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Additive Manufacturing of Polymer Composites: Applications, Challenges and opportunities

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3D printing, or additive manufacturing (AM), is effective at making prototypes and final products from polymer composites. The mechanical limitations of pure polymer components, however, emphasize the need for printable polymer composites with superior performance. The distinctive benefits of 3D printing, such as cost-effectiveness, waste reduction, configurable geometries, and quick material swapping, are not fully recognized by young industrialists, limiting their market penetration. This research review paper provides an overview of the applications, challenges, and opportunities associated with additive manufacturing of polymer composites. The article commences by examining the diverse methodologies employed in the additive manufacturing of polymer composites, encompassing various 3D printing techniques. The paper then examines the extensive spectrum of applications made possible by additive manufacturing of polymer composites, which require components that are both lightweight and possess high strength. Lastly, this paper compares difficulties in additive manufacturing of polymer composites, with respect to several strengths and weaknesses of various 3D printing techniques. The need of future research and interdisciplinary collaboration to overcome challenges and unlock the technology's potential are discussed in details. This article offers valuable insights for researchers, policymakers and industry professionals in understanding current state and future potential of additive manufacturing of polymer composites.

Keywords: 3D printing, Additive manufacturing, Applications, Composite, Polymer

1 Introduction

Additive manufacturing (AM) is also known as 3D printing (3DP) or rapid prototyping. The process of making three-dimensional objects from digital models by printing them in successive layers[1]. Common examples of such materials are plastic, metal, concrete, ceramics, etc[2]. Initial efforts to create 3D printing technology were conducted in the 1980s. In 1981, Hideo Kodama presented a technique for effective photopolymer fast prototyping[3]. It wasn't until a few years later that Charles Hull developed stereolithography. In order to create a 3D model of a product or building using AM technology, a CAD (Computer Aided Design) model must first be created. The .STL file, which contains G-codes for the 3D printer, is generated from the .STL version of the meshed CAD model. The procedure is performed in layers, resulting in less waste and more precision. AM technologies have gone a long way in the past 20 years, and are now widely accepted as a viable means of producing working parts and products. Standard printing materials in AM technology include thermoplastics like polycarbonate (PC)[4], acrylonitrile butadiene styrene (ABS)[5,6], polylactic acid (PLA)[7], and polyamide (PA)[8]. Epoxy resins and other thermosetting polymer materials aren't ideal for 3D printing because they need to be cured with heat or UV radiation[9]. Several commercial uses of polymer composites based on 3D printing are shown in Fig. 1.

Many diverse sectors are benefiting from the innovations made possible by additive manufacturing[10,11]. It allows for the production of lightweight, complicated cross-section regions like honeycomb cells[12] as well as a variety of other components with cavities and angle cuts to control the permissible weight to strength ratio in the aerospace and automotive industries[13]. It's easy for architects to simulate elaborate buildings and evaluate their practicability and use. In the realm of education, 3D printing facilitates the creation of models for the purpose of visualising and understanding physical concepts. Recent years have seen significant advancements in the medical field thanks to the use of AM technology, namely in the fields of tissue engineering and organ printing[14], as well as the creation of prosthetic bones and

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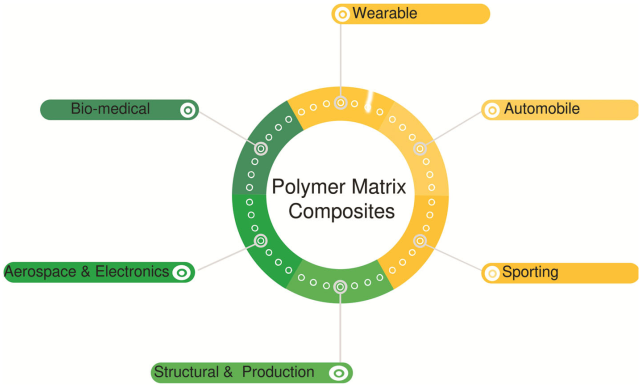

Fig. 1 — Several commercial applications of 3-D Printing based polymer composites.

teeth[15]. However, because to the poor qualities of pure polymer materials, 3DP is still limited to conceptual prototype designing and modelling[16]. Due of these defects, pure polymers have limited usefulness. In 2020, international marketplace for 3D printing services and products was expected to be worth around $12.6 billion USD. In the years after 2020, analysts predict a CAGR of about 17% for the industry.

The mechanical behaviour of 3D-printed composites is a reflection of the qualities of the constituents, the morphology of the reinforcement, the adhesion between the constituents, the volume fraction of the reinforcement, and the manufacturing method, just as it is for traditional composites[17]. The production process for 3DP may be managed by selecting appropriate print settings[18]. The combination of these characteristics is what promises that 3D-printed parts will meet the functional necessities, and possible variations between them makes it an interesting topic to investigate how 3DP parameters affect mechanical qualities[19]. Many of the extrusion process's characteristics are relevant regardless of the filament material being used[20]. Fiber orientation and fibre volume percentage are two examples of material characteristics that are unique to fiber-reinforced composites[21].

Matrix and fillers have been used to improve the functional and structural characteristics of pure 3D-printed polymers in ways that would be impossible with just one component[22]. Particles, fibres, or nanomaterials with superior physical and mechanical qualities are included into polymer matrix composites during production[23]. In the past, complicated polymer and composite geometries were produced by casting or moulding, followed by machining if necessary[24]. Although systematic and orderly, these procedures and approaches are nonetheless incapable of manipulating intricate inner workings. Conversely, additive manufacturing allows for the fabrication of complicated geometries with great precision and low material waste, all under the direction of a computer programme. In this way, AM technologies have completely revamped the industrial sector by making it more accessible and accurate[25].

Over the last three decades, academics' attention has been strongly drawn to 3DP, with a particular focus on developing novel techniques and procedures for manufacturing pure polymers. Polymer matrix composites with improved desired potentials have been 3D printed in amazing ways in recent years. AM and polymer composites are promising in aerospace, automotive, medical, and consumer applications. To fully benefit from this technology, any one understand its difficulties and prospects. So, the purpose of this article is to provide a synopsis of 3DP technology and how it relates to manufacturing polymer composites. We begin by talking about the various printing methods used for polymer composites. Second, we zero in on printing techniques and ways to enhance the characteristics of polymer composites for use in aircraft, electronics, and medicine. New findings are reviewed and compared to older studies to demonstrate development and progress in the discipline. We conclude by discussing the existing and future implementation's limitations, research needs, and difficulties.

2 Materials and Methods

2.1 3DP technologies for polymer composites systems

Modern 3D printing factories are embracing the trend of multimaterial printing, in which many materials may be deposited in a controlled manner and a preblended composite feedstock is used. Both methods can impart unique physicochemical features into the final materials[26]; however, the choice of composite creation is often dependent on the printing system types[27].

2.1.1 Binder jetting (BJ)

The technology behind Binder Jetting is essentially an Inkjet printer with a few adaptations. This method was initially developed at MIT[28]. This method of binding utilises an inkjet rather than a laser. By building up successive layers, a 3D object is created using 2D inkjet printing technology. In this procedure, with printer, moving on two axes, a liquid binder is carefully placed. As with every other type of 3DP, this one starts with the creation of a 3D drawing and its subsequent import into printer software. Powder is constantly being utilised during the printing process, hence a dispenser is employed to provide a steady supply. Sintering, infiltration, heat treatment, or hot isostatic pressing are all necessary processes for the metals and ceramics before they can be used. However, most metals and plastics may be used directly from the printing devices without any additional processing[28].

2.1.2 Direct energy deposition (DED)

This technique is used for fixing things instead of making new ones, unlike other 3D printing procedures. By melting the material during the depositing process, DED techniques simplify the production of materials[29]. The deposition head is utilised in the DED process, and it is composed of an integrated two powder feed nozzles and energy source. Feeding a thin wire or metal powder into the process is how this is done. The component to be produced is typically placed on the platform, and inert gas tubing may also be present. To control where a laser beam and, in certain cases, the powder beam are being deposited, a 4 or 5 axis machine is used. By applying a focused heat source and waiting for the material to solidify layer by layer, the DED process may repair and create new material objects on top of the existing goods.

2.1.3 Fused deposition modelling (FDM)

When it comes to 3D printing with composite materials, FDM is the minimum needed and the standard. Thermoplastics are commonly utilised for Layer by layer, the printer melts polymer filaments of a specific diameter, which is then extruded onto the base platform via the nozzle to produce the finished part. Orientation, layer thickness, raster angle, and air gap may all be adjusted via printing settings[30]. Fused deposition modeling's main advantages are its low cost, quick prototyping, and ease of method. When two nozzles are used, it is possible to print with two different materials at once, creating components with multiple uses. Some issues arise when using FDM with polymer composites. It is challenging to keep filler particles evenly distributed throughout the polymer during extrusion[31]. However, FDM is often only possible with thermoplastic polymers since the material must have a low enough viscosity to be extruded and a high enough melting point to solidify rapidly enough.

2.1.4 Laminated object manufacturing (LOM)

LOM was first made available to the public in 1991 by California-based company Helisys Inc. (now known as Cubic Technologies)[32]. Models are made using a fast prototype method in which metal, plastic, or paper laminates are epoxied together before being sliced using a laser cutter to get the required shape. First, a sheet is adhered to a substrate using a heated roller; secondly, using a mechanical cutter or laser, successive layers are precisely cut and attached in order (forming, then bonding). After one layer is finished, the platform carrying it moves downward, making room for the new sheet of metal to be rolled into place before returning to its starting position to accept the subsequent layer. This procedure is to be repeated until a working prototype is achieved. Lamination, ultrasonic metal seam joining, and computer numerically controlled milling may all fall under the umbrella term UAM [33].

2.1.5 Powder bed fusion (PBF)

PBF is a technique of manufacturing in which the thin layer of powder is used to construct a plate, and a powder is fused using an energy source (laser or electron beam) fuses to conform to the component's shape[5]. Sections in three dimensions can be made by selectively deliquescing powders with a laser. In PBF operations, pulverised material is unfolded over the previously attached layer in preparation for the process of the succeeding layer, producing a discrete rather than continuous output. The finely ground material is delivered by hopper, and a roller or brush distributes it uniformly across the powder bed to produce the platform. The ideal thickness of each sheet of unfolding powder is based on the conditions of the operations and the substance utilised. Other names for Powder Bed Fusion (PBF) include Electron Beam Melting (EBM), Selective Laser Sintering (SLS), Direct Metal Laser Melting (DMLM), Selective Laser Melting (SLM), and Direct Metal Laser Sintering (DMLS)[5].

2.1.6 Selective laser sintering (SLS)

It's another kind of processing that uses powder, much as powder-liquid printing. Instead of using a liquid adhesive to fuse the layers together, a laser beam is used in this process. Each layer of powder is fused together by a high-powered laser beam in a carefully managed atmosphere. At each stage along the way, the piston-operated platform is lowered. Powder that isn't needed for the final product is discarded[34]. Laser intensity, scanning rate, and particle size are crucial for a high-resolution end result. In addition, Lee et al.[35] addressed how using various lasers might modify the technique's settings. This method's key benefits are its high resolution and good quality. Due to the unbounded powder around the created item, this method does not require any additional supports, making it a support-free fabrication method[36]. This method is not without its flaws, such as its high cost, the length of time it takes to complete a single project, and the possibility of porosity if the powder doesn't melt and fuse completely.

2.1.7 Stereolithography (SL)

Stereolithography (SL) is the oldest 3DP technology, and the first 3D printers to be put into action were SL machines utilizing for creating 3D models, prototypes, components, and patterns in since 1920s. Multiple 1970s researchers explored the potential of 3D printing, but it wasn't until 1984 that Charles Hull announced and patented the technology[37]. Understanding the SL process is necessary before attempting to define the word "Stereolithography." To get started, the system creates a CAD file, which is then transformed into an STL file. The geometric information needed by a 3D printer is contained in this STL file. Ingredients include a perforated table, a UV-curable photopolymer liquid, source of laser, and a computer system for managing a procedure. 3D printers function in such a manner that the perforated table is submerged into a tank having liquid after reading STL file type. Because of the perforations, liquid polymer can reach the table as it goes downhill. At the very minute the liquid touches a table, UV laser strikes on a top surface of a photo liquid polymer, instantaneously curing it. This table descends once more to produce a geometric stack in which each successive layer is fused, beginning with a bottom layer. When a last layer is complete, 3D printed part is submerged into a second resin to separate it from liquid polymer. After this step, the 3D printed object may be baked in a UV curing oven, which strengthens the resin's bonds between each layer. All the layers firm up, the strength grows, and the necessary surface polish is achieved within this oven at the set temperature. As a result, the end result of all these steps is the whole product.

The proper selection of AM/3D printing machinery is of utmost importance in order to attain the intended quality, resolution, and mechanical functionality of printed PMC constituents. Various additive manufacturing (AM) techniques, including Fused Deposition Modeling (FDM), Stereolithography (SLA), Selective Laser Sintering (SLS), and Binder Jetting, exhibit distinct capabilities with respect to resolution, build size, and material compatibility. The most popular method, FDM, extrudes molten thermoplastic material through a nozzle to produce the required shape. SLA utilizes a UV laser to selectively consolidate layers of liquid resin. Binder Jetting uses a liquid binder in conjunction with powdered material to make the printed product, whereas Selective Laser Sintering (SLS) uses a laser to selectively fuse powdered materials together. Considerations regarding resolution, part size, material compatibility, and post-processing influence the selection of the printing machine. To get the mechanical properties and quality of the part you want, you need to adjust machine parameters like layer thickness, printing speed, temperature control, and support structures.

The cost-effectiveness of producing polymer composites (PMCs) is of utmost importance as 3D printing technology continues to progress. The costs of materials are subject to variation depending on factors such as the polymer matrix, reinforcements, and specialized materials utilized. The cost of machines varies significantly, spanning from thousands to hundreds of thousands of dollars, which encompasses both maintenance and operating expenditures. The efficiency of production is contingent upon various factors, including but not limited to the speed of printing, the size of the build, and the demands of post-processing. It is crucial to take into account both the size of the build and the level of complexity involved in post-processing. The assessment of these factors facilitates the making of knowledgeable determinations regarding economical 3D printing methodologies for PMCs.

2.2 Applications Novel Materials in 3DP

In order to sustain and expand their research efforts, the concerned community is inspired by the many potential industrial uses outlined above. Recent innovations and practical uses of novel materials in 3DP were the focus of this investigation. The advent of 3D printing has brought about a significant transformation in various sectors, such as aerospace, architecture (via scaled models and facades), medicine (prosthetics and implants), consumer products, automotive (through rapid prototyping and lightweight designs), and education (by facilitating interactive models and prototypes). New materials are cutting-edge substances that provide untapped potential for 3D printing. This technology has enabled customization and innovation in these industries.

The appropriate materials selection is a critical aspect of 3D printing of polymer composites. Number of polymer matrices can be utilized, like thermosets and thermoplastics due to its uniqueness of mechanical, thermal, and chemical properties. The polymer matrix choice depends on several factors like printing process compatibility, desirable mechanical properties, and resistance to environmental. Reinforcements, like particles (ceramics/ metals) or fibers (carbon/ glass) are normally incorporated into the polymer matrix for enhancing a stiffness and strength of the composites. These reinforcements helps to significantly improve a mechanical performance of the printed polymer composite parts. The distribution and orientation of reinforcements play a vital role to determine the mechanical properties and anisotropic behavior of the final printed parts.

2.2.1 Aerospace Application

Since the advent of 3D printing technology, the aircraft sector has reaped its benefits. This technique allows for the creation of products with intricate designed geometries in a more manageable amount of time. In addition, the benefits of 3D printing items for the aerospace sector are their low manufacturing volume, extended usable lives, high temperature resistance, and low weight. To enhance the propellant flow performance, structural integrity, outgassing qualities, and heat resistance of a propulsion component, Kestilä et al.[38] looked into the advantages of plastic 3DP combining by atomic layer deposition (ALD) coating. The results showed that the coating utilised may aid in reducing outgassing on upper temperatures, however data was quiet unclear, thus additional study is required.

2.2.2 Automotive Application

Technical deployments and new design trends from research encourage corporations for building newer models and facelifts in the near term, necessitating the development of new tools or the reshaping of current tools, which poses new issues for the automobile industry[39]. Tools for a stamping technique used to make car body panels and brake pedals have been made using additive manufacturing [40]. On the basis of data, it was unwavering that metal additive manufacturing greatly accelerated the time to tooling for stamping tools while simultaneously improving their performance [41]. The automobile sector has very strict deadlines, therefore this might be a deciding factor in ensuring on-time tool manufacturing [42]-[43].

2.2.3 Consumer Product

In this age of decentralised manufacturing, the prosumer's reimagining of consumer goods is the dominant paradigm. In order to better address the unique creative demands of consumers, this prosumer-based ecology of consumer products will work to reduce the proliferation of duplicate functionality and increase the diversification of features[44]. Medical rapid prototyping (MRP) aided, patient-specific surgical guidelines were discussed by Dahake et al. [45]. (CSGs). Results showed that compared to traditional CSGs, MRP-assisted CSGs significantly increased surgical efficiency in terms of time saved, accuracy of results, and overall cost. Using AM in the repair supply chain decreases amount of stock kept on hand and the number of goods that need to be refunded to consumers due to long repairs [46].

2.2.4 Ceramic Material

3D printing is not yet capable of producing objects from materials like ceramic and concrete since their constituent powder cannot be melt by it. However, at their glass transition temperature, metals and polymers can be fused together. Ceramic has a relatively high melting temperature compared to polymer and metal, making the 3D printing process of ceramic particularly challenging [47].

Ceramic produced by 3D printing has mechanical qualities that are on par with those of ceramic components produced using conventional methods of fabrication. Through improvement of 3D printing settings, present 3D printing technology have also produced ceramic components with no big holes. The manufacture of porous-free ceramic objects is made possible by integrating colloid processing methods with inclusion of additional densifying plan the 3D printing process [47].

2.2.5 Digital and Smart Material

Before mass-producing a product, it's important to test a prototype to make sure it works, get feedback on the design, and spark conversation about the product's concept. Metals, thermoplastics, and photopolymer are just few of the many materials that are appropriate for 3D printing [48]. Addition of fourth dimension to 3D printing allows the item to react to different stimuli.

2.2.6 Electronic Material

Recent decades have seen remarkable progress in use of electronic materials for 3D printing [49]. Some have questioned the viability of this method for mass-producing devices [50]. With today's technology, factories can mass-produce working electronics like inductors, resistors, capacitors, and antennas with no need for secondary processing[51]. Inkjet printing and aerosol jet printing are typical methods of 3D printing electronic material because they use a nozzle for printing rather than coming into direct touch with the electronic material. To create a thin transistor layer that could be utilised on flexible plastic, Kim, Lee, Jeong, and Moon[52] employed silver ink that they manufactured themselves. A separate scientist discovered printing the resistors by a conducting polymer. Findings demonstrated that a greater resistance value may be achieved with excellent reproducibility[53].

2.2.7. Medical Application

Increased use of AM techniques, devices, and materials would bring different possibilities in medicine and dentistry field, thanks to advancements in both current and future technology[54]. SLM, SLA, FDM, and DLP are just some of the 3DP processes that have found applications in the dental field. By referring to a 3D printed physical model of the skull or other structures, surgeons can gain an overview of a complicated structure before doing surgery[55]. Medical apparatus manufacturing [56], Metal implants Powder bed fusion [57], medical regenerated organ and tissue applications[58] and additive biomaterials in medical AM are all examples of other AM processes and application areas[59]. Current 3DP-based polymer composites applications in industry and academia are highlighted in Table 1.

3 Result and Discussions

As can be seen from the aforementioned works, the potential of 3DP and polymer composites in variety of scientific and technical fields is substantial. The

Table 1 — 3DP-based polymer composites Applications

Ref.	Application	3DP Used	Material System	Major Results
60	Aerospace	FDM	ABS/PLA, and short carbon microfibers	Aerospace printing performance was enhanced by filaments containing short carbon micro fibres.
61	Automobile	SLS	Nylon and carbon fiber	The final printed piece seemed complete and within acceptable tolerances.
62	Biomedical	3D printer Model Maker II	PLA, wax, and polysulphonamide	The PLA scaffolds made were designed to have intricate internal architectures that resembled human trabecular bone.
63		Theri Form	PLGA polymer with β-tri-calcium phosphate	New bone area percentage in the scaffolds that were created was significantly higher than in the unfilled control defect.
64	Energy	3D printer HOF1-X1	ABS/Graphene	From room temperature to glass transition temperature, composites' linear thermal coefficient was considerably lower, hence it was essential to introduce tiny thermal stress.
65	Food	Powder bed binder jetting, and inkjet printing, FDM, SLS	Different types of natural polymers	Many different types of 3DPs were shown to be capable of printing a variety of natural edible polymers, as was discussed in the review paper.
66	Smart devices	Direct ink-writing	Reactive diluents, Polyurethane acrylate oligomers, and rheology modifier.	This platform paved the way for the production of useful heterogeneous materials by providing a 5D design space for their creation.
67		FDM	Shape memory and TangoBlack+ polymer fibers.	The biomedical applications for produced shape memory polymer structures are promising because of the advantages of simple production and the adjustable multishape memory effect.
67		FDM	Polymorph and carbon black	Printed electrical sensors that can detect mechanical flexing and capacitance changes were proven to be feasible using the created material and unmodified FDM.
68		3D optical printing	Polyethylene glycol diacrylate	A piezoelectric coefficient of 40 pC/N was observed in composites containing a chemically modified barium titanate nanoparticle at a mass loading of 10%.

automotive, aerospace, structural, energy, biomedical, electrical, and smart device industries are only some of the ones that have benefited from 3D printing and related technology. In addition, adequate feedstock systems are not often easily accessible, which might be a barrier to the development of polymer composites using 3DP technology. In-house polymer composites systems have therefore been documented in the literature, and the 3DP systems' practical value has been elevated as a result. However, these procedures call for thorough optimization of materials' processing states and chemistries, both of which are shown to be extremely successful with respect to the ultimate outputs.

Since 3DP allows for improved process control and the exact positioning of reinforcements in subsequent stages, it is gradually replacing several traditional production processes for polymer composites. Recent articles have also looked at the viability of employing reinforced thermoset polymers for high-stress uses [69,70]. However, using a viscous feedstock is difficult because of the fillers; material systems like these usually necessitate optimising parameters or swapping out specific components. It's also not clear if the highlighted applications in the review's main text will ever be commercialised or will remain in the purview of R&D labs. As an example, the vast majority of newly created biomedical equipment and instruments have not yet received FDA approval (USA).

3D printing method that is commonly cost-effective and available. This device offers a higher degree of adaptableness with respect to rendering it a viable option for the production of functional components, thermoplastic material compatibility, and expediting the prototyping process. 3D printers have a direct functionality and configuration, rendering them easily accessible. However, the method exhibits certain constraints. This technique yields a comparatively lower resolution in contrast to alternative methods, thereby leading to discernible layer lines and surface irregularities. The several strengths and weaknesses of various 3D printing techniques are as shown in Table 2.

Table 3 below details some of the possibilities and difficulties that have been identified in 3DP research on polymer composites. It is essential to demonstrate the repeatability and consistency of produced components to establish a collective outputs of 3DP and polymer composites systems. However, it is challenging to foresee how the printers' current

Table 2 — Comparison of strengths and weaknesses of various 3D printing techniques

Ref.	Process	Weaknesses	Strengths
28	Binder Jetting	Printing requires a substrate, but there aren't many options and the parts aren't very sturdy.	High resolution, multiple copies, and no post-processing are only some of the benefits of this method. An expansive print run is feasible.
29	Direct Energy Deposition	Low quality in terms of resolution and surface finish, lengthy production time, and scarce raw materials.	Allows for denser part fabrication, directional solidification, and improved features; sees widespread use in component refurbishment.
71	Fused Deposition Modelling	The quality is not as high as SLS or SL, A complicated procedure, albeit precise timing must be determined for each individual component.	Making complex shapes is simple, there is no waste produced, the system is highly adaptable, the quality of the finished product is excellent, and the initial investment is low.
60	Laminated Object Manufacturing	Problems with surface quality and dimensional accuracy are common when producing complex items.	Procedural Rapidity; No Extraneous Help Needed Cost-effective and able to handle massive workloads.
72	Powder Bed Fusion	The technique is time-consuming and requires post-processing, and the materials it produces have poor structural characteristics.	Powder recycling, low cost, low maintenance, and a large selection of available materials all round up this advantageous package.
73	Selective Laser Sintering	Large surfaces, Requires post-processing, Tiny holes have a high manufacturing cost and accuracy issues.	Good precision and accuracy; doesn't rely on anything else. SLS is well-suited for mass production and can be used to make complex items that cannot be made using the aforementioned methods.
73	Stereolitho- graphy	The method is time-consuming since so little of the part's surface is exposed to the laser (only approximately 0.15mm), the initial investment is somewhat high, the photosensitive resin is a pain to work with, and overhanging features are especially challenging to create.	Even complex components can be made with relative ease. Casting patterns generated from 3D printed parts using this method benefit from the method's high thermal durability, high surface finish, and versatility.

Table 3 — Opportunities and Challenges in 3DP of polymer composites

SN	Opportunities	Challenges
1	Accreditation: Obtaining certification for the products after they have passed testing is important for expanding their commercial potential. The academic input will help this go smoothly.	Commercial launch is challenging because of varied regulations in different nations.
2	Analyses and inspections: The potential here lies in the ability to conduct tests on printed objects in situations that are very representative of their final settings.	Certainly, it is quite challenging to create a test environment that accurately mimics the real world. Standardized specimens have been used for the most majority of testing, and they may not accurately represent the complexity of the actual geometries.
3	Development of Feedstock: There has been a lot of room for innovation in the creation of specialised feedstock for the many varieties of printing systems, making it possible for the final output to be put to use by the intended audience.	All sorts of specialists, including materials scientists, production experts, and statisticians, will need to work together to accomplish this.
4	Production Print: This requires utilising a variety of optimization and statistical techniques to find the optimal process conditions for effectively making the prints.	The primary difficulty is identifying the most important factors without making a biassed choice that could lead to unintended consequences.
5	Up-gradation of System: Many of available 3DP systems can work with and are tailored for pure polymers. In addition, the benefits could be amplified by combining various 3DP configurations.	Time is required to replace the basic components of 3DP systems in order to tune them to developed PMCs.

capacity will span the wide range from micro to macro. 3D printing with polymer composites has allowed for the creation of some very cutting-edge applications (such as biomedical constructs, energy storage devices, and electronic and electrical devices), it is still necessary to compare these to the industry standard in terms of sustainability, energy, life expectancy, and effectiveness. Many research projects focused on smart product manufacturing are still looking for better product lifecycle managing and real-world applications.

Furthermore, 3DP-based polymer composites, by tightly linking the process development, material development, testing, process control, and certification of 3DP-produced goods, will set the stage for the important advancements of many other developing technologies. Similarly, businesses and corporations should warmly welcome intellectually produced 3DP-based polymer composites. Without the cooperation of academics and industry, this technology will not thrive. Overcoming current manufacturing issues and improving industrial competitiveness requires the use of the multidisciplinary research in the number of research efforts to revolutionise 3DP-based inspection and production methodologies[74]. Furthermore, by combining several 3DP technologies, we may get beyond the material and setting limitations that now plague conventional printing. Efficient multimaterial structures may be printed using a variety of printing methods.

4 Conclusion

Due of its eco-friendliness, 3D printing may one day replace more traditional methods. In addition to saving money, 3D printing is also environmentally beneficial, thus it may help lessen the impact of industrialisation on the planet. New processing methods and functional polymers, as well as the advancements in 3D printing techniques covered here, are transforming the industrial industry and will ultimately benefit society. High-performance items with multi-scale tailored structure and function are becoming increasingly feasible as the resolution of 3D printing approaches the nanoscale. In addition, by planning the chemical and physical characteristics of polymers in advance, we can enable shape-shifting and regulate the movement of the printed goods. While AM technologies are maturing and opening up new avenues of exploration in a number of different sectors, there are still certain obstacles that must be addressed before they can be fully implemented. When used as a roadmap for future research, they have the potential to open up exciting new avenues for the creation and usage of polymers. We provide a number of pressing issues that need to be investigated further.

- Performance: The infiltration and consolidation are utilised as additional post-treatment stages to enhance the functionality of printed items. On the downside, these extra measures lengthen the procedure and add to the already high price tag. The existence of void in printed items is a major contributor to their weak mechanical strength. As a result of weak interfacial connection with the matrix, reinforcing it may make the material even more porous. Therefore, the reinforcement's beneficial effect may be cancelled out by the porosity it induces. There is a substantial need for more study into how to prevent the creation of voids during printing and maintain a strong interfacial contact between the matrix and the reinforcement. Furthermore, printing cannot guarantee the repeatability and consistency of manufactured components; hence, methods to assure the consistent qualities of printed parts need to be explored in detail.

- Material: The availability of printable materials is a major roadblock to the widespread use of 3D printing. Only powder-formed materials, thermoplastic polymer with a low glass transition temperature, and a few photopolymers may be utilised in 3D printing at the present time. But these restricted materials couldn't satisfy the various needs of industry applications, thus the diversity of materials must rise. The adaptability of composites printing technology may be expanded by the synthesis of matrix materials with unique features, the discovery of new reinforcement, and the discovery of a suitable mixing composition. The research and development of sustainable materials holds much promise for lowering material costs and minimising negative environmental effects.

- Machine: Most modern printing methods are laborious, and producing high volumes of components is challenging. These factors prevent widespread use of the technology. It is necessary to create new printing processes that are based on the rapid and scalable processing of materials. The SLA technique, for instance, has been greatly facilitated by the advent of digital light processing. The processing time is drastically cut short since a layer of photopolymer may be synthesised within a single time projection. Other methods also need to be refined in a similar fashion. The importance of feedback systems is another expanding field. Today, if something goes wrong with the printing process, it has to be stopped, which wastes time and resources. A printer with a built-in feedback system may react to any changes made to the printing process.

3D printing of polymer composites has come a long way in recent years, despite the fact that there are still numerous obstacles in the way. The aforementioned works demonstrate that scientists are investigating novel materials and novel applications for 3D printing of polymer composites. As a result of the work presented in this paper, the field as a whole will make greater strides in the future. Polymer composite 3D printing opens up new research possibilities in terms of materials, process control, scalability, and product performance.

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