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Effect of infill pattern and infill density on mechanical behaviour of FDM 3D printed Parts- a current review

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ABSTRACT

Additive Manufacturing (AM) offers flexibility in customising, designing, minimising waste, faster prototyping and manufacturing complex profiles. The process parameters play a crucial role in the mechanical strength of the 3D printed product. The paper's objective is to provide a concise review of additive manufacturing techniques, focusing on the Fused Deposition Method (FDM) and its process parameters, mainly infill pattern and infill density and its effect on the physical behaviour of 3D printed parts. The article also includes the functional and industrial applications of rapid prototyping. The article's contribution is to explain to the researchers from academics and industry how and why infill density and infill pattern affect the mechanical properties of the 3D printed part.

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1. Introduction

1.1. History and development

Hideo Kodama initially introduced the concept of Additive Manufacturing (AM). Later, Charles Hull invented the stereolithography technique, which developed as the first commercial technology [1]. Additive manufacturing is the process of creating or fabricating a 3D object directly from a CAD model through layer-by-layer manufacturing [2]. In recent years, AM has attracted industrialists and researchers, and much effort has been put into this sector to develop faster and cheaper AM techniques that will help us get better print quality. These techniques produced critical and intricate products with comparatively lesser manufacturing cost and time [3]. The significant advantage of AM techniques is the design freedom for the development of new products, which is one of the limitations in the conventional manufacturing process [4]. The application of AM methods drastically reduces the lead time of product development [5].

1.2. Additive manufacturing

A CAD model is modelled using any 3D modelling platform in the conventional process. The mould development is done using the dimensional data of the CAD model. The finished part is manufactured by using the developed mould. In AM techniques, the final piece is created immediately through the CAD 3D model by eliminating the in-between processes like mould development [6,7]. Ziemian et al. [8] discussed the factors involved while converting the CAD 3D model into a 3D printed part through FDM. Fig. 1 shows the steps involved to create a 3D model with AM techniques. Various available CAD platforms are used to create 3D models. The CAD data is converted into STL (Standard Tessellation Language) format, which the 3D printer interface understands. Slicing software like Repetier®, Cura® are used to slice the STL file into subtle layers [9,10]. 3D part is produced layer-by-layer by AM technologies with set process parameters. Post-processing is performed if needed after the printing is done to improve the surface finish of the final product [11–14].

AM techniques are classified based on different methods and raw materials [15,16]. The various techniques are differentiated based on the binding or sintering techniques. The raw materials are in the form of powder, liquid, and solid [17]. The classification of AM techniques is shown in Fig. 2

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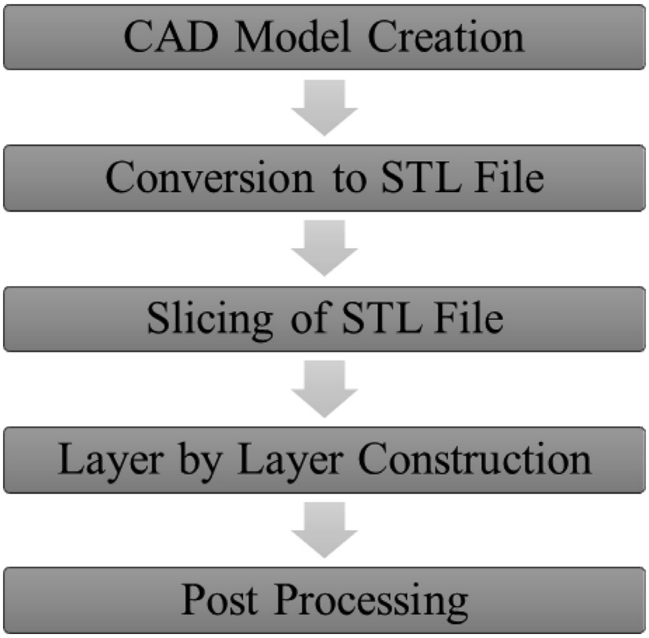

Fig. 1. General steps involved in additive manufacturing.

1.3. Fused Deposition Modelling

Fused Deposition Modelling (FDM) or Free Form Fabrication (FFF) is used extensively due to less expensive methods and raw materials [18]. In the FDM technique (see Fig. 3), a polymer filament is fed to a heated extruder to melt the filament to a semi-molten temperature which is further deposited and cools down to develop a 3D structure [10]. The degree of freedom of the extruder and platform depends on the fabrication of the printer. Generally, the extruder has movement in the z-directions, whereas the build platform moves in × and y-directions [2]. The movement of the extruder and build platform is guided by the G-code generated by the slicing software. In some FDM systems (3D printers), multiple extrusion nozzles feed polymer components, especially when composite gradient components are required [19–21]. The frequency, adjustment and performance of extrusion are highly dependent on the thermoplastic filament structures, and as a result, different 3D printers are designed for specific filament materials [22,23]. The polymers filaments of Acrylonitrile butadiene styrene (ABS) and Polylactic Acid (PLA) is mainly used due to lower melting points [24]. In contrast, polymers like Polyethylene terephthalate glycol (PETG), Polyether ether ketone (PEEK) are rarely used due to their higher melting point, which is difficult to handle [25].

The various process parameters in FDM include air gap, layer thickness, raster width, infill pattern, raster angle, infill density, etc. These parameters are essential in influencing the physical properties of the 3D printed component [26,27]. These process parameters also affect the lead time and the cost of the 3D printed part. In the initial years, the 3D printed products were used for the aesthetic purpose or feel a prototype, but with the change in time, the technology has been developed considerably, giving the freedom to replace the conventional manufacturing parts with 3D printed parts. It is essential to understand the influence of the respective process parameter on the physical behaviour of the 3D printed product, which is the objective of the review. Two process parameters, mainly infill density and infill pattern, are studied to understand the strength-to-weight performance of the 3D printed specimens.

1.4. Process parameters

Process parameters play a vital role in controlling the physical behaviour, including part strength, surface quality and accurateness of the FDM printed part. The parameters control the size, shape, build time and interior structure. The user needs to set the parameters before creating the slicing of the STL file. The primary process parameters include layer thickness, model build temperature, infill pattern, infill density, raster width, raster air gap, shell thickness, raster angle, and build orientation (see Fig. 4).

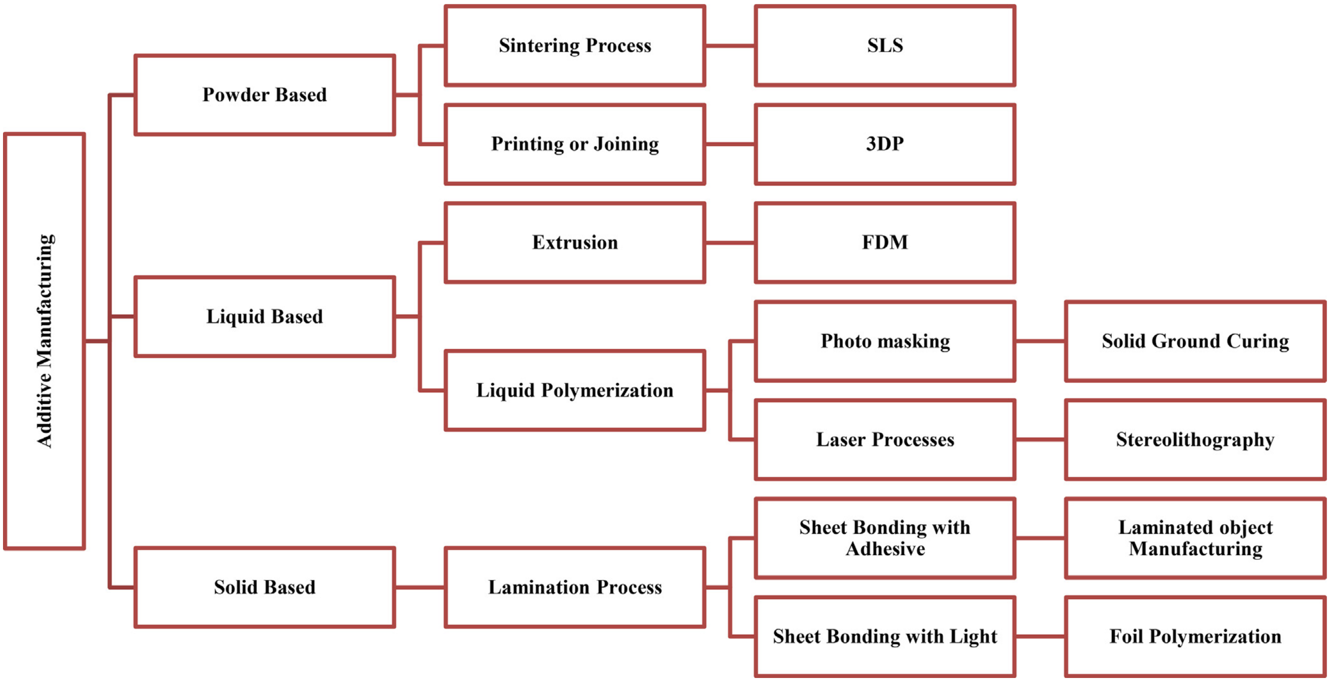

Fig. 2. Classification of Additive Manufacturing Techniques [17]

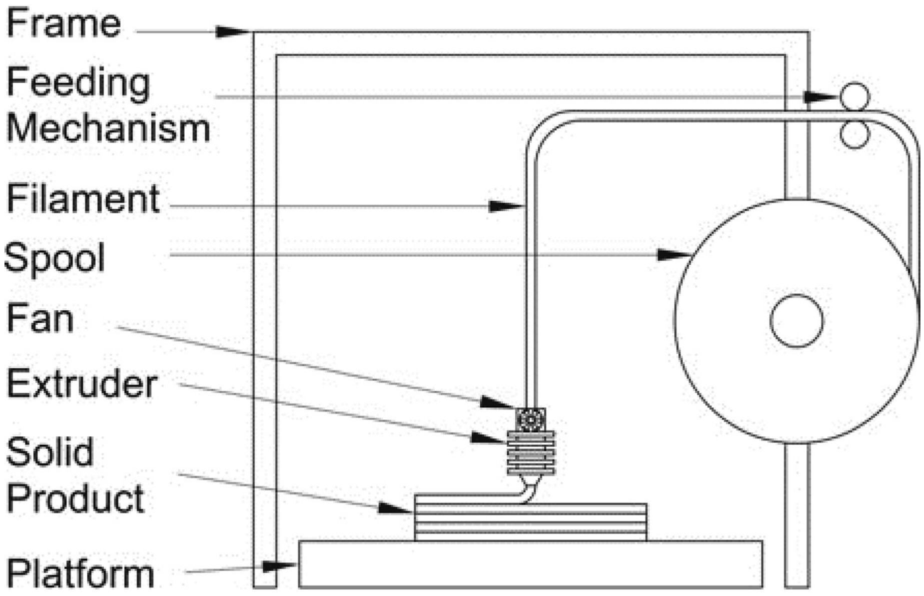

Fig. 3. Parts of Fused Deposition Modelling technique [10]

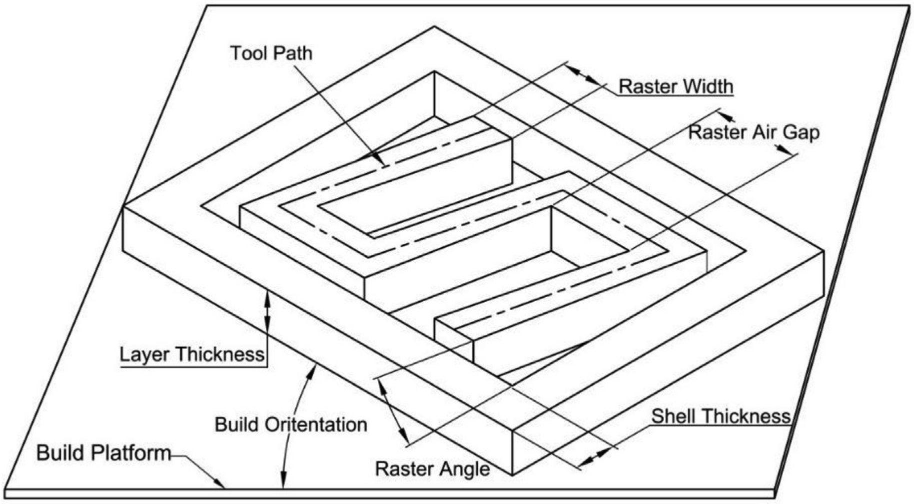

Fig. 4. Process parameters of FDM technique.

1.4.1. Layer thickness

Layer thickness can be defined as the slice height of the STL model for the part building. Layer thickness controls the motion of the nozzle or platform in the z-direction to build the next adjacent layer. The surface quality and accuracy are inversely dependent on the layer thickness.

1.4.2. Model build temperature

The temperature at which the liquefier is set to feed the semi-liquid material to the nozzle to extrude on the previously layered layer is called a model build temperature. These temperatures influence the bonding between the layers.

1.4.3. Infill pattern

Infill pattern controls the motion of the nozzle or platform along the XY direction in filling the area of the layer. The infill pattern controls the build time, amount of raw material and strength of the FDM part (Fig. 5).

1.4.4. Infill density

Infill density is the amount of material used to fill the layer's inner area. This setting can make a part either fully or partially solid. The setting of the infill density is fed in the form of percentages like 25%, 50%, 75% or 100%. It again affects the build time, amount of raw material and strength of the FDM part. The various infill patterns are shown in Fig. 5.

1.4.5. Raster width

Raster width can be defined as the width of the infill pattern used to fill the interior regions of the part. It is dependent on the tip size of the nozzle. Raster width inversely affects the part accurateness and surface finish of the specimen.

1.4.6. Raster air gap

The distance between the two adjacent rasters is defined as a raster air gap. The gap between the shell boundary from the raster fill inside the contour perimeter is called the raster air gap. If the raster air gap is negative, the two adjacent rasters will overlap.

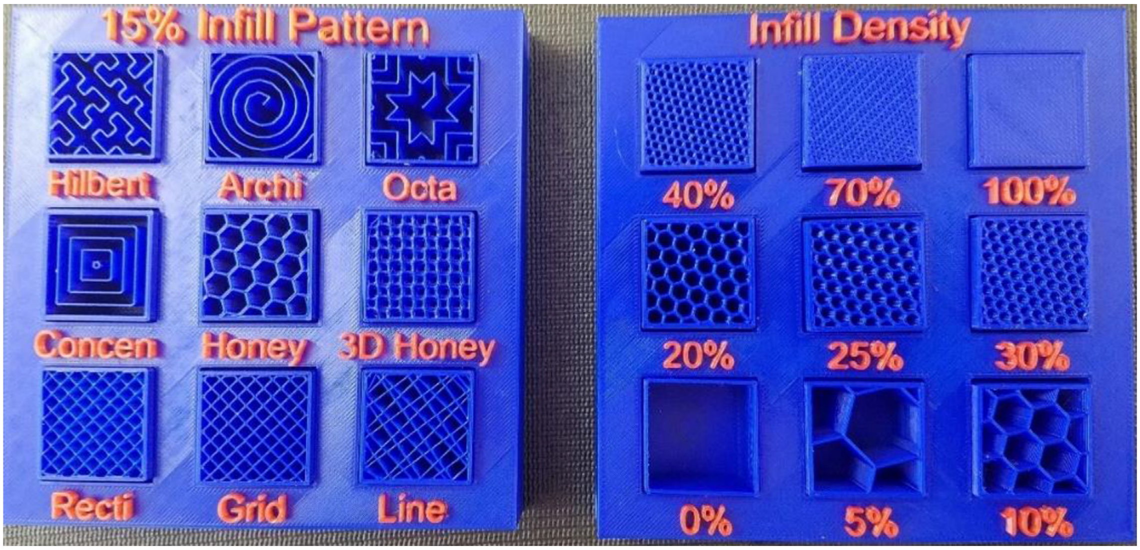

Fig. 5. Sample of various infill densities and infill patterns [28]

1.4.7. Raster angle

Raster angle is the direction of the tool path motion concerning the x-axis of the platform. The range of raster angles is between 0° to 90°, set according to requirement. If the setting of the raster angle is fixed as ± 45°, then in one layer, the direction of the tool path will be + 45°, and in the next layer, it will be –45°. Raster angle is one of the reasons that the FDM part behaviour is anisotropic in nature.

1.4.8. Shell thickness

When the nozzle or platform moves in z-direction for a new layer, the nozzle creates the boundary before filling it. Shell thickness defines the number of turns the tool will take around the edge of the layer. It is generally defined as one, two or three, i.e., the number of perimeters to be made before filling.

1.4.9. Build orientation

Build orientation is the position inclination of the part to be made. Build orientation is one of the critical parameters because it decides the support material, which eventually affects the build time, amount of support material, the surface finish, and mechanical properties. Fig. 6displays a different build orientation of the same 3D printed specimen, where Fig. 6 (a) and (b) are oriented without a support structure, while Fig. 6(c) consists of the support structure.

The article's objective is to present the effect of infill density and infill pattern on the physical properties of the 3D printed specimen developed by the FDM technique. The literature selection is based on process parameters comprising infill density and infill patterns. If any other parameters are considered, it is also discussed along with it

2. Literature review

A comprehensive literature review has been presented in this section. Additive Manufacturing main objective is to create a 3D prototype that can be either for aesthetic purposes or actual condition usage. This section gives the details and discusses the current work done to study the changes in mechanical properties by varying process parameters focusing on infill density and infill pattern. One of the main drawbacks of these techniques is anisotropic physical, resulting in limited applicability.

2.1. Investigation of physical properties of ABS specimens

Fernandez-vicente et al. investigated the strength of ABS material varying the infill pattern and density by the open-source 3D printed FDM technique. It revealed that a higher percentage of infill density resulted in a low amount of void-formation, resulting in higher tensile strength. The tensile strength is most insufficient

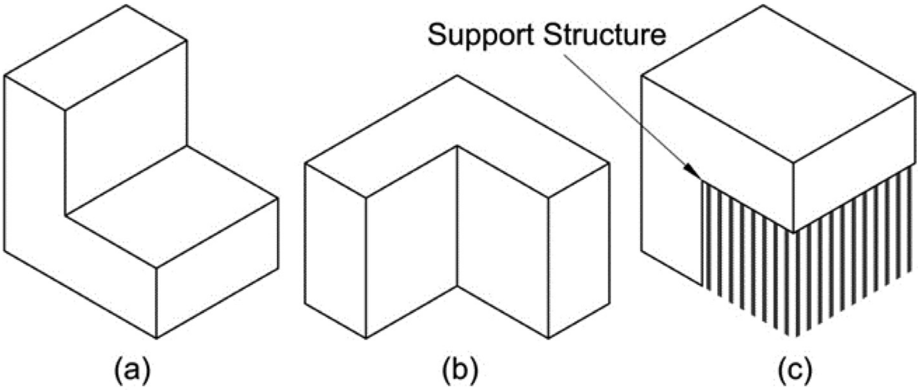

Fig. 6. Positioning of the 3D printed part with different build orientation (a) and (b) without support structure as well as (c) with the support structure.

for a rectilinear pattern with 20% infill. But for the same pattern, 100% infill density showed a tensile strength of 36.4 MPa. The honeycomb pattern showed better tensile strength on a similar density. Change in infill percentage mainly determines tensile strength [29]. Panes et al. examined the manufacturing parameter of FDM for PLA and ABS concerning the mechanical properties like infill pattern and layer thickness. The result revealed that while increasing the layer height (0.1 to 0.02), the strength decreases by 75% for ABS and 11% for PLA. The tensile strength increases due to incremented infill pattern (50%) by 25% for ABS and 27% for PLA [30]. Samykano et al. examined three process parameters: raster angle, layer height, and infill density, which have been considered to affect the mechanical properties of ABS. It was revealed that the elastic modulus, yield strength, ultimate tensile strength, fracture strain and toughness with 80% infill percentage, 0.55 mm layer thickness and 650 raster angle are 31.57 MPa, 774.50 MPa, 19.95 MPa, 0.094 mm/mm and 2.28 J/m^3, respectively. This phenomenon happens because the strength composition is correlated with the specimen to oppose the tensile strength. Due to this raster angle shows the maximum value. The layer thickness is an essential factor to reach the maximum tensile strength because this creates less distortion on the specimen. Layer height indirectly improves the mechanical strength due to temperature gradient [31].

Palanisamy et al. carried out a comprehensive review of the PolyJet, and FDM printed parts on the mechanical properties. In fused deposition modelling, the specimens with higher infill density (100%) offer more bonding between layers and are more resistant to deformation due to a lesser air gap. The results showed that infill density and raster angle must be optimised for better properties in the FDM part. The part formed in the x-direction showed better mechanical properties like hardness, compression, and tensile strength. Mechanical properties were affected by post-processing, built direction and type of finish [19]. Motaparti et al. investigated different processing parameters of standard FDM, i.e., air gap, build part orientation and raster angle. The compressive properties (modulus strength and yield strength) were tested, and ABS material was used to manufacture the sample. The result revealed a higher compressive strength at the horizontally build-orientated part and comparatively lesser strength at the vertically orientated position. A change in build orientation and the process parameters had to be made to maximise the compressive strength [32].

2.2. Investigation of physical properties of PLA specimens

Chacon et al. examined the effect of build orientation, layer thickness and feed rate of PLA material. It showed that the most favourable mechanical performance is observed on strength. Upright specimen displayed inter-layer failure and lower strength. Meanwhile, the on-edge specimen showed *trans*-layer failure but higher strength. With the increase in layer thickness, ductility decreased, while the flexural and tensile strength decreased with increased feed rate. The complex geometry's functional assembly affected the different stress states induced during the test [33]. Abbas et al. discovered the effect of infill density on compressive strength in an FDM specimen made of PLA. The result indicated that, at 20% and 80% infill density, compressive strength was 20.5 and 30 MPa. Also, parts built with 90-degree build orientation had higher mechanical strength. Lower infill increases the building speed significantly. The nozzle must take more distance, with the rectangular size being small to print the same specimen with the high infill percentage [34]. Tanveer et al. investigated that the tensile strength and impact strength of a PLA specimen printed by an open-source 3D printer is affected by infill density. The result indicated that the single infill density has less tensile strength than the multiple infill densities. These arrangements also help reduce raw material to some extent, and it is also true in the case of impact strength, where higher infill density gave a higher impact strength. In the case of variable infill density, tensile strength can be increased by keeping the denser infill layer on the outside, while impact strength can be increased by keeping the more viscous layer on the inside [35]. Rajpurohit et al. examined the impact strength of a FFF fabricated PLA on the parameters - raster angle, raster width and layer height. The experiment revealed that raster angle was the main component of the process parameters that influenced the impact strength. The higher impact strength was found at 0° raster angle, and the value kept decreasing with the increase in raster angle. The highest impact strength was found at a 0° raster angle with 700 μm raster width and 300 μm layer height. At the crack front, the weak intersection between the layer, the amount of absorbed energy by 900. The layer thickness may be thick to get the higher impact blow. The more increased thickness achieves better strength due to the interfacing bonding. Better adhesion between the adjacent raster helps obtain desirable impact resistance [36].

Yadav et al. evaluated the compressive strength of PLA specimens made with FDM with different infill patterns and infill densities. The Hilbert curve showed 121.35 MPa (maximum compressive strength), Line (73.84 MPa), Rectilinear (78.88 MPa), Honeycomb (62.56 MPa), Octagram spiral (60.01 MPa), Archimedean (70.07 MPa), at 80% infill density. It showed that the compressive properties of PLA printed specimens increase with a higher infill percentage. The roughness of the surface decreases for rectilinear patterns. Compared to other patterns, the rectilinear pattern shows the least roughness value at 20% infill density [37]. Gunasekaran et al. (2020) investigated the effect of process parameters of 3D printing on impact, hardness, flexural, and tensile strength of materials. The result revealed that by increasing infill density, the physical properties of the printed specimen improved at 25% and 100% infill density, the projected value of hardness, impact, tensile, and flexural strength are found to be – 73 HRC, 61 J/m^2, 39 MPa, 42 MPa and 97 HRC, 53 MPa, 70 J/m^2, 53 MPa, respectively. The specimens were printed in the x-direction, therefore, having better flexibility. A minimum layer thickness leads to an excellent layer bonding at high infill density. Due to the increase in infill density, the mechanical strength increases because of inter-layer adhesion between two consecutive layers [38].

Aloyaydi et al. investigated the mechanical behaviour of 3D printed specimens by varying infill density and performing the low-velocity compression test and impact test. The result showed that the triangular pattern displayed the penetrating energy of 7.50 J and 1190.5 N peak force. These results presented that the type of infill patterns impacts the mechanical properties. The triangular infill pattern had more sheared/contact points per unit area; therefore, it performed better than other patterns. Hence, a triangular infill pattern with 60% infill density (40% porosity) is most suitable for bio- implant or tissue part. The performance of each infill pattern depends on the number of contact points for that pattern [39]. Ezeh et al. determined the effect of non-zero mean stress and raster angle on the behaviour of an additively manufactured PLA specimen. The results obtained from the experiment showed that the manufacturing direction could be neglected because it had little to no impact on the specimen's accuracy and overall strength. Also, how the static stresses affect an FDM PLA specimen fatigue strength can solve the design problem of max stress in the cycle [40]. Yao et al. studied the ultimate tensile strength of a PLA specimen according to ISO 527–2-2012 standard. Printing angles of 0, 15, 30, 45, 60, 75, 90°were taken along with layer thickness of 0.1 mm, 0.2 mm and 0.3 mm for each angle. The specimen used in this instigation was printed by a MakerBot Replicator 5 + desktop 3D 126 printer with a PLA filament diameter of 1.75 mm. The tensile speed of the universal tensile machine was kept at 0.1 mm/min and the temperature at 23° Celsius. The results indicated that the tensile strength of the sample kept on decreasing with the increase in layer thickness. An interlayer fracture was likely to occur while testing the sample at increasing layer thickness. The ultimate tensile strength was also reduced by decreasing the printing orientation [41].

Mishra et al. (2021) investigated the different infill densities and patterns to examine the absorbed energy of 3D printed PLA components during plastic deformation. The result demonstrated that energy absorption was maximum at 85% infill density for each infill pattern. The impact strength does not increase linearly with infill density, as observed at 100% infill density. The resistance region is continuous and compact; therefore, crack propagation is more than 85% infill density. The stress concentration factor was not optimum for a concentric pattern as this pattern can't withstand even low energy and can easily be fractured [42]. Patil et al. investigated multiple optimisation scenarios to enhance the process parameters of an FDM 3D printed PLA sample. Although infill pattern was the primary focus of this experiment, other parameters used were infill percentage, layer thickness and printing speed. The analysis was done based on surface roughness, printing time and filament consumed in the experiment. Specific parameters used in this investigation were – 70% infill percentage, 0.2 mm layer thickness, 100 mm/h of printing speed and triangular pattern. The result concluded that infill percentage had the highest and printing speed had the lowest effect on the performance of the 3D printed FDM part. Layer thickness and infill pattern also showed significant influence on the characteristics of the part. A 12.560 μm of surface roughness was found with 4.22 m of filament consumed in 88 min of printing time [43]. Farazin et al. investigated the effect of three important process parameters on a PLA sample's tensile properties: infill density, layer thickness, and printing speed. The obtained results from the experiment showed that at high infill density, the sample had a low degree of strain fracture and increased brittleness. A density of 40% was more suitable in providing appearance and shape in specimens, where strength was not the primary requirement. It was also seen that by reducing the thickness of the layer, the specimen became extremely brittle but increased surface finish and accuracy. Printing speed had less impact on the mechanical property than other process parameters [44].

2.3. Investigation of physical properties of Composite specimens

Lebedev et al. carried out a comprehensive review on the mechanical properties of PLA based composite material. The effect of filler content and deposition angle was measured. The results showed that the mechanical properties were affected by both these factors. The addition of fillers increased young's modulus and a decrease in yield strength, and expanding the filler further decreases the latter by 7% [45]. Nadernezhad et al. studied the effect of process parameters and mechanical strength for PLA/ NCT (Polylactic acid/ carbon nanotube) of nanocomposites. The sample was manufactured with the help of the FDM process. The result showed that, while increasing the layer thickness, the mechanical properties of the sample decrease, and with the increase in infill percentage, mechanical properties are enhanced. In mesostructured, the infill pattern played an important role in load transfer. Higher mechanical strength and thermal stability were observed with the honeycomb pattern [46].

Torre et al. determined that specimen buckling initiates from a slenderness ratio of approximately 9.5. The result from the specimen showed linear elastic behaviour, broke abruptly after slight deviation, and proved to be excessively brittle. It also verified that the critical load would decrease with an increase in slenderness ratio [47]. Samykano evaluated the tensile properties of 27 specimens with varying combinations to examine their tensile properties. The investigation revealed that the ultimate tensile strength increases with increased infill density. The tensile values for the favourable printing parameter were 0.08012 mm/mm - fracture strain, 28.45150 MPa – ultimate tensile strength, 20.19923 MPa - yield strength, 828.06000 MPa - elastic modulus, and 1.72182 J/m^3 – toughness. A high infill density has a higher ultimate tensile strength because more material is present to withstand stress internally efficiently. Tensile strength is found to be maximum at lower layer height. However, no relation can be found on ultimate tensile strength by layer height and raster angle [48].

3. Summary and discussion

The summary of the description physical properties of parts fabricated by the FDM technique is discussed and represented in Table 1. Various studies on physical properties by altering the printing process parameters can be seen. Optimum process parameter conditions for the excellent physical properties have been attained for several FDM supporting materials. However, lesser work has been found comprising computational studies of the physical properties of specimens manufactured by the FDM process.

Infill density and infill pattern influence the mechanical properties of the 3D printed part. With changes being made in these process parameters, the structural strength of the specimen varies. An increment in infill density increases the tensile strength and the compressive strength of the material. The lower infill density creates an air gap (also known as mesostructure) between the layers, which results in variation in the component's strength. Mesostructures create vents between printed structures that act like crack propagators under tensile loading whereas loading absorbers in compression. The geometry of the mesostructure depends on parameters like infill density and infill pattern. The increase in strength of the specimen increases the weight and printing time of the sample. Experimental work has been done to get the specimen's optimal strength to weight ratio. Variable density in sandwich form is used to optimise the strength-to-weight.

4. Application of Additive manufacturing

Since its introduction in the mid-1980 s, Rapid Prototyping (RP) has become an extensively used technique satisfying the needs of a wide variety of industries ranging from medical to musical [49]. RP's versatility and rapid tooling have turned it into a process employed in various applications. Some of the most famous applications are listed below:

4.1. Medical industry

The demand for rapid prototyping is on the rise in the medical industry.

RP can design and manufacture new medical products from surgery planning to custom implants. Other fields using RP include oncology, orthopedic, diagnosis [50].

4.2. Mechanical industry

Rapid prototyping in mechanical engineering is used to manufacture large mechanical parts. RP provides easy flow analysis and helps identify stress concentration points. It has extensive scale application in the automotive and aerospace industry [51].

Table 1
Summary of physical properties characterisation in FDM technique.

Investigator name	Material	Process parameter	Mechanical properties
Fernandez-vicente et al. [29]	ABS	Infill pattern and density	Tensile strength
Motaparti et al. [32]	ABS	Air gap, build part orientation and raster angle.	The compressive properties (modulus strength and yield strength)
Abbas et al. [34]	PLA	Infill density	Compressive strength
Chacon et al. [33]	PLA	Build orientation, layer thickness and feed rate	Ductility, flexural and tensile strength
Lebedev et al. [45]	Composite material	Deposition angle	Young's modulus and yield strength
Panes et al. [30]	PLA and ABS	Infill pattern and layer thickness	Tensile strength
Nadernezhad et al. [46]	Composite material	Layer thickness and infill percentage	Young's modulus and tensile strength
Ezeh et al. [40]	PLA	Raster angle	Static stresses and fatigue strength
Tanveer et al. [35]	PLA	Infill density and percentage	The tensile strength and impact strength
Yao et al. [41]	PLA	Printing angles and layer thickness	Ultimate tensile strength
Samykano et al. [31]	ABS	Raster angle, layer height, and infill density	Elastic modulus, yield strength, ultimate tensile strength, fracture strain and toughness
Aloyaydi et al. [39]	PLA	Infill patterns	Compression test and impact test
Gunasekaran et al. [38]	PLA	Infill density	Hardness, impact, flexural, and tensile strength of materials
Rajpurohit et al. [36]	PLA	Raster angle, raster width and layer height	Impact strength
Torre et al. [47]	Composite material	Slenderness ratio	Elastic behaviour
Yadav et al. [37]	PLA	Infill patterns and infill densities	Compressive strength
Farazin et al. [44]	PLA	Are infill density, layer thickness and printing speed	Tensile properties
Mishra et al. [42]	PLA	Infill densities and patterns	Impact strength
Patil et.al [43]	PLA	Infill pattern infill percentage, layer thickness and printing speed	Surface roughness, filament consumed
Palanisamy et al. [19]	ABS and PLA polyether-ether-ketone and polyetherimide	Infill density and raster angle	Bonding between layers and resistance to deformation
Samykano [48]	Composite material	Infill density	Tensile strength, fracture strain, ultimate tensile strength, yield strength, elastic modulus, and toughness.

4.3. Electrical appliances

Rapid prototyping is used to generate specific contours in modern-day electrical items. Nearly all electronic household items are designed and manufactured using RP techniques. It also has a vast impact on low volume manufacturing [52].

4.4. Instrumental application

RP technologies are used in the fabrication of acoustic instruments. Musical instruments like flutes have been previously designed and manufactured using FDM and PolyJet processes [53].

4.5. Footwear design

Complicated designs of footwear can be achieved using RP techniques. 3D printed items are lightweight, strong, and more reliable than conventionally built models [54].

4.6. Concept models and functional prototypes

RP lets the user create a physical concept model that can demonstrate the design and validity of the product. It also allows us to develop prototypes to understand better the product's fit, function, and manufacturability. A functional prototype balances aesthetics and usability while proving that the product can be economically feasible [55].

5. Future work

The article has given away a review of current work done by researchers on FDM techniques and their limitations. Additive manufacturing has great potential in the existing industrial era, but a significant limitation is that available material can withhold real-world situations. Surface quality is poor and is dependent on various manufacturing parameters and raw materials. The strength of 3D printed parts exhibits anisotropy properties, which heavily depends on the process parameter. Additive Manufacturing has proved to be an excellent technology for prototyping but still needs to improve much for the real-life working conditions. It was observed in the article that the physical properties of 3D printed parts were heavily dependent on the process parameters and various attempts made by most of the researchers to optimise the process parameters employing varying statistical tools. However, only the literature discusses the FDM technique; more techniques and various other raw materials can be addressed. Several works other printing process parameters are available, but as it may, there is a wide gap between a real edge work of computational and exploratory examination.

6. Conclusion

The article gives an overview of AM techniques and their classification. The steps involved in AM technique and its advantage over the conventional manufacturing process. The FDM technique and its process parameter, mainly infill density and infill patterns, are discussed. The effect of infill density and infill patterns on the mechanical behaviour of the 3D printed parts. The infill density and infill pattern are a crucial factor for the strength of 3D printed specimens as it affects the strength-to-weight. Infill density is directly proportional to strength, whereas the rectilinear pattern is the strongest. Flexural and tensile strength decreases with the increase in feed rate. Stacking layers of different infill percentages creates a higher tensile strength value. The more increased thickness reaches better strength due to the interfacing bonding. Better adhesion between the adjacent raster helps obtain desirable impact resistance. With the rise in infill density, the physical behaviour of the printed specimens is improved because of inter-layer bonding between two consecutive layers. The design of infill patterns during printing impacts the mechanical properties. The triangular infill pattern had more sheared/contact points per unit area; therefore, it performed better than other patterns. The samples with higher infill density (100%) offer more bonding between layers and are more resistant to deformation due to a lesser air gap. Following observations can be attained from this review

- An increase in infill density increases the mechanical strength of the part due to inter-layer bonding between consecutive layers.
- Lower infill density increases build speed and decrease the amount of material required.
- A high level of tensile strength can be obtained by stacking layers of different infill densities, resulting in lesser raw material.
- The honeycomb pattern showed better tensile properties at 100% infill than the rectilinear pattern.
- Impact strength increases, and tensile strength decreases by increasing the layer thickness.
- Printing speed showed less impact on the part's mechanical properties than other parameters.
- A horizontally built part showed better compressive strength than a vertically built part.

It is essential to take optimum infill density to balance strength, building cost, and time. It is beneficial to take variable density according to requirements. The mesostructured can be adjusted according to loading conditions by selecting variable density. It can be concluded that the parameter of infill density and infill pattern needs to be set smartly to get the optimum result

CRediT authorship contribution statement

Md. Qamar Tanveer: Conceptualization, Formal analysis, Supervision. **Gautam Mishra:** Writing – original draft. **Siddharth Mishra:** Writing – review & editing. **Rohan Sharma:** Writing – review & editing.

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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