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3D Fused Deposition Modeling (FDM) for Rapid Prototyping: Recent Developments, Challenges, and Opportunities

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ABSTRACT

Fused Deposition Modelling (FDM) or Fused Filament Fabrication (FFF), It is the most popular rapid prototyping technique, is basically used to fabricate three dimensional (3D) objects. Its ability to build complex designs in limited time money makes it more accessible than other RP techniques. Recently, this technique has been considered as the most promising for fabrication of 3D products from polymeric materials for aerospace, automobile, biomedical (tissue engineering), and architectural application. FDM by layer-by-layer deposition process does not mimic geometry as designed in the computer aided design (CAD) software. In this context, the adjustment of process parameters are; wall thickness, infill density, build plate temperature, print speed, layer thickness, nozzle (diameter, angle and length, extrusion, and temperature. Therefore, this paper is reviewed developments of FDM, process optimization, fused filament production process, characterization of FDM, and process optimization. Challenges and future perspectives were included in this review paper.

1. Introduction

Presently the dominant technology for producing physical models for testing and evaluation purpose has been rapid prototyping (RP). CNC prototyping has its own limitations involving the geometric errors due to machine tool accuracy and inaccuracy of machining and thermal errors due to frictional force between the tool and the job. Other disadvantage includes the loss of the raw material as the process is subtractive, the fixture required in CNC machining have their different complicated designs for different types of parts, increased costing due to manufacturing of valves and fixtures themselves, hiring skilled labor for overviewing the process that adds to its cost. (Pranjai Jain, 2013).

The manufacturing world has taken big strides with the advent of additive manufacturing (AM) and 3D printing (Aabith et al., 2022), has the potential to be a technological revolution in the manufacturing industry. It provides an opportunity to produce objects with a high precision rate based on a digital design of the product (Shahrubudin et al., 2019; Sharma et al., 2021). 3D printing, often known as additive manufacturing, or solid freeform (SFF) produces viable, robust, and permanent parts (Döbröczöni, 2022; Wang et al., 2017). Many in the industry use the terms 3D printing and additive manufacturing interchangeably (Attaran & Attaran, 2020). Presently, a dominant technology for producing physical models for testing and evaluation purpose has been rapid prototyping (RP) (Pranjai Jain, 2013). 3D printing in the area of rapid prototyping. Rapid manufacturing and rapid tooling has provided excellent service since 30years (Ahmed, 2019; Döbröczöni, 2022), and one of AM's benefits is that it does not require any specialized or expensive tooling, allowing it to work with various materials (Döbröczöni, 2022; Ramakrishna & Maheshwari, 2018). Owing to tremendous benefit offered by 3D printers, now, its accessibility for industrial and hobbyist users has drastically increased during the recent decades (Ramakrishna & Maheshwari, 2018). By 2025, the AM market will provide an annual economic impact of $200 billion to 600 billion dollars (Döbröczöni, 2022).

Additive manufacturing techniques can create various complex shapes and structures while properly managing materials, resulting in less waste and various other advantages over conventional manufacturing, making it increasingly popular (Kristiawan et al., 2021). 3D-printing refers to the process of fabricating 3D solid objects through the use of computer-aided design (CAD) to formulate layer-by-layer custom designs joining of feedstock with the help of external stimulation (Agrawal, 2014; Ahmed, 2019; Luis & Moncayo, n.d.; Ramakrishna & Maheshwari, 2018; Wang et al., 2017).

The application of 3D printer is increasing dramatically, and the rapid development of this technology shows promising results to improve manufacturing, especially using composite material (Ali et al., 2019). The initial focus on 3d printing technology was rapid prototyping and precise manufacturing. It has found their possible applications in aerospace industries for creating complex lightweight structures, architectural industries for structural models (Savija, 2020), art fields for artifact replication or education, and medical fields for printing tissues and organs (Wang et al., 2017; Yahya Bozkurt, 2021), smart home, stationery and training aid, and creative gifts (Liu et al., 2019).

There are various types of RP process available today. It can be classified based on the initial form of its material. It can be categorized as liquid based, powder based, and solid-based (Agrawal, 2014). Some main types of RP are; selective laser sintering (SLS), binder printing, inkjet printing, stereolithography (SLA), fused deposition modeling (FDM) and laminate object manufacturing (LOM). Among them, three are the key 3D printing technologies, namely FDM, SLS and SLM. (Ali et al., 2019;

Wang et al., 2017; Yahya Bozkurt, 2021). Using diverse AM technologies, researchers investigated the influence of 3D printing parameters on various reactions like printing orientation, printing pattern, nozzle temperature, printing speed (Döbröczöni, 2022). FDM uses materials in the form of a filament (Ali et al., 2019).

The filament-based additive manufacturing was introduced earlier than the SLS based 3D printer. Only after 2013, The idea of using several materials in printing a single component in FDM technology is very new. Currently, available FDM printer has a maximum of two-nozzle system, besides a very few proposed methods of multi-nozzle systems (Ali et al., 2019). The quality of printed parts can be controlled by altering printing parameters, such as layer thickness, printing orientation, raster width, raster angle and air gap (Wang et al., 2017). In this paper recent developments or technologies, process parameters, optimization, challenges, opportunities and future perspective of 3D printing Fused deposition filament rapid prototyping met hod were being reviewed.

2. Fused Deposition Modeling (FDM)

Fused filament fabrication (FFF) (or fused deposition modeling – FDM), one of the fastest-growing (Wickramasinghe et al., 2020), it is the second most extensively used rapid prototyping technology, after stereolithography (Agrawal, 2014; Krishna Mohan et,. al) . It was developed by Stratasys (Krishna Mohan, et., al 2022) in the early 1990s as another 3D printing approach that like SLS uses preformed polymer as the building material. However, in this case, the processing energy input is involved at the pre-deposition stage to obtain a polymer melt material that can be applied through a fine print head or nozzle, as shown Figure 1;(Stansbury & Idacavage, 2016). It is the AM method that uses thermoplastic material in the form of filament to build 3D objects layer-by-layer by heating, extruding and depositing filament of thermoplastic polymer material with a heated nozzle (Aboma Wagari Gebisa, 2018; Wickramasinghe et al., 2020), in which the CNC machine controls nozzle movement. In industrial applications, the FDM method is one of the most popular manufacturing techniques due to its low cost of printer device, ease of use and variety of inexpensive filaments. (Agnieszka Szust, 2022).

Research on this material stigmatizes the limitations of the material for this technique. Currently, 51% of the products are polymer-plastic filament types. It is because these materials not only have sufficient criteria to be used and developed but also help to make FDM processes for manufacturing products more manageable and more optimal. The butadiene styrene (ABS)most well-known polymers used in this technique are polylactic acid (PLA) and acrylonitrile (Kristiawan et al., 2021). It has become a broadly used rapid prototyping technology. is one of the methods used in 3D printing (Agrawal, 2014). Technically, the FDM technique has the same role as injection molding in the manufacturing aspect. For example, mass customization. It means producing a series of personalized items, so that each product can be different while maintaining low prices due to mass production. It does not need the additional costs of making molds and tools for customized products (Kristiawan et al., 2021; Zahedi, 2019). The FDM machine’s working principle is to heat the filament on the nozzle to reach a semiliquid state and then extruding it on a plate or layer that was previously printed.

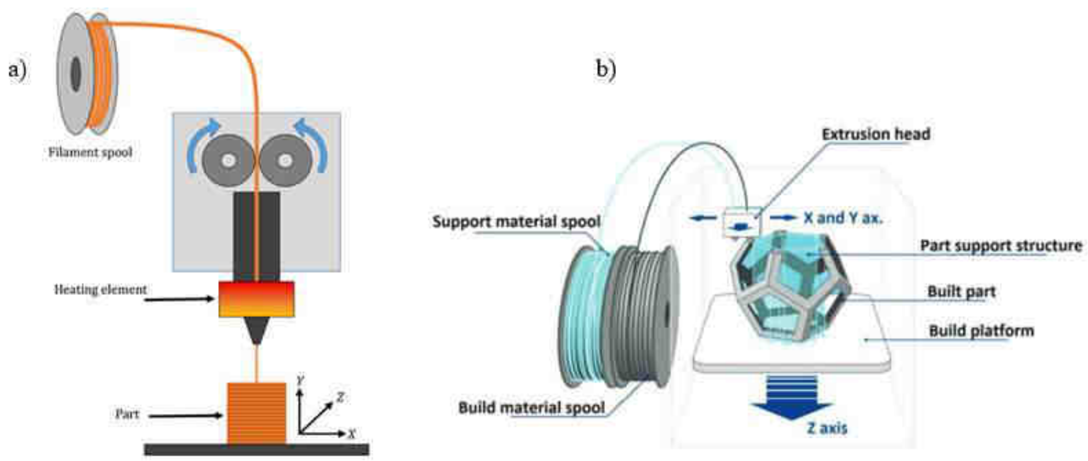

Figure 1: (a) the FFF technique relies on one or more heated nozzles that spatially distribute extruded polymer as a fine filament in the layer-by-layer building approach using a spatially translatable platform, (b) conceptual sketch of FDM (Kun, 2016; Stansbury & Idacavage, 2016).

FDM process comprise of two portable heads (one for building the part and one for the backings) which store strings of liquid material onto a substrate. The material is warmed simply over its liquefying point so it solidifies promptly after expulsion and frosty welds to the past layers (Agrawal, 2014). This process has variety of applications in numerous fields such as mechanical engineering, biomedical engineering and tissue engineering etc. (Agrawal, 2014), automotive and aeronautics, construction, defense, and demanding (Pervaiz et al., 2021; Zahedi, 2019).

There are three functions, which combines to process modeling. First, the material is fed mechanism, which take place, by two opposite rotating rollers. Second, melting raw material (thermoplastic materials) by means of electric heating. Third, the soften material (filament) is fused through a nozzle and deposited to build complex parts layer by layer based on cad design (Klippstein et al., 2017). As (Daminabo et al., 2020), FDM printing process was considered to generally three stage. Stage one is process of filament fabrication with specific composition, then feeding in to print head. Stage two filament manipulation in print head, extrusion and cooling process and the third stage part removing and post processing.

3. Recent developments of FDM

The co-founder of Stratasys, Scott Crump, patented the name: fused deposition modeling (FDM) in 1989, and in recent times, FDM-based 3D printers have emerged as the most popular 3D printers used in printing thermoplastic polymers and composites. Industrially, FDM machines are also considered to have significant advantages for cost-efficiency and simplicity (Klippstein et al., 2017). According to a recent study, it is expected that the global market for 3D printing is projected to grow from USD 12.6 billion (in 2021) to USD 34.8 billion (by 2026) at a 22.5% compound annual growth rate (CAGR). 3D printing of composites is still in an emerging stage. But many industrial technologies, including defense, automotive, and aerospace, possess huge opportunities for 3D CFRP printing. This has many advantages such as reducing part manufacturing time and waste, achieving intricate geometries, and no expensive tooling is required. Currently, 3D printing is being used for the manufacturing of tools made of composites and the composite prototype parts (Pervaiz et al., 2021). It is easy to implement and can create very high-quality products, and not the best option for printing complex designs or parts with intricate features. The technique is well suited for quick and low-cost prototyping of simple parts and basic proof-of-concept models. Today, many printers are using this technology that ranges in price from only a few hundred dollars on up. FDM midrange desktop printers are available at $2,000.00. Industrial systems start at $15,000.00 (Attaran & Attaran, 2020). Compared to other AM methods, as the FDM method offers many advantages including cost effectiveness, now, many researchers are moving towards FDM to study this process thoroughly. Figure 3 indicates the number of research publications relevant to the FDM process from 2009 to 2019.

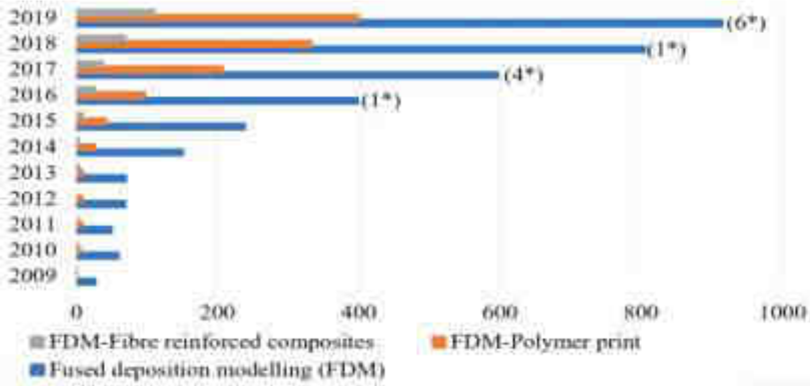

Figure 2: Number of publications on: FDM, FDM- polymer prints and FDM fiber- reinforced composites from 2009 to 2019. The number within the brackets indicate the number of review papers on FDM- fiber- reinforced composites (Wickramasinghe et al., 2020).

3.1 Consolidation 3D printing of CFRPCs

The challenges of the current state of the art of the printing technology is the very low 3D printing speed of CFRPCs. The above-mentioned challenge is mainly caused by intrinsically contact needed and slow heat conduction from the convectional heating nozzle to the continuous carbon fiber reinforced thermoplastic filaments (Tian et al., 2022). (Li et al., 2019) proposed a high-speed 3D microwave printing technology of continuous carbon fiber reinforced thermoplastics, using microwave heating in 3D printing of CCFRP instead of the traditional resistive heating, shown in Figure 2a. without the intrinsic slow speed and contact-needed heat transfer dis-advantages, the instantaneous and volumetric heating benefits of microwave allows the fabrication of composite at higher speed. Due to the short impregnation and bonding process in 3D printing process, fabricated products generally had a lower mechanical performance than those fabricated by conventional molding techniques due to the inclusion of many voids and lower interfacial shear strength between adjacent layers. To resolve this problem a hot compaction roller technique for 3D printing to reduce voids and improve the adhesion between layer in a 3D printing products (Tian et al., 2022)

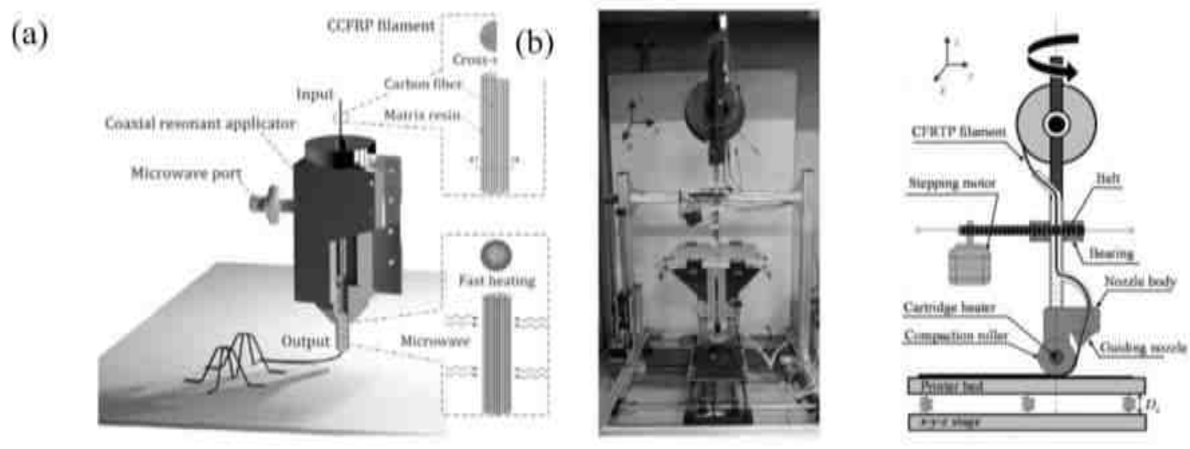

Figure 3: (a) 3D microwave printing process (b) 3D compaction printer (Tian et al., 2022).

The latest development in composite FDM feedstock is the introduction of continuous fibers as reinforcement into the polymer matrix. This was first introduced by a company known as Markforged in 2014. The technology is basically the application of anew composite filament fabrication (CFF) technique in combination with the traditional FDM technique, which involves the use of two nozzles; one for the prepreg composite filament and the other for the pure polyamide feedstocks (Figure 3). With this new system, a composite 3D-printed part with a remarkable performance (10 times stronger than a typical 3D-printed part) can be manufactured.

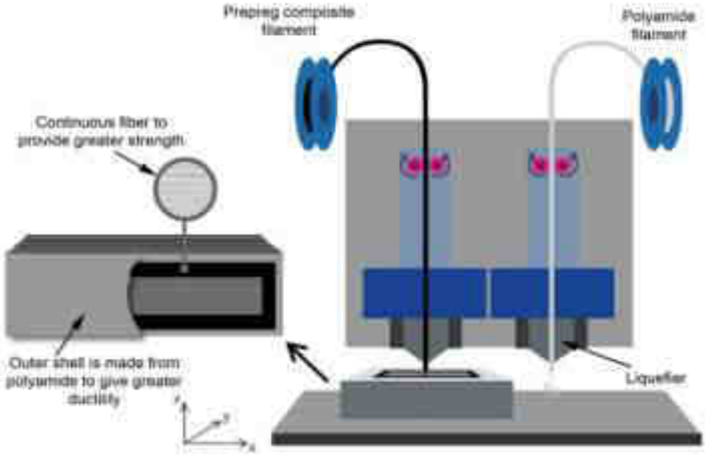

Figure 4: Schematic diagram of composite 3D printer with dual extruders, one nozzle to print the polymer and another one to print the continuous fibers (Noraihan et al., 2019).

3.2 Filament manufacturing process

A filament production process uses a single or twin-screw extruder to extrude a filament with specified diameter tolerance; based on the screw extruder's nozzle design, and the FDM 3D printing machine used. Considering this, the adjustable screw speed, pressure, and temperature were found to be the key parameters during filament production; that must be well controlled to achieve the target diameter of the required polymer-based filament that has been formed beforehand (Klippstein et al., 2017).

The selection of filament diameter won’t affect printing quality; as long as the printer’s settings are fine-tuned. A larger-sized diameter (3 mm) provides a stronger filament, and consequently, the process requires more pressure but is slower at forcing the material into the nozzle (Noraihan et al., 2019). Filament is made of pure polymer with a low melting point. In some cases, the strength of pure polymer needs to be enhanced. Therefore, many researchers and industries have developed polymer composites as 3D printing filament material by combining the matrix and enhancing the components to achieve systems with structural properties and functional benefits which cannot be achieved by just any constituent. The filaments made from pure polymers that are usually commercial can be directly processed as FDM material. However, the process of making composite filaments must first receive special treatment because every reinforcement in a composite polymer will result in different characteristics (Kristiawan et al., 2021).

The pure polymer filament for FDM materials can be made through the process of extruding pellets or raw materials from polymers as shown Figure 4. This process is carried out using extruders that push or force the material through holes in the die to get the product as an extrudate. The materials can be mixed by several methods depending on the characteristics of the ingredients of the mixture. It can be completed by mixing the solution and then drying before being extracted or by the dry mixing method (Kristiawan et al., 2021). Choosing the right filament material for achieving process efficiency and effectiveness would involve using material systems with favorable and controllable physical-chemical, rheological, structural and mechanical properties; considering their effects on printability, applicability, and performed at a stage subsequent to processing (Klippstein et al., 2017).

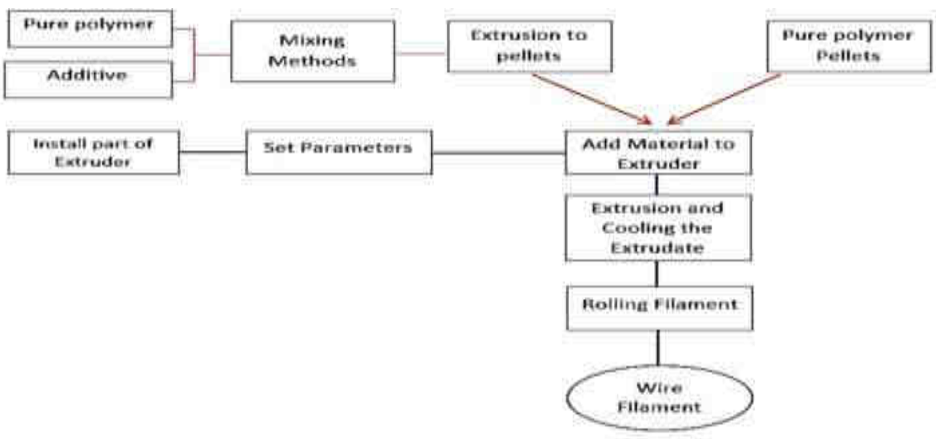

Figure 5: Filament work flow (Kristiawan et al., 2021)

In this extrusion process, several things affect the filament. Die temperature, roller puller speed, spindle speed, and inlet temperature affect the filament cable diameter. Because in this process, the parameters will affect the viscosity of the material, which causes the output of the material to be extruded at the nozzle die, not according to the desired diameter. According to its composition, polymer filament is divided into two categories, namely, pure polymer filament and composite filament.

4. Characterization of FDM process

The relationship between printing parameters and mechanical characteristics is determined by many types of testing like compression, torsion, tensile. The FFF technique also produces manufacturing time and the accuracy dimension of the printed part as output variables. Researchers have chosen a simulation to make a numerical solution to investigate different ME factors in plastic materials, with various goals and objectives. One proposal is to study the manufacturing process solely from the standpoint of material deposition, neglecting the mechanical characteristics of the printed parts. A further approach is to analyze the mechanical properties of 3D printed samples using simulations that do not duplicate the material extrusion process but change the printing parameters such as layer thickness, infill density, print speed, and nozzle temperature (Döbröczöni, 2022).

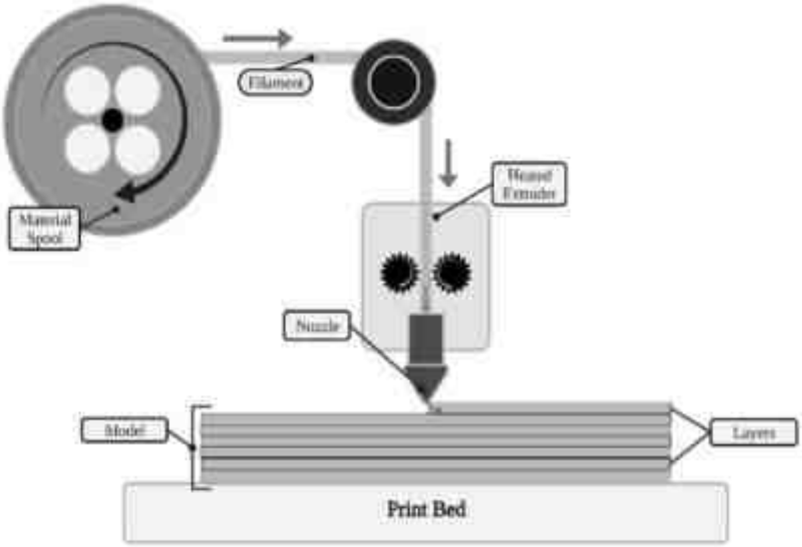

Figure 6: Fused deposition modeling technique illustrated (Krishna Mohan, et,.al; 2022).

The FDM technique is utilized to produce parts with outstanding part quality, increased productivity, safety, cheap production costs, and reduced lead times. To satisfy each application, the process parameters need to be tuned individually to suit them. The simplicity they can be classified as i) extruder related (bed temperature, nozzle temperature, and nozzle diameter); ii) process related (raster angle, raster width, build orientations, etc) and iii) structural parameters as shown Figure 6 (Krishna Mohan et al., 2022; Kristiawan et al., 2021), and which is listed in Table 1.The perks of selecting an optimum set of parameters are quite advantageous, selecting the appropriate process parameters ensures the parts fabricated have high dimensional accuracy, wastage of material is minimized, production time is reduced and reduction in the cost of producing each part is achieved.

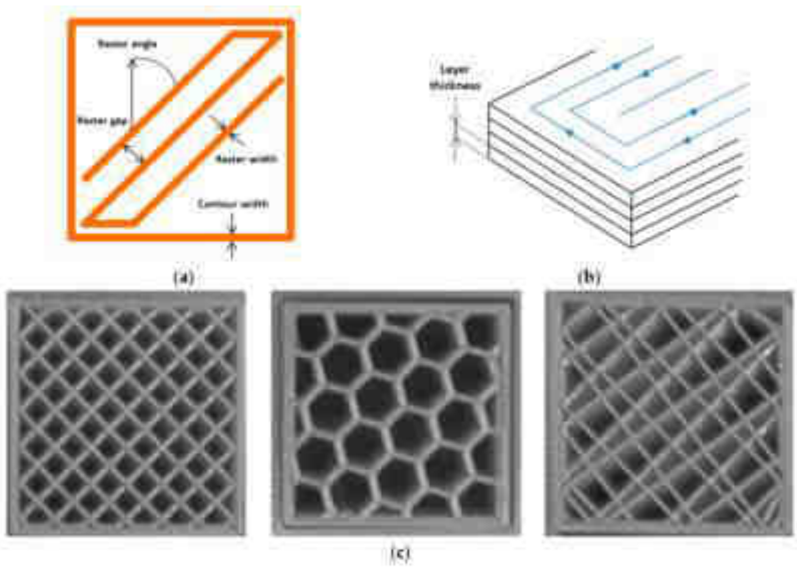

Figure 7: Structural parameters: (**a**) Parameters of the toolpath; (**b**) layer thickness; (**c**) infill geometry (Mazzanti et al., 2019)

The process parameters are; wall thickness, infill density, build plate temperature, print speed, layer thickness, extrusion, and temperature (Krishna Mohan et al., 2022), the aim is to optimize parameters to get high accuracy in printed parts.

Table 1. Description of the printing parameters (Mazzanti et al., 2019)

Parameters		Description
Extruder Geometry	Nozzle diameter	Size of the exit orifice of the extruder
	Filament diameter	Size of the filament required by the extruder
Processing	Melt temperature	Temperature of the molten material exiting the extruder
	Hot plate temperature	Surface temperature of the workspace plate
	Printing speed	The velocity of the material deposition
Structural	Layer thickness	The thickness of the layer deposited by the nozzle
	Infill geometry	The internal structure of the printed component
	Infill density	Material percentage filling the component apparent volume
	Number of layers	Number of shells deposed
	Raster angle	The angle between the deposed material and the x-axis
	Raster gap	The distance between two contiguous paths on the same layer
	Raster width	Width of the deposed material
	Patterning	Path followed to deposit the material on the workspace

4.1 Model for Defect Analysis in FDM Printing

The model arises from the need to understand the influence of the main printing parameters on the volume of defects present in the work piece, in order to make this analysis as general as possible in a way that it can be used in common polymers for application in FDM process, but also for Melt FDM. The model focuses on the identification of type of defects and the theoretical volume of those. The model aims to explore the effect of changing nozzle diameter, changing width, number of shell lines, slicing angle on the single layer, and changing part size, keeping the above parameters constant (Ferretti et al., 2021).

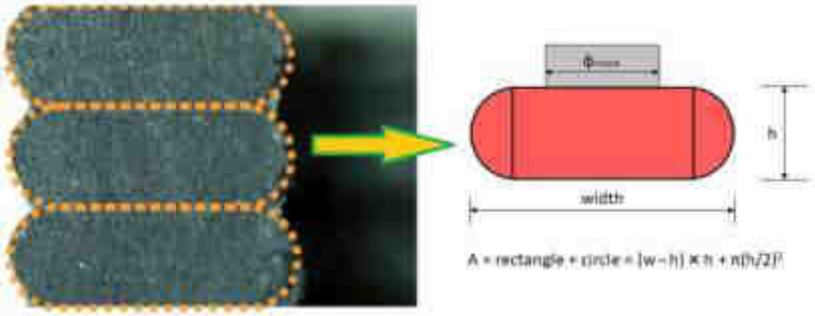

Figure 8: Printing line geometry characterization (Ferretti et al., 2021).

The starting point is the analysis of the shape of a single line and its parameterization. It was verified that the model presented by Slicer and then taken up and reported in Figure 7 is valid as a simplification. In fact, each line is designed with a geometry that combines two semicircles and a rectangle. This geometry is in fact the same one that uses the slicer internally to generate the toolpath.

4.2 Mechanical properties

The print parameter combination on the FDM machine is determined by the type and size of filament used in this process. Therefore, it is crucial to examine the effect of a combination of mechanical performance parameters (Kristiawan et al., 2021). The complex requirements of FDM have made the material development for the filament a quite challenging task (Kristiawan et al., 2021) The printing orientation also has a significant effect on the mechanical properties. its specimens are printed along the longitudinal direction in order to reach their highest strength. All test specimens are printed with the designed extruder. The tensile strength is affected by extrusion temperature and infill density in an identical way. Tensile strength is more influenced by extrusion temperature rather than infill density; higher extrusion temperature favors the high tensile strength of the test pieces up to a certain limit (Sandy et al., 2016). The print orientation of FDM manufactured objects affects the print time and amount of material used for the manufacturing process as well as tensile properties, depending on the direction of tensile forces in relation to the interlayer plane. When the tensile force direction is parallel to the interlayer plane, the tensile strength is the highest. The tensile strength decreased dramatically when the force direction is perpendicular to the interlayer plane. The tensile properties of anisotropy in FDM printed objects is non negligible and should be considered during the design process of the parts that will be manufactured with FDM technology. There are various important factors that affect the quality of part produced by FDM method of rapid prototyping but the most important are primarily the speed of deposition, layer thickness and resolution of the object fabricated (Agrawal, 2014). The following explains some of the main parameters of the FDM printing process. Figure 8a explains the build orientation guided by the step where the part is oriented toward the X, Y, and Z axes on the build platform. Layer thickness shown in Figure 8b is the thickness of the layer deposited on the nozzle tip. The user's thickness value in a specific range is defined by the nozzle diameter and limited by the printer accuracy. Some studies suggest using a thinner layer to increase both the surface quality and dimensional accuracy (Kristiawan et al., 2021). Figure 8c describes the FDM tool path containing several parameters, namely, raster angle, raster width, contour width, number of contours, and so forth.

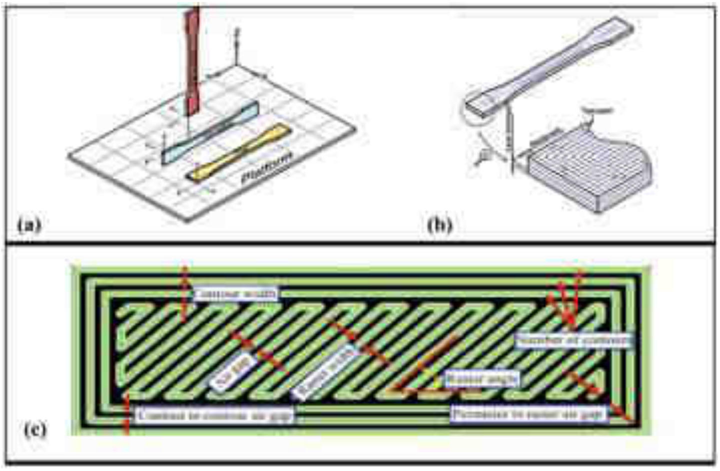

Figure 9: (a) Build orientations, (b) layer thickness, and (c) FDM tool path parameters (Kristiawan et al., 2021).

(Agrawal, 2014), in his work, the scaffold prepared from FDM have some irregularities in its geometry and orientation due to melt flow behavior of the material or some other parameters of the machine component. Pressure drops, nozzle exit diameter and nozzle angle are the key parameters responsible for these irregularities. The researcher were used mathematical model and CFD to study the melt flow behavior, his proposed redesign suggests the nozzle diameter should be decreased to 0.3 mm, since higher pressure drop at small nozzle diameter leads to continuous flow of the material from the extruder. This modification in these parameters helps in the fabrication of scaffold with fine geometry, better resolution, and proper orientation.

4.3 Morphological analysis

A morphological analysis of the printed specimens provides useful information on the voids, microcracks, fusion quality between PLA and fibers and failure modes. In this context, structural defects should be detected and their impact on the properties of the specimens should be analyzed. Figure 9 shows the failure of bending specimens including of two steps of: 1) formation of micro-cracks, and 2) crack propagation up to final failure. As shown in Figure 9(a), the first micro-cracks occur between the layers which propagate along the specimen length by increasing the load and cause delamination between the two layers.

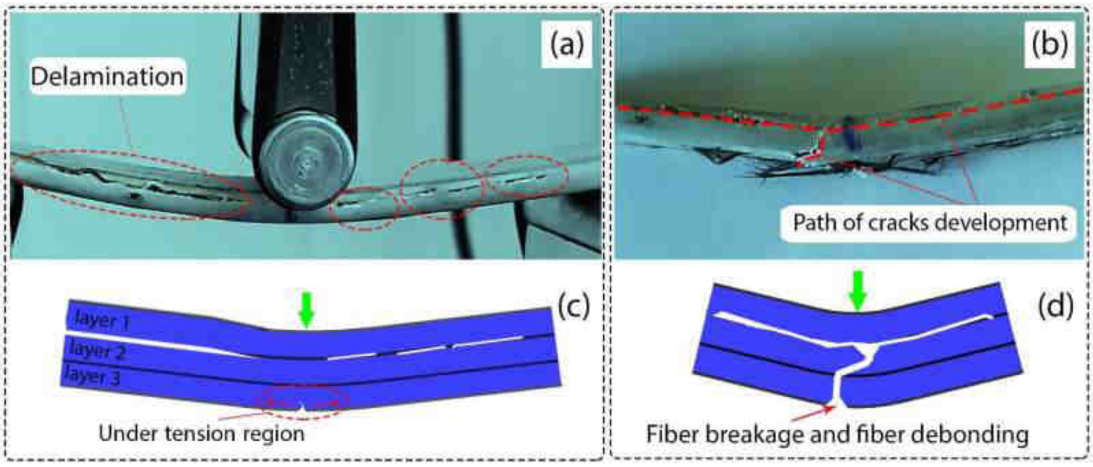

Figure 10: Failure modes of CCFR-PLA specimen under bending test, (a) specimen under bending test and delamination initiation, (b) specimen after failure and fiber breakage, (c) schematic view of bending test, (d) schematic of final failure (Zahedi, 2019).

Several processing parameters influence the mechanical properties of part manufactured by FDM process, recent research has focused on studying these parameters namely; air gap, raster width, raster angle, contour number and contour width. Among the parameters considered, the influence of raster angle was the highest. Four types of defects were identified, defect refers to the presence of gaps in the structure that are not generated randomly, but depending on how the material is placed. This type of defect is then repeated and, if the condition during printing do not change (constant extrusion temperature, constant ambient temperature, no speed change during printing), this type of defect is repeated on each layer (Ferretti et al., 2021).

A) Defects that consider the volume missing material compared to perfectly flat surface, similar to a surface made with a traditional manufacturing process like injection molding.
B) Defects that appear a shell and the adjacent shell line; if there are more than two counter lines, this defect ponders that total volume of the voids
C) From a purely geometric point of view, there are no differences in the geometry of defects B and C, defect C however refers to the lines of the infill (Figure 5)

D) Defect D, as seen in Figure 6, a defect that takes into account the formation of empty areas (without extruded material) due to the fact that the number lines in the infill is approximated by defaults.

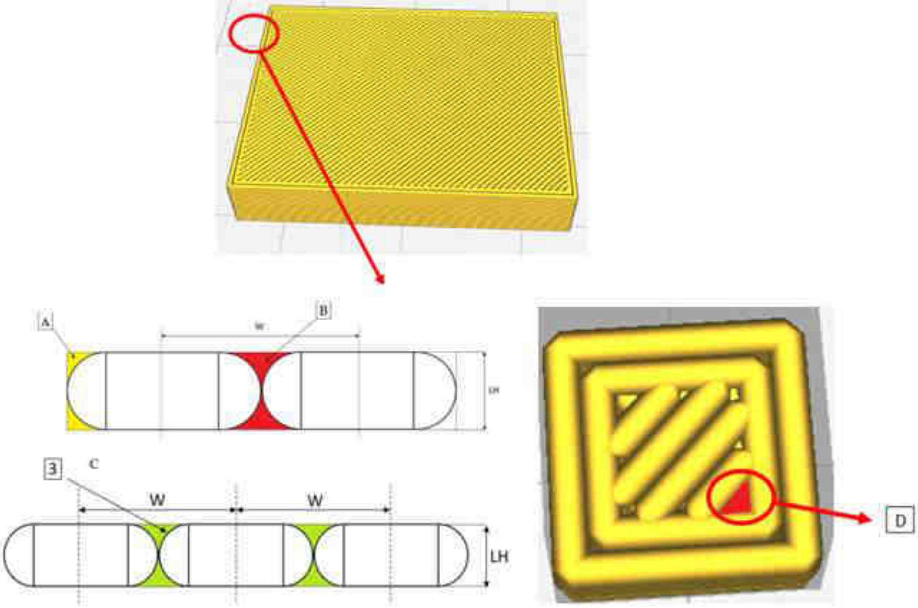

Figure 11: Defects (A, B, C and D), adopted from (Ferretti et al., 2021).

Defects play a key role in 3D printing since they are responsible for the reduction in mechanical properties with respect to injection molded parts. (Ferretti et al., 2021) suggested in his study, the presence of pores/voids in the 3D printed structure leads to a decrease in the final density of the specimen and depends on the printing parameter. In addition, in the FDM printing process, it is necessary to optimize and reduce the presence of voids in the structure because, even if the defects undergo a sintering process, they decrease in size, but still remain present in the structure. Moreover, some pores appear due to the chosen prin ting strategy (i.e., places where two perimeters joined or where the infill started and jointed). This alignment of pores was observed in CT (Computed Tomography) scans of specimens produced by FFF with other highly filled filaments, and they can lead to weaker mechanical properties. This phenomenon could be seen in Figure 11.

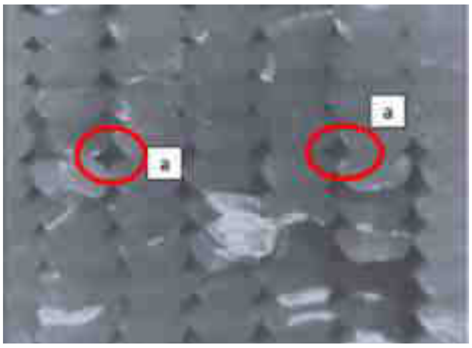

Figure 12: Defect appearance on a PLA specimen: (a) material voids between adjacent lines (Ferretti et al., 2021).

5. Optimization

This optimization process starts by using the recommended printing settings given by the filament producer. At a first stage, the width must be set equal to the nozzle dimension. Afterwards, the minimization of the layer height is performed according to the nozzle diameter and the minimum resolution value of the printer (Ferretti et al., 2021). One of the steps that can be taken to improve the mechanical properties of a filament is adding additives to the filament composition (Kristiawan et al., 2021). Despite the many advantages of FDM, quite a few drawbacks are also intrinsically linked to this technology. For instance, the filamen t temperature plays a very important role in controlling the viscosity of the molten filament: This must not be too high, to allow easy flow through the nozzle orifice, yet it should not be too low, otherwise the deposed filament would not provide enough structural support for the subsequent layers Perhaps the biggest issue, though, is the mechanical properties of the final products. These, in fact, are lower if compared with those of similarly shaped objects realized through standard processing methods (e.g., injection molding), due to the inevitable presence of voids. Moreover, the mechanical properties of the printed object are anisotropic and highly dependent on processing parameters, as will be seen later (Mazzanti et al., 2019).

The first optimization loop cycle, seen in Figure 12, is needed to remove the macro defects on the printed surface of the part. An additional process is focused on removing defects B and C from the part. In Figure 13, it is possible to see the result of th e proposed optimization loop on a 3D printed PLA specimen.

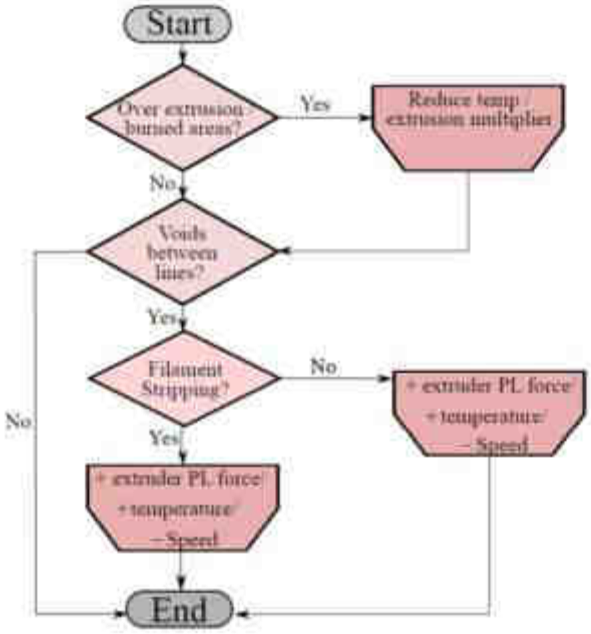

Figure 12: Flow chart of the optimization process (Ferretti et al., 2021).

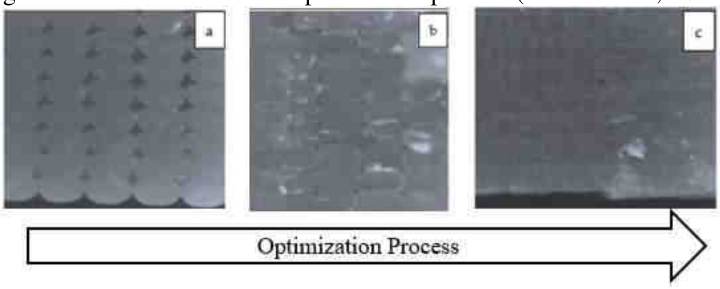

Figure 13. Printing quality on the microscope (20×): (a) not optimized; (b) increasing performance; and (c) fully optimized, modified from (Ferretti et al., 2021).

6. Challenges

One common drawback of FDM printing is that the composite materials have to be in a filament form to enable the extrusion process. It is difficult to homogeneously disperse reinforcements and remove the void formed during the manufacturing of composite filaments. Another disadvantage of FDM printers is that the usable material is limited to thermoplastic polymers with suitable melt viscosity. The molten viscosity should be high enough to provide structural support and low enough to enable extrusion. Also, complete removal of the support structure used during printing may be difficult. Notwithstanding these drawbacks, FDM printers also offer advantages, including low cost, high speed and simplicity. Another advantage of FDM printing is the potential to allow deposition of diverse materials simultaneously. Multiple extrusion nozzles with loading of different materials can be set up in FDM printers, so printed parts can be multi-functional with designed composition (Wang et al., 2017).

Additive manufacturing technology has been developed in the manufacturing industry; however, limited choice of materials and low printing speeds in large-scale production make 3D printing challenging in the industry (Sharma et al., 2021). The most common challenges or drawbacks associated with printing parts with the FDM technology include*: Stepped layers, overhang and bridging*, *stringing, warping, hygroscopicity, and structural inhomogeneity* details are explain briefly in (Klippstein et al., 2017). Looking forward, it is clear that many such challenges lie ahead before the promise of 3D printing can be broadly achieved for building structures, but the recent, rapid development of increasingly realistic proofs-of-concepts is highly encouraging. The continued contributions of pioneering structural engineers are critical to help push this transformative technology from small-scale geometric representation to high-performance, full-scale structures (Mueller, 2016). 3D printing of polymer composites has undergone significant developments in recent years, it is still not widely accepted by most industries. Several limitations of this technology need to be overcome on material, performance and machine; the details are in (W. Xin et al., 2017).

7. Future developments

For future research, studies should be conducted on the use of recycled carbon fibers, so that cheaper and less energy consuming products can be fabricated. These recycled carbon fibers will be helpful in reducing the environmental and financial impacts of additive manufacturing of CFRPs using virgin fibers. Another area for future research work is to study the physical and mechanical properties of carbon fiber reinforced polymers from different aspects, different than the ductile strength and the flexural properties (Pervaiz et al., 2021).

Fully recyclable green composite: fiber reinforced polymer composites were widely used in aerospace, automobile, wind energy, and sport products due to the high specific strength. With dramatically increasing usage, recyclability of composites is becoming a critical limitation to the industrial application. Especially, carbon fiber reinforced composites, the most widely used composites, have not yet been properly recycled probably due to their inherent heterogenous nature of matrix and the reinforcement, leading to poor materials recyclability, in particular for thermosetting composites (Tian et al., 2022).

8. Conclusion

FDM 3D printing is a versatile additive manufacturing technique that has emerged as one of the most prevalent techniques to have garnered the attention of the community. In this paper, the discussed technical parameters and the modification methods in the reviewed literature can significantly improve the mechanical properties and accuracy of FDM 3D-printed products. Mechanical properties and morphological properties of the printed product is studied, the process parameter, machine parameter and structural parameter is optimized to finding the optimum material property of printed products. FDM technology allows the obtaining of unique individual elements with satisfactory properties. Problems with the quality of 3D printing stems mostly from changing of environmental conditions, the required high accuracy calibration of a printer, that is a necessary condition for obtaining proper adhesion of the first layer to the table. In order to obtain correct, non-deformed prints from some materials, direct cooling of the printed item is also necessary. It will certainly be of interest to see whether the 3D printing platform lives up to the expectations of empowering the industrial revolution and whether polymer-based materials, undoubtedly with continued advances, remain the cornerstone of this pivotal technology.

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