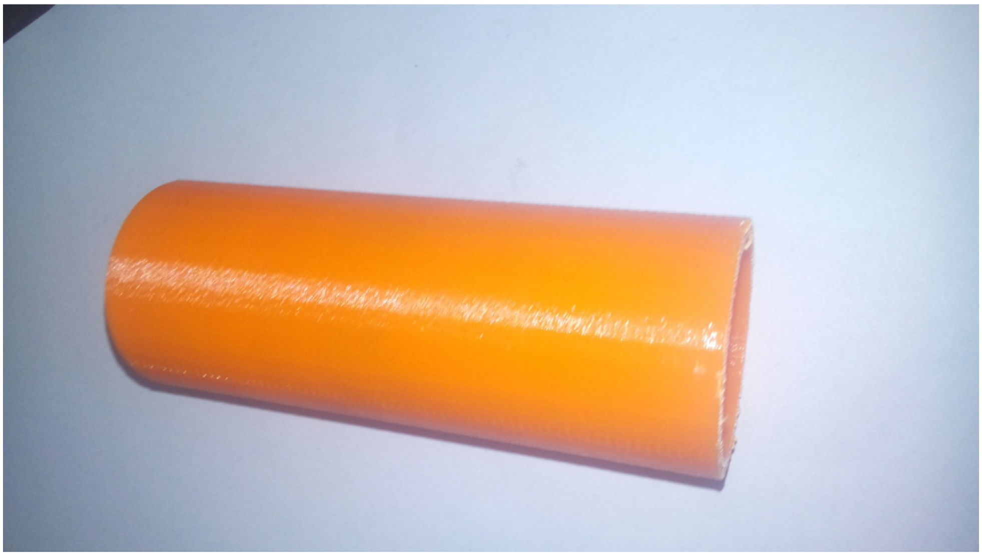

Fig. 10. Specimen after 3-D printed.

3.2. Manufacturing of vertical orientation (90 degrees) specimen

In the manufacturing technique of vertical orientation (90 degrees) specimen, we use the additive manufacture method and the workflow is shown in the figure. (See Fig. 5)

Step 1: 3-D modeling of Vertical orientation (90 degrees) specimen.

The 3-D modeling of vertical orientation (90 degrees) specimen is done using UG-NX.(See Fig. 6)

Step 2: The stereo lithography CAD file (.stl) is imported to UP-mini 3.0 software and the footplate is 3-d printed using ABS polymer.(See Fig. 7)

4. Conclusion

The 3-D printing of hollow components is discussed in the paper as an alternative to the conventional moulding process. The paper discusses a review of research work over the years proposes the first stage design and analysis of the plain component using ANSYS workbench and also the manufacturing of these plain elements with various permutations of infill density, layer thickness, and print quality. The components have been produced by the said parameters of printing which will be tested and compared for optimal deposition parameters in the subsequent work. By considering the gathered data, an optimization model that realizes the material usage, build time and strength characteristics, and their related variables will be presented and used to assist the components with optimal deposition parameters which will be further considered for design with internal support structures with the incorporation of varied parametric internal structure matrix.

5. Images of 3-D printed specimen

See Fig. Figs 8-10.

CRediT authorship contribution statement

Mahendra N. Vhatkar: Methodology, Resources, Conceptualization, Software, Visualization, Writing - original draft, Writing - review & editing. **Geetanjali V. Patil:** Supervision. **Iresh G. Bhavi:** Supervision. **Syed Abbasali:** Supervision.

Data availability

The data that has been used is confidential.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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