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REVIEW

Review on multi-objective optimization of FDM process parameters for composite materials

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Abstract

3D printing is a process used in many industrial sectors like automobile, aircraft, buildings and several medical fields to fabricate products.Fused deposition modeling is a type of 3D printing processes also known as fused filament manufacturing. Two main response parameters must be considered when using FDM to manufacture parts: Part strength and dimensional accuracy. Though FDM is a popular method for producing complicated geometric products in a less time, it has limitations, including poor mechanical characteristics and dimensional accuracy. An extensive review is carried to know the influence of following process variables on mechanical characteristics such as Thickness of layers, Printing speed, Extrusion Temperature, Infill Density, Infill Patterns, nozzle Diameter, raster Angle, build orientation. It is crucial to choose the best possible combination of process parameters. The FDM process parameters can be optimized using a variety of strategies. As a result, a comprehensive review has been presented on pre-processing to examine the characteristics for printed parts. The two components of study are critical for increasing overall characteristics, i.e., improving functional utility and enriching the uses of FDM printed parts. The current report meant to provide basic assistance and guidance to researchers working on the subject of FDM Process Parameters.

Keywords Fused deposition modeling · Process parameters · 3D Printing · Optimization · Extrusion · Composite

1 Introduction

The ability to manufacture smart materials is crucial to their widespread adoption. There are many different types of smart materials and ways to make them. However, many conventional approach come in the semiconductor based casting production, which stay costly, slow, and labor-intensive. The urgency of cost effective sensing and intellectual systems for the upcoming energy and industrial growth has fueled the exploration to new low-cost methods of generating smart mechanisms and methods from smart materials. The increased complexity of 3D printing devices and the accessibility for new advanced materials have fueled interest in additive manufacturing (AM) as a viable substitute to conventional techniques for producing smart material in recent years [1]. Smart materials have a set of join properties that allow them to display behaviors that span several physical domains [2]. Electrical, chemical, thermal, mechanical and magnetic domains are only a few cases of different physical domains in advanced materials research. Figure 1 illustrates a possible link between four of these domains.

Extrusion-based 3D printing has been referred to as fused deposition modeling (FDM) and has been regarded as maximum cost-effective 3D printing method. Its building ingredients are thermoplastic polymers that come from filaments. A part has been made in FDM by depositing melted material in a path defined by the CAD model layer by layer. FDM has been extensively used 3D printing technologies worldwide because of its excellent precision, lower production cost, and large material availability [4]. Related to its other expensive substitutes, like SLS, FDM has been the best

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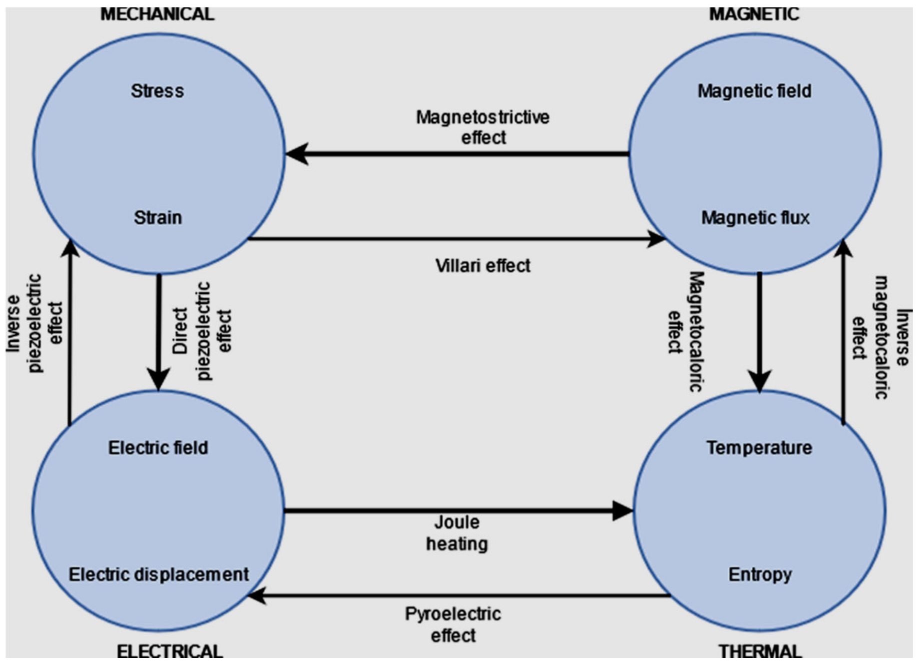

Fig. 1 Visual illustration of the coupling between some domains [3]

solution as soon as the requirement has been from a single unit to a small batch.

Furthermore, the construction material has been less expensive and generally available, making prototyping, re-prototyping, and design modifications not as much of costly to print than extra tools. Coloring and surface texture costs are also decreased because the prints are colored and have a good surface texture right out of the printer, eliminating the need for post-processing. In the process, the prints generates by melting and solidifying the filament, there has been not any danger of wastage, unlike MJF or SLS [5], which use powder and are disposed to wastage. FDM can print a wide range of materials, from low to high strength (in increasing order of tensile strength: (Polycarbonates (PC), Polypropylene (PP), Thermoplastic Polyurethanes (TPU), Nylon polyamide Polyethylene terephthalate glycol (PETG), Acrylonitrile butadiene styrene (ABS), Polylactic acid (PLA)) over ten different types of plastic filaments [6]. Another advantage has been readily available on the market at a low cost. However, the surface finish of FDM produced items has not been as fine as that of SLA or Carbon DLS resin printed parts. As FDM mechanism by layering liquefied plastic, the tread casing has been visible, looks rough and was found to be anisotropic. Thus, post-processing has been required to smooth the surface, which adds to the expense [7]. FDM has been unquestionably a solid choice for prototyping when minute details aren't critical. FEM technology wildly used in automobile applications such as: Bumpers, valves, dashboards etc., biomedical applications such as: dental implants, knee replacement etc. smart homes, stationeries and teaching utilities, besides innovative presents due to its ease of usage, and lower fabrication rate [8] (Figs. 2, 3, 4).

Polylactic acid (PLA), due to its lower melting point, softer, and decent biocompatibility, has been extensively used materials in FDM technology [9]. PLA is biodegradable, and thermoplastic has been utmost cutting-edge material produced to numerous applications [10]. PLA has the potential to be used in medicinal applications due to its biocompatibility and lack of metabolic toxicity. Presently, in the world of 3D printing, FDM 3D-printed PLA parts are a key research area [11].

2 Process parameters affecting mechanical properties of printed parts

The present works summarize the various parameters, i.e., Print Speed, Extrusion Temperature, Infill Pattern, Raster Width, Air-Gap on Compressive, Impact Strength, Layer Thickness, Build Direction, and Raster Orientation affects the FDM process for plastic products.

2.1 Thickness of layers (LT)

The layer requirement generally impacts heat dissipation (which determines part strength) and construction time. According to theory, if the influence of LT is studied independently of the additional factors, it has two opposite properties. Consequently, the number of layers is lowered when the LT increases and the distortion effect is minimized while the strength is enhanced. Though, growing the layer thickness

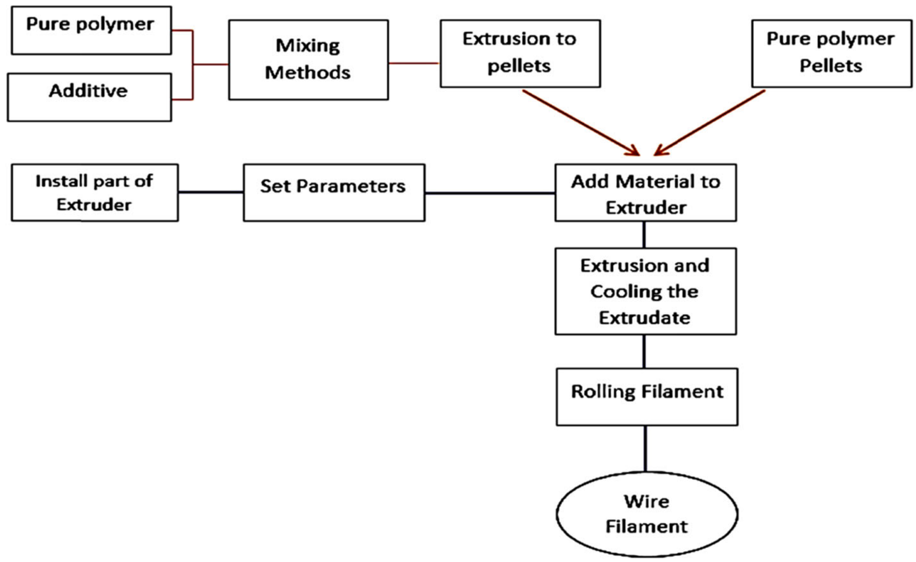

Fig. 2 Filament workflow

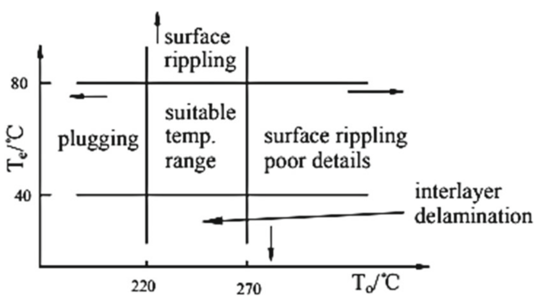

Fig. 3 Suitable zone for T_o and T_e [12]

makes a staircase pattern on the substance, resulting in poor texture and accuracy [12].

Once the layer thickness has been reduced, and the quantity of layers is increased, heat transmission from the upper to the lower layers causes the temperature at the bonding contact to rise (Suitable T_o and T_e diagram is shown in the figure). As a result, correct diffusion occurs across adjacent rasters, increasing the strength. Increasing the number of layers, on the other hand, raises the total heating and cooling cycles, resulting in increased residual stress. This can lead to part delamination, deformation, and interlayer cracking, diminishing strength [13]. The layer thickness is defined as a range among zero and the nozzle diameter employed in theory. Though, to ensure secure adhesion between consecutive layers, the layer thickness should be less than the nozzle diameter [12]. It has been observed that they theoretically are as thin as 0.01 mm even when the nozzle diameter is 0.5 mm, but it isn't desirable because of the long build time. Compared to other parameters such as part orientation and shell thickness, the effect of layer thickness, as discussed in one literature, contributes to roughly 85% of the accuracy of FDM-produced parts [14]. A 0.1 mm layer thickness takes a majority considerably with 0.2 mm for better tensile strength of printed parts where build time is not a concern [15]. The figure shows the % of research study has concerned with other parameters.

2.2 Printing speed

WPC components' morphology and mechanical properties have been studied for the 30–70 mm/s printing speed [16]. With increasing printing speed, the printing time decreased; and small amount of difference is observed in the time savings in irrelative work envelope of the printed WPC part at some specific speed. Furthermore, the tensile and flexural properties of the printed WPC part were not affected by the printing speed. In contrast, the compressive strength along with the modulus printed part (FDM) declined by 34.3% and 14.6%, respectively, when the printing speed was raised from 30 to 70 mm/s. The Fig. 5 shows the SEM image of micrographs of surface morphology at various speed of the printed parts.

To determine the feasibility of eigenvalue analysis for fused deposition modelling additive manufacturing, measurements done in the experiments performed on fused deposition modelled parts were compared to eigenvalue analysis results for an idealized part having homogeneous properties [17]. The print speed was increased by 1.5 times and then decreased by 0.5 times. The faster build resulted in a surface finish having low quality, and the principal FRF peak was raised to 4726 Hz, as shown in the Fig. 6. The Young's modulus of these FDM constructions differs from the values mentioned literature performed simulation by Solid works.

Extrusion efficiency the quantity of actually extrusion plastic over evaluated amount (EE) is the first factor. The combined influence for extruded temperature and printing

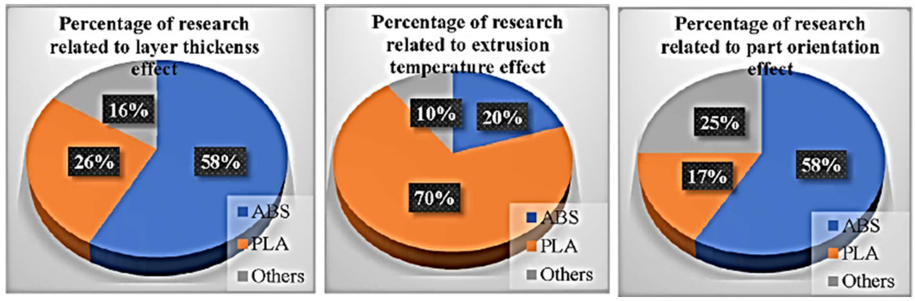

Fig. 4 The % of research carried out (a) the effect of layer thickness parameter, (b) the effect of extrusion temperature parameter (c) the effect of part orientation parameter on dimensional accuracy using different resins [14]

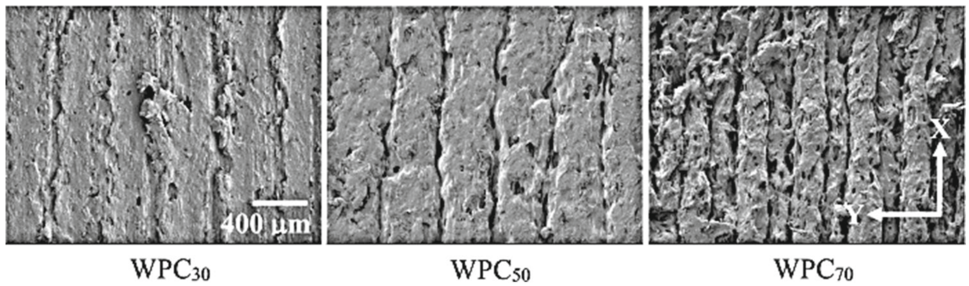

Fig. 5 shows the SEM image of micrographs of surface morphology of WPC printed parts at the various speed [16]

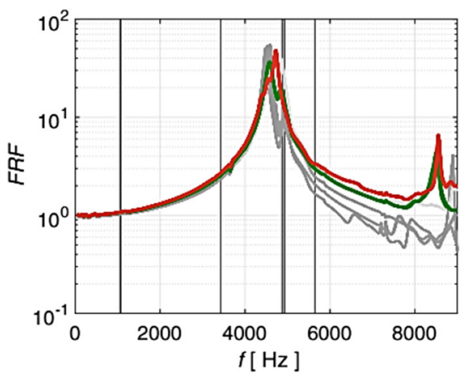

Fig. 6 Frequency response function for Build # 1–3 (dark gray), 4 (light gray), 7 (red), and 8 (green). Vertical lines at resonant frequencies are predicted by Solidworks Simulation [17]

speed determines its value. The other parameter like temperature set by the earlier layers (sub-layer), depend on various coefficient over other factors taken for study [18]. Colour figure online.

2.3 Extrusion temperature

If appropriately set, the extrusion temperature can have a favorable impact on a part's mechanical qualities. Fusion among the fresh and earlier layer occurs already cooling of the extrusion filaments beneath glass transition temperature for increased mechanical attributes. The longer the period of the cooling and maintained above glass transition temperature, good bonding effect is observed. This could explain reason of mechanical qualities for PLA parts outperform in comparison to ABS [19]. Based on principle laid by FDM, which in the form accumulating layer-by-layer, a temperature differential may arise for FDM 3Dprinted PLA method. The fall in former layer temperature harmed interface bonding, resulting in distortion, distorted edges, and, as a result, a loss of mechanical characteristics in PLA components. Hence, its important toward exploration in what way, temperature gradient on the mechanical property and shape precision of PLA components can be lowered. The temperature gradients decrease primarily by adjusting plate temperature and printing layer height [20]. The influence of FDM printed layer-height and plate temperature over impact hardness for FDM 3D printed items have been examined. The better results were obtained across plate having 160 °C temperature and 200 mm layer-height, that signifies the better interface and improved porous character, as shown in Fig. 7.

Hence improvements in Mechanical characteristics have significantly observed having no warped edges and high geometric accuracy. Also, it has been encountered all the pores at the interface layer are not removed completely [21]. Temperature is a critical parameter that must be managed optimally to achieve greater mechanical strength. The viscosity of the filament is linked to the temperature in FDM, and a very high temperature causes the viscosity of the material to increase, resulting in poor finishing and dimensional inaccuracies [22]. Zhou et al. [23] obtained temperature data using an infrared sensor. According to their findings, increasing the temperature of the nozzle and platform lengthens the diffusion period, resulting in higher bond strength and overall mechanical qualities. The printing speed has more significance thermal parameters like temperatures. It was discovered that increasing the temperature, the final part's properties improved favourably. This could be because different experimental designs were used. The later project used

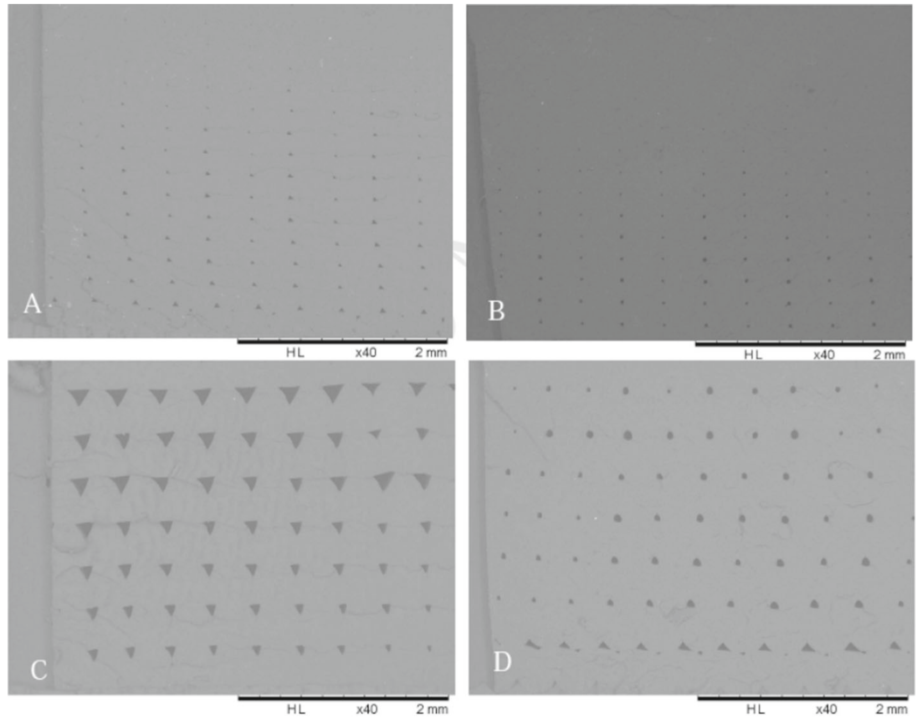

Fig. 7 Impacted fractured surfaces of PLA components via FDM, **a** 0.2 mm, 30 °C (layer height, plate temperature); **b** 0.2 mm, 160 °C; **c** 0.4 mm, 30 C, and **d** 0.4 mm, 160 °C [20]

the L18 Taguchi design, whereas the former experiment just changed the extrusion temperature while keeping the rest of the printing parameters fixed, as shown in the figure. However, based on the trend, it can be depicted that, the graph is not linear between the strength extrusion temperature and that it peaks nearly around 200–220 °C, with mechanical qualities deteriorating above that temperature [24] (Fig. 8).

The variables like Speed, extrusion temperature, besides layer-thickness were studied using Taguchi's optimization method, and it was discovered extrusion temperature has maximum significance (Rank 1) that exhibits mechanical qualities in product. The ABS & PLA have no correlation among the extruded temperature .Ouballouch et al. [26] reports impact of process variables on the mechanical characteristics for 3Dprinted composite parts was investigated. The same tendency was observed in both cases, with the strength (ultimate) for the components increasing along temperature up to a specific range. The effect of process factors on the standard specimen was investigated using composite material. Scanning microscopic images were utilized to study the fractural surface. The studies depicted that the raise extrusion temperature makes component resilient, but as this exceeds temperature of 220 °C, the mechanical characteristics of the part decline dramatically.

2.4 Effect of Infill density

Parts can be made solid or with a partial solid with a term called as infill ratio, which can range from 0 to 100% using additive manufacturing (solid part means 100% infill ratio). The pattern of the infill density can be honeycomb or rectilinear. When the material inside a component increases, the part's load-bearing capacity should increase. Jatti et al. [24] discovered this when measuring parts' flexural and tensile strengths. Ramkumar [27], who used a standard to measure the specimen's impact resistance, noticed a similar pattern by The IZOD test was performed. Alafaghani et al. [28] used the 0.02% offset method to assess the elastic modulus of the PLA part under tensile loading and concluded that increasing the infill percentage from 20 to 100% improved the elastic modulus, and the stiffness increased progressively as depicted through Fig. 9.

Although the influence of infill density may appear clear, the UTS was calculated using the entire cross-section area in the research listed above. Because the cross-section was not solid, merely cross-section portion (infilled) carries weight (for infill smaller than 100%). As a result, adequate metrics quantify the fractional infill should be devised. To eradicate problem, Akhoundi et al. [29] looked into the tested components' mechanical properties and compared each part's mechanical qualities to the mass to quantify the infill. The findings toward fracture strength and related stiffness modulus are shown in Fig. 10a, b.

The flexural mechanical properties are similar, indicating that the infill density has small effect on the material's mechanical properties but that reducing the infill density result in a reduction of part's load bearing capability. Though, when only tensile testing is considered, the 50% infill is not as

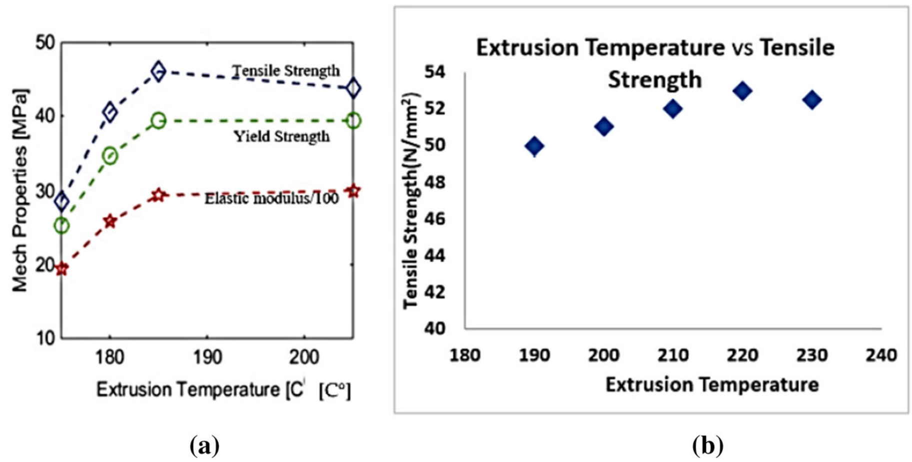

Fig. 8 Effect of the extrusion temperature on the mechanical properties of the part. **a** Extrusion temperature versus mechanical properties [25] **b** Extrusion temperature versus ultimate tensile strength [24]

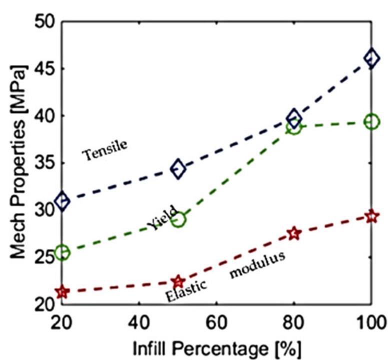

Fig. 9 Mechanical properties dependent on the infill ratio % [28]

effective as the 100%and 20% infills in most circumstances. The infill variation does not affect the part's particular tensile and flexural moduli because the solid shell provides the part's primary strength.

2.5 Effect of infill patterns

Besides, infill ratio and infill pattern influence the part's mechanical qualities. Consequently, when infilled filaments are loaded, the infill pattern influences how they interact with one another. The effect of the infill pattern over part's Compressive strength has been investigated [30]. The ultimate tensile strength of triangle, grid, and hexagonal infilled portions was similar (56–72 MPa), whereas the quarter cubic infill had much inferior value of 27 MPa. The grid pattern also has maximum tensile strength owing unique layer arrangement, in which the infill layers are traversed one over the other, as depicted in the figure (Fig. 11).

It was also revealed that employing patterns with layers stacked on top of reduces impact strength thereby making the part more brittle. According to the research on the impact parameters of FDM-ed products, a uncurving pattern within all layers allied has lower impact resistance than a honeycomb infill pattern. This occurred because the honeycomb pattern's crack propagation is hampered by raster orientations of 0, 60, and 120 degrees.

The same observation were observed by Chadha et al. [31], where they investigated the grid, triangle, and honey-comb performance infill patterns in flexural and tensile loads. The observation has been made under both bending and stress that the triangle design had the best strength, followed by the grid and honeycomb patterns. The printed filaments did not modify the circular cross-section of the grid pattern, according to SEM scans of the fracture surfaces. This indicates that those filaments didn't experience necking, which could indicate a brittle fracture. Honeycomb and triangle patterns, on the other hand, failed to be ductile, and the cross-section of their filaments became oval due to necking. To improve the part's tensile strength, Akhoundi et al. [29] suggested that all filaments direction aligned with load application direction or that the fusion between adjutant fibers be enhanced. Cwikla et al. [32] demonstrated that an ABS item filled with a honeycomb design had comparable strength when filled with concentric pattern having infill ratio of 40%. The circumferential pattern was not advised for torsional purposes since the torsional rigidity would be lower due to its symmetrical geometry. Conventional grid and rectilinear designs, on the other hand, have adverse effects on mechanical qualities.

2.6 Effect of the nozzle diameter

The nozzle diameter is also responsible for mechanical characteristics of FDM parts. Controlling the air-gap among nearby plastic strands is feasible by combining nozzle size and layer thickness control. Its impact has been investigated in various studies, which are mentioned here. Triyono et al. [33] has done the study of nozzle diameter on the stress (ultimate) for 3Dprinted material. The nozzles employed in this investigation ranged from 0.3 to 0.6 mm. The thickness

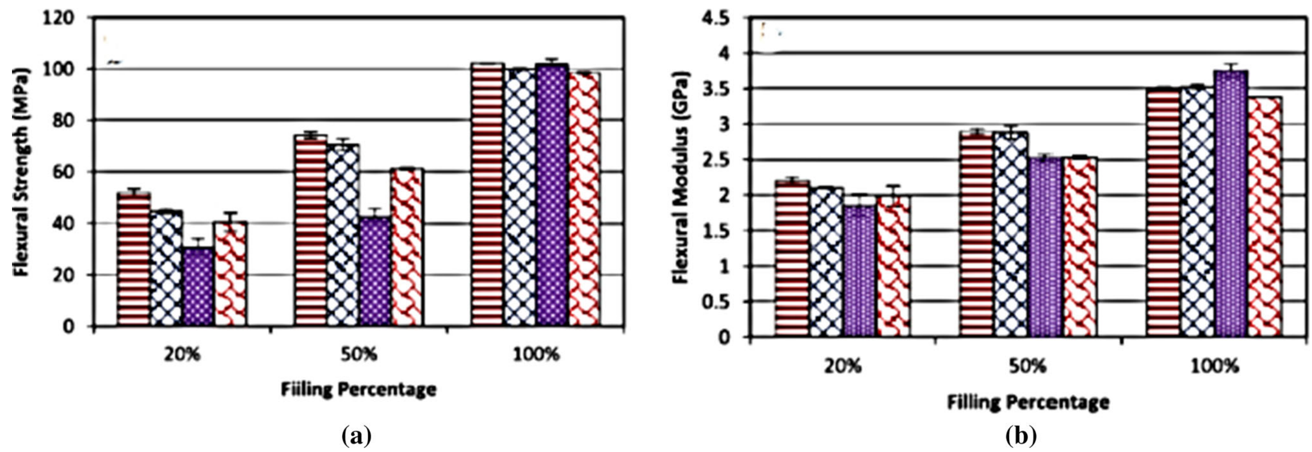

Fig. 10 **a**, **b**, Mechanical properties of the parts [29]

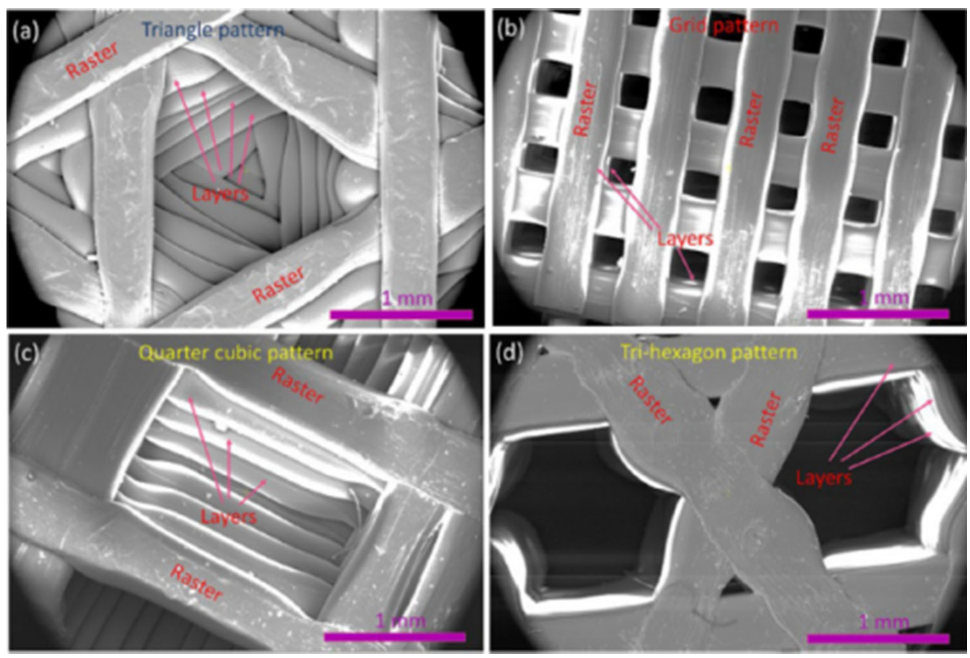

Fig. 11 SEM picture of 3D printed specimen at different infill pattern: **a** triangle pattern, **b** grid pattern, **c** quarter cube pattern, and **d** tri-hexagon pattern [30]

of the layer was layed at 20% the diameter nozzle. It was discovered that as the nozzle diameter increases, the UTS also increases. Voids reduction (air gaps) between adjusting strands was found using scanning electron microscope imaging to explain the rise in UTS. The raster becomes broader as the nozzle diameter is raised, and overlapping between neighboring strands occurs, fused during solidification. As a result, the specimen was reinforced. The rise in UTS with nozzle diameter was also discovered in this investigation, even when the layer thickness was doubled (layer-thickness 20% of nozzle diameter). It implies the nozzle diameter to layer thickness ratio is parameter that determines part's tensile strength.

Using a Taguchi-based design of experiments, Nabipour and Akhoundi [34] studied the nozzle diameter effect UTS of Acrylonitrile butadiene styrene material. It was discovered that, unlike their Polylatic acid equivalents, a contrary relationship among nozzle diameter and UTS for ABS materials. The Compared to other process parameters, the nozzle diameter had the smallest impact on the UTS. Large nozzles ranging from 0.5 to 1.5 mm, should be observed. This investigation did not study the influence of the nozzle diameter to layer ratio. The nozzle diameters utilized in this study were bigger than those employed by Kuznetsov et al. [35] and Triyono et al. [33]. One of the explanations for the gap between the results could be this. This could be one of the causes for the mismatch between the two sets of results.

2.7 Effect of raster angle

Most studies focused to investigate the influence of raster angle on the tensile, flexural, and impact strength of ABS printed objects. From literature, this has been observed that a raster angle of 0 enhances the tensile strength of FDM parts, whereas a 45/45 (staggered raster) raster angle improves the impact strength. Wang et al. [36] used 3 different raster angle which were 0°, 45°, and 90° to investigate the effect of raster angle on the tensile strength of ABS printed items. The Taguchi L18 array has been used to design the experiment. The author's findings back up prior research that found the 0 raster angle to be the best. This article obtained the highest tensile strength of 24.36 MPa using the minimum level raster angle. Using a Taguchi based design of experiments i.e. L9 OA and ABS resin material, Nidagundi et al. [37] investigated three values of the raster angles factor, explicitly 0, 30, and 60.

The SN ratio revealed that when the raster angle increases, the ultimate tensile strength of parts falls. As a result, the scientists found that the 0 raster angle, together with 0.1 mm layer thickness and 0 component orientation, is the ideal level for tensile strength. Using the minimum levels of the three factors described before, a maximum tensile strength of 27.674 MPa was attained. Panda et al. [38] revealed that a raster angle of 54.7311 was ideal for enhancing part flexural strength. This is because decreasing raster angles result in longer rasters acting as stress concentrators. As a result, bonding becomes weaker, resulting in poor mechanical performance. The conclusions of Zieman et al. [39] back up prior research that indicated 0 raster angle to be the best level for optimizing ABS printed part tensile behavior. The experiment used four raster angles: 0, 45, 90, and 45/45. (the latter represents the crisscross raster). The mean ultimate tensile strength was found to be a maximum of 25.15 MPa when utilizing a 0 raster angle and 9.16 MPa when using a 90 raster angle. This is because tensile strength is determined by the alignment of the stress axis with the fiber axis of printed items. As a result, raising the raster angle causes a mismatch between two axes, resulting in weaker tensile parts. The figure shows the fatigue test results for items printed with various raster angles. The default configuration of the raster angle parameter (45/45) resulted in the greatest mean number of cycles to failure. In terms of fatigue strength, the second-best raster angle was 0 (Fig. 12).

The raster angle of 0 yield the highest tensile and flexural strength. Long raster (0°), long short raster (+ 90°/0°), and staggered raster (+ 45°/45°) were the three levels of raster angle evaluated by the authors. During the printing process, the long-short-raster means that a layer with a 90° raster angle is followed by a layer with a 0 raster angle. According to the findings of an ANOVA study that shows the percentage contribution of parameters, the raster angle parameter has the greatest influence on the impact strength (0.127%) of PLA parts, followed by tensile (0.002%) and fractural strength (0.003%) (0.034%). Staggered-raster (+ 90°/90°) was shown to be the best levels with regard to the impact strength.

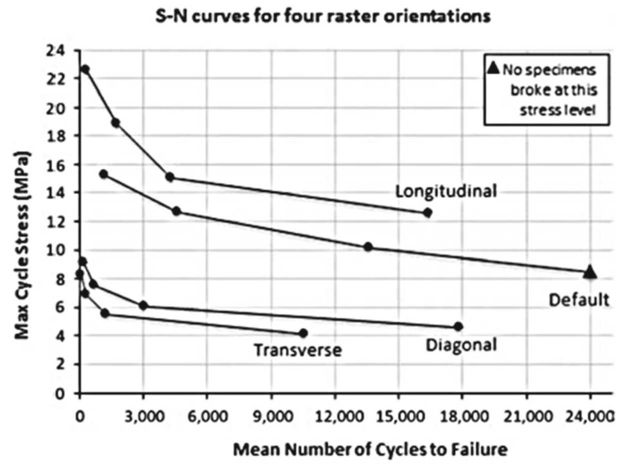

Fig. 12 The tension–tension fatigue test results for acrylonitrile butadiene styrene (ABS) parts with different raster orientations: longitudinal (0°), default (+ 45°_/− 45°_), diagonal (45°), and transverse (90°) [39]

2.8 Effect of build orientation

The build orientations determine the coordination for part building regarding Z axis. Typically, build platform area tells about work envelope defined by XY axis, and the z-axis determines part height. With regards to tensile strength of FDM parts, most research indicates that lower levels (0° or 15°) of build orientation are best. However, fractural and impact strength features reveal varied optimum directions in diverse investigations. Zhou et al. [23] discussed effects of build orientation for mechanical properties as a key aspect to consider. The finding from the studies depicted that FDM parts with filaments deposited along Z direction had higher tensile strength than those printed along traverse direction. The following is the explanation for this. Filaments can withstand the load by themselves when they are orientated in the load. In contrast, transverse direction printing can only resist the load by the bonding forces between them. Mode III combines modes I and II and yields a middle result [40]. The effect of construction orientations over strength (ultimate) of ABS parts was investigated by Nidagundi et al. [37]. The authors looked at this parameter at three degrees of control: 0°, 15°, and 30°. The mean SN ratio decreased as the orientation angle increased in the experiments, and the higher the SN ratio, the greater the tensile strength. This suggests that the ultimate tensile strength of printed objects is best when the construction orientation is 0. Besides that, the build orientation parameter was shown to have a 37.33% influence on part tensile strength, making it the maximum significance related

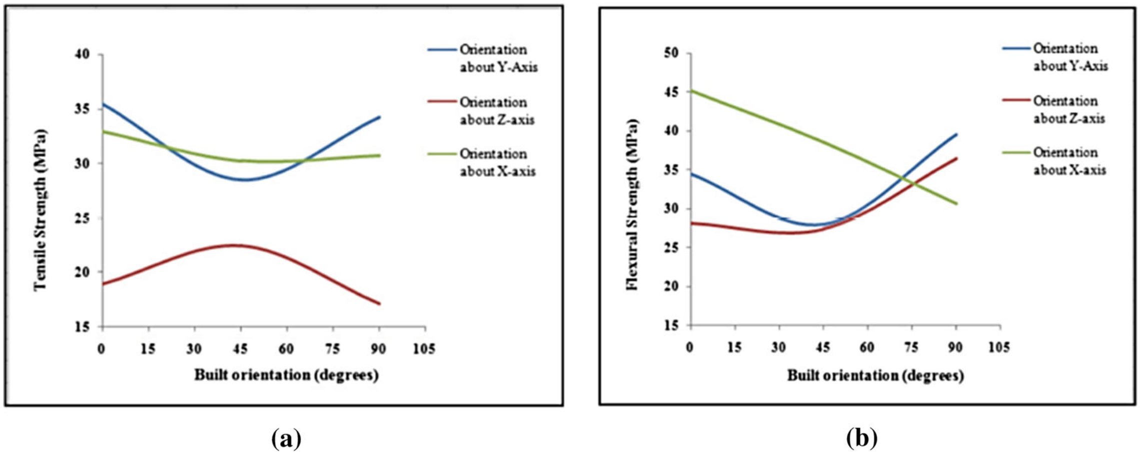

Fig. 13 The mechanical strength of ABS printed parts using different build orientation levels: **a** tensile strength; **a** flexural strength [41]

to layer-thickness and fill angle factors. The authors looked at the x, y, and z-axes independently for three distinct levels of build orientation (0°, 45°, and 90°). The results depicted that highest tensile strength obtained when orientations variable are fixed zero.

For example, tensile strength values of 35.45 MPa, 22.51 MPa, and 33.00 MPa were recorded utilizing a 0o build orientation concerning the x, y, and z-axes, respectively. Orientation levels having higher build, lead to greater flexural strength omitting x axis for fractural strength. There is 0° orientations to X axis yielded a most value of 45.20 MPa. The figure depicts the correlation among ABS part tensile and flexural strength and unlike build orientations level concerning the x, y, and z axes [41]. Abdelrahman et al. [42] used PLA resins and different level of governs to study the build orientation: X°Y°, X90° Y0°, X0° Y90°, X0° Y45°, and X90° Y45°. The experiment's outputs included printed pieces' tensile strength and maximum fractural load. The X0° Y0° construction orientation was used to obtain maximum mean tensile strength 9.36 MPa and fractural force around 1409 N. It was discovered Y component for construction orientations increases, hence mechanical behavior for PLA components deteriorates (Fig. 13).

3 Conclusion

The controls over process parameters are necessary to improve the efficiency of FDM process. In this paper, a comprehensive literature summarized for reporting the effect of process variables. Researcher required creating a balanced approach to find the optimal settings for the different operating conditions. To accomplish so, research should be conducted to assist users in determining the best printing parameters for their specific needs. It's worth noting that this paper focuses on the robustness of 3D printed items; certain people may require great dimensional precision (which isn't covered in this evaluation), which may necessitate a different set of ideal parameters). The following are the important findings that contributed in the improvement in characteristics of printed parts.

1. Because of the diversified results and outcome, more comprehensive research required in investigation of influence of infill patterns over mechanical characteristics of 3D printed parts. The mechanical properties largely controlled by infill materials.
2. Based on literature, the nozzle diameter to layer thickness ratio is the crucial parameter influencing FDM printed parts' tensile and flexural strength. However, it appears that certain restrictions should be examined further. Furthermore, there is currently minimal information over the impact and compressive strength of nozzle's diameter.
3. As per literature, pre-development procedures like laser heating are currently in usage. Other pre and post-development approaches, like coating, similarly require specific care. The more comprehensive investigation might be conducted over FDM part as these are sterilized for medical reasons.
4. Even though the literature has looked into infill patterns and density, there is still work on infill patterns with low infill percentages. In addition to other significant considerations, cooling rate and ambient variables must be considered.
5. It is also essential to examine the strength characteristics for unlike materials like plastics and metals. Because various materials have different melting points, their bonding mechanisms must be researched further. Furthermore, the impact of the cavity created for printed part over strength qualities.
6. Furthermore, because most study focuses on linear and circular features, more intricate forms with overhangs,

gradients, and curvature which mimic better real-time difficulties, that must be examined during strength attributes.

7. Regarding tensile strength, the low levels (0^o or 15^o) of build coordination yields in better performance. However, flexural and impact strength features reveal varied optimum settings in multiple types of research. It has been observed that utilizing a raster angle of 0^o enhances the tensile strength, whereas by deploying $\pm 45^o$ raster angle improves the impact strength.
8. Several previous tests were used to evaluate the FDM augmentation approach. The extruded layer surface pre-deposition heating process had a favorable influence over mechanical qualities. The anisotropy effect was also shown to be minimized following preheating.

Future Scope:

It should be highlighted that a "lab experiment" using "dog bone" Specimen made by ASTM and ISO Standard may not yield results that are applicable to practical situations. It is need to conduct further research on real life components, which may be another area of focus for future studies.

Using different optimization strategies, some researchers build a mathematical model that connects response and parameters. For Example, the genetic algorithm (GA), the naked mole-rat algorithm (NMRA), the artificial neural network (ANN), the particle swarm optimization (PSO), and other heuristic optimization techniques. Because of several parameter combinations may correlate to the best outcome. So, there will be a future need for more research into muti-parameter optimization for the FDM process.

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