

**A SYSTEMATIC LITERATURE REVIEW ON APPLICATIONS OF
THERMOPLASTIC MATRIX AND THERMOSETTING REINFORCED
POLYMER COMPOSITES IN 3D PRINTING**

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Abstract

This systematic literature review (SLR) examines the applications, properties, and processing of thermoplastic matrix and thermosetting reinforced polymer composites in 3D printing, providing insights into current advancements and future directions. The study investigates polymer matrix types, the role of reinforcements such as fibers, nanoparticles, and hybrid fillers, and the suitability of various additive manufacturing techniques, while identifying research gaps and industrial challenges. A rigorous SLR methodology was employed, searching peer-reviewed journals, conference proceedings, and databases including Scopus, Web of Science, ScienceDirect, SpringerLink, and IEEE Xplore, covering 2016–2025. Keywords such as “thermoplastic matrix composites,” “thermosetting reinforced polymers,” “3D printing,” “additive manufacturing,” and “nanocomposites” were used. Data extraction focused on polymer types, reinforcement characteristics, processing methods, mechanical and thermal performance, and applications. Findings show that thermoplastic composites (Polylactic Acid, Acrylonitrile Butadiene Styrene, Polyethylene Terephthalate Glycol-modified, Polyether Ether Ketone, Polyetherimide) are preferred for recyclability, processability, and design flexibility, while thermosetting composites offer superior mechanical strength, thermal stability, and chemical resistance. Reinforcements enhance tensile, flexural, and impact properties, with hybrid and functional composites enabling electrical conductivity, self-healing, and antibacterial properties. Advanced 3D printing methods (Fused Deposition Modeling, Fused Filament Fabrication, Stereolithography Apparatus, pellet extrusion) enable precise fiber alignment, layer control, and complex geometries, supporting aerospace, automotive, medical, and industrial applications. Challenges include interfacial bonding, anisotropy, thermal degradation, and limited standardization, highlighting the need for research on high-performance, multifunctional, and sustainable 3D-printed composites.

Keyword-Thermoplastic matrix composites, Thermosetting reinforced polymers, 3D printing, Additive manufacturing, Fiber and nanoparticle reinforcements.

1. Introduction

The rapid progress of additive manufacturing, also known as 3D printing, has had a huge impact on material science and engineering. It has made it possible to make complex shapes

with unmatched precision. Polymer composites are now a major focus of 3D printing since they are very strong, light, and can be used in many different ways. Most of the time, composites are put into groups based on the type of matrix they utilise. Thermoplastic or thermosetting matrices are the two most prevalent forms.[1], [2]. Thermoplastic matrices can melt and then harden again, rendering them simple to use and recycle. This makes them valuable in many areas, like medicine, aeroplanes, and autos. Thermosetting materials, on the reverse hand, go through indestructible curing, which generates connected networks that are stronger, able to survive at high temperatures, and additionally resistant to chemicals.[3], [4].

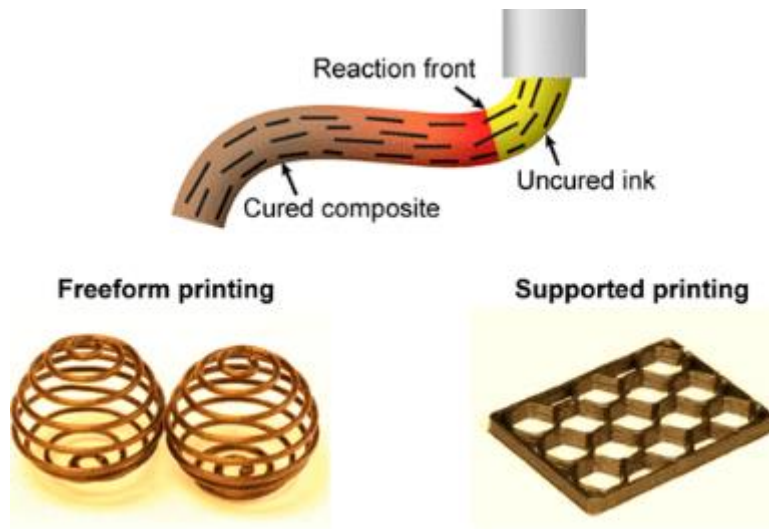


Figure 1 Polymer Composites in 3D Printing

Adding things like fibres, nanoparticles, as well as hybrid fillers to diverse polymers makes them work stronger on their own. Reinforced composites are better for functional or load-bearing usage because they have better tensile strength, resilience to impact, and dimensional stability. By putting thermoplastic or hot-setting matrices together with appropriate reinforcements, you may build materials that can tolerate certain weather and operational needs. As a result, the study of these mixtures in 3D printing has garnered significant interest from both academic or industrial researchers aiming to enhance material performance.[5]. Fused deposition creation (FDM), stereolithography (SLA), and selective laser sintering (SLS) are all examples of 3D printing technologies that have made it easier to work with these complicated composites. FDM usually uses thermoplastic materials because they can melt and flow. SLA and SLS, on the other side, can work with thermosetting polymers very accurately and with a smooth surface.[6], [7], [8], [9]. Using material design in printing technologies makes sure that parts are manufactured with regulated microstructures, stronger mechanical qualities, and fewer defects in the production process. Additive printing lets you produce bespoke shapes and functional colours that are tough to make with other technologies. Even while the sector has had some triumphs, it still has a lot of problems to deal with.[10], [11]. Concerns exist with the adhesion across the matrix or the reinforcement, the variable physical characteristics, and the thermal degradation occurring during manufacture. We need to look into these problems more closely. Also, for large-scale application, it's necessary to find the

best printing temperatures, manage how the filler spreads, and make sure the procedure can be done again and over again. To come up with ways to improve the performance of materials and make polymer composites more useful in advanced manufacturing, it's important to know what these limits are. This systematic review aims to provide a comprehensive examination of the current research landscape concerning thermoplastic matrix and thermoplastic matrix reinforced polymer alloys in 3D printing. This study examines recent research to identify emerging trends, significant applications, and technological advancements. It also examines difficulties that are happening now and what might happen in the future.[12], [13], [14], [15]. The results give material scientists, engineers, or practitioners who want to use additive manufacturing to make high-performance, functional parts important information. A novel technique to produce robust, light-weight, and malleable structures that the could be valuable in many different fields is to combine reinforced composites of polymer with 3D printing.[16], [17].

1.2 Objectives of the Study

- a) To explore the types and characteristics of thermoplastic matrices and thermosetting polymers used in 3D printing applications.
- b) To analyze the role of reinforcements in enhancing mechanical, thermal, and functional properties of polymer composites.
- c) To examine various 3D printing techniques suitable for processing thermoplastic and thermosetting composites.
- d) To evaluate the current applications, advantages, and limitations of reinforced polymer composites in additive manufacturing.
- e) To identify research gaps and propose future directions for the development of high-performance 3D-printed composites.

1.3 Motivation for the Study

Development into advanced polymer composites has grown because industries including aerospace, automotive, biomedical, and electronics need materials that are lightweight, high-performance, and can be changed to fit their needs. Thermoplastic matrices and thermosetting reinforced polymers provide unique advantages that make them great for 3D printing. These advantages include better mechanical strength, thermal stability, and chemical resistance. Additive manufacturing makes it possible to make complex shapes, functional parts, and gradient structures that traditional methods can't make. This could change the way things are made[18], [19], [20], [21]. Despite their potential, challenges like as interfacial bonding, filler dispersion, anisotropic properties, and process optimisation hinder widespread adoption. A systematic review enables a comprehensive understanding of the most recent advancements, technological advances, and practical limitations associated with these composites. This study aims to integrate existing knowledge to aid academics and practitioners in developing more efficient, reliable, and high-performance polymer composites, thereby accelerating their industrial application and fostering innovation in additive manufacturing[22], [23], [24].

1.4 Research Questions

- a) What types of thermoplastic matrices and thermosetting polymers are most commonly used in 3D printing applications?
- b) How do different reinforcements influence the mechanical, thermal, and functional properties of polymer composites?
- c) Which 3D printing techniques are most effective for processing thermoplastic and thermosetting reinforced composites?
- d) What are the current industrial and engineering applications of these composites in additive manufacturing?
- e) What challenges, limitations, and research gaps exist in the development and application of 3D-printed reinforced polymer composites?

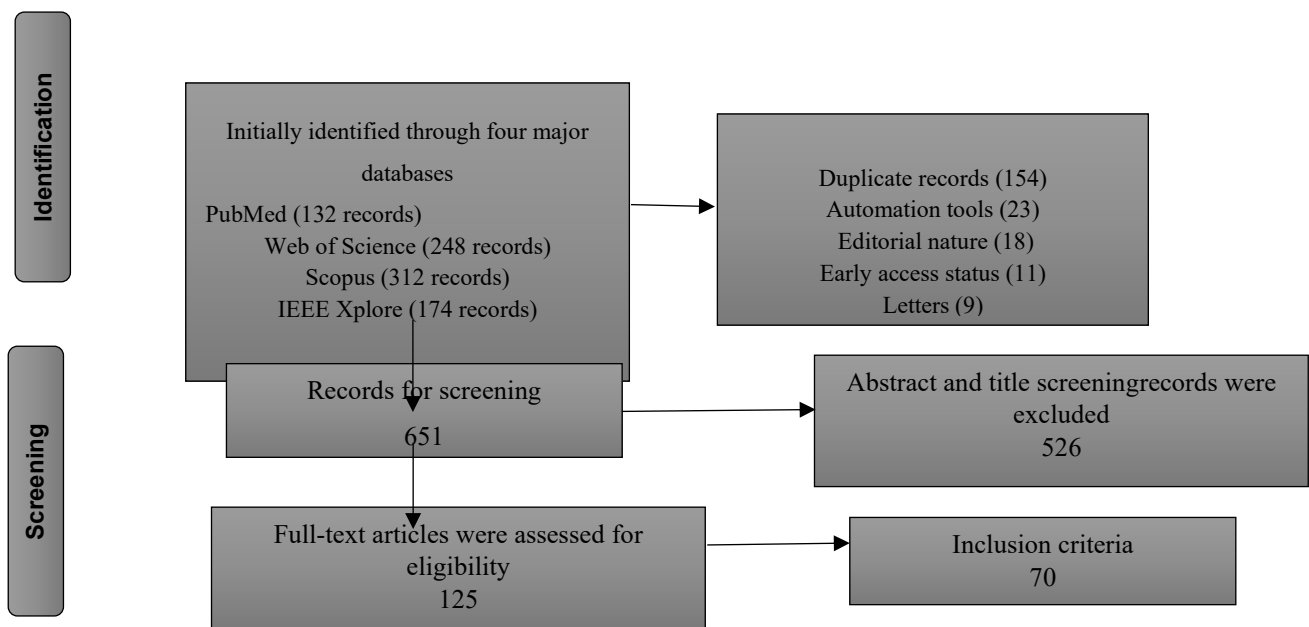


Figure 2 Polymer Composites in 3D Printing SLR

2. Literature Review Methodology

2.1 Systematic Literature Review Approach

A systematic literature review (SLR) was performed to comprehensively locate, assess, and integrate relevant research studies concerning thermoplastic matrix and thermosetting reinforced polymer composites in 3D printing. This technique offers a rigorous and transparent framework that mitigates potential bias, enhances repeatability, and ensures consistent evaluation across numerous studies[25], [26]. The review systematically gathers and examines data, bringing together real-world information to explain how materials behave, how they are processed, and how well they work. The methodology helps find new trends, new technologies,

and gaps in current research, which lays a strong base for future research in additive manufacturing.[27].

2.2 Data Sources and Databases

Peer-reviewed journals, conference papers, and well-known scientific archives were the key places where this in-depth look at the literature got its information. This made confident that this research was true and of the finest quality. Peer-reviewed journals showed that experimental results were correct, and conference proceedings showed new trends and methods in 3D printing. Researchers in several domains, such as materials research, polymer engineering, or additive manufacturing, might see their work in well-known databases. This work is important for learning about both flexible and thermosetting steel composites. We made sure we had all the details we needed by carefully searching through significant databases like Scopus, Web of Science, ScienceDirect, and SpringerLink, and IEEE Xplore. This strategy made it easy to find useful articles, such as novel uses for additive design and basic research.

2.3 Search Strategy and Keywords

Everyone set up with and followed a strict and careful search plan to make sure we discovered all the research that was pertinent to this study. We used Boolean operations like AND, OR, and NOT to put concepts together and make them more specific. This made the found results more informative and correct. Some of the most important words were thermoplastic system composites, thermosetting reinforced materials, 3D printing, manufacturing with additives, mechanical characteristics, and "nanocomposites." This shows who the study looked at both the materials and the way they were used. The search strategy employed synonyms or variations to fix difficulties with words that were used in different ways in different fields. To make sure that everything was the same and easy to find, only publications with English-language content were included. The review concentrated on articles published between 2016 and 2025, emphasising recent advancements, emerging trends, and technological developments in polymer composites for manufacturing with additives, while excluding obsolete or less relevant literature.

2.4 Inclusion and Exclusion Criteria

This systematic review included studies that looked at thermoplastic matrix and thermosetting-rigid polymer composites in relation to 3D printing or additive manufacturing. We only considered research publications that reported testing results, simulated results, or modelling outcomes to make sure they were reliable and rigorous. Also, the papers that are chosen must be accepted by peer-reviewed publications or other trustworthy scientific sources to make sure that the information is correct and trustworthy. The exclusion criteria removed research that had nothing to do with 3D printing uses as well as evaluation articles, editorials, viewpoints, and newspapers in tongues other than English. This made sure that the review process was relevant, clear, and consistent.

2.5 Screening and Selection of Articles

A preliminary search for databases yielded several studies concerning thermoplastic matrix or thermosetting solid composite polymers in 3D printing. The first stage in analysing the papers was to look at their titles and abstracts in order to rapidly discover studies that were related to their research goals. After the first evaluation, all redundant entries were deleted to avoid redundant entries and make certain that the information used for analysis was valid. We thoroughly examined the remainder of the articles to assess the clarity, utility, and quality of their methodologies, experimental findings, and observations. The final selection comprised papers that provided substantial real-world data, comprehensive experimental methodologies, precise material descriptions, and insights into processing techniques and practical applications of additive manufacturing.

2.6 Data Extraction and Synthesis

In every study that was chosen, important data was carefully gathered. This included the kind of polymer matrix, the types and amounts of reinforcement, how to make and process it, its physical attributes like tensile or impact strength, its thermal stability, or the specific uses that were mentioned in relation to 3D printing or additive fabrication. This entire extraction made it possible to compare the manner in which materials acted in a systematic fashion, which helped find patterns, ongoing issues, and novel solutions across studies. The data were then combined to show new technology, changing trends, and how they could be used in real life. This presented a full picture of the way distinct composites acted in different processing situations. This methodical approach gives a complete view of the pros, cons, and future potential of hydrophilic matrix and thermosetting constructed polymer composites in new additive manufacturing technologies.

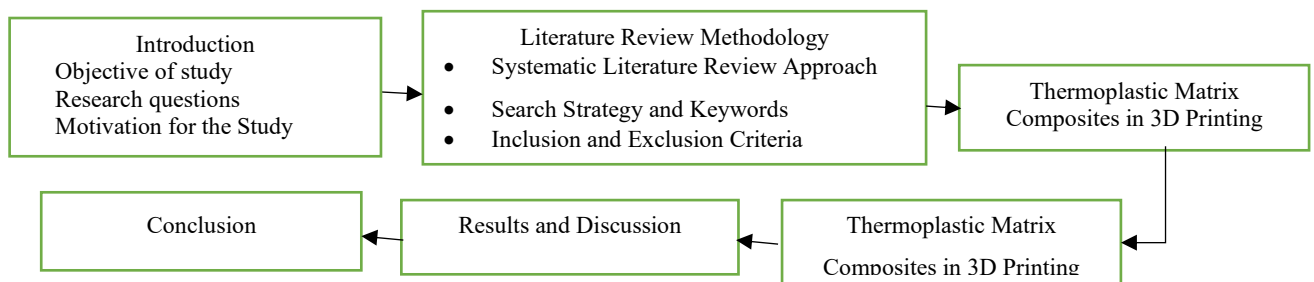


Figure 3 Polymer Composites in 3D Printing

3. Thermoplastic Matrix Composites in 3D Printing

Thermoplastic composites with matrix have garnered considerable interest in additive manufacturing owing to its processability, recyclability, and advantageous mechanical qualities. These composites mix thermoplastic polymers with diverse reinforcements to

generate materials that are durable, light, strong, and endure a long time. This makes them good for many industrial uses.[28], [29].

3.1 Types of Thermoplastic Matrices

Some of the most popular thermoplastic matrices used for 3D printing are polycarbonate (PC), polyether ethylene ketone (PEEK), polypropylene terephthalate glycol (PETG), or acrylonitrile butadiene styrene (ABS). This study selected these polymers based on their melting characteristics, viscosity, thermal stability, and compatibility with other materials. Each form of polymer has its own set of perks and cons. It's easy to print using PLA, and it breaks onto its own. On the other hand, PEEK is quite strong and can handle heat.[30].

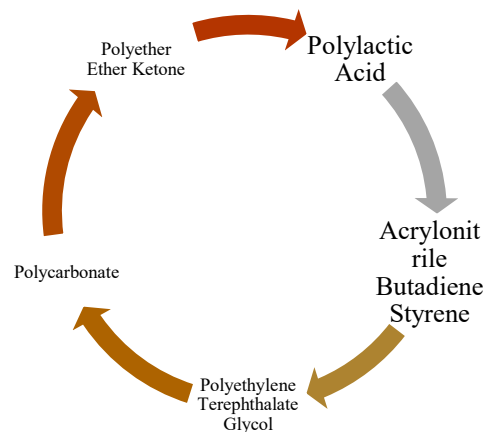


Figure 4 Types of Thermoplastic Matrices

3.1.1 Polylactic Acid (PLA)

PLA is a biodegradable, renewable polymer that is widely used in 3D printing because it has a low melting point, is easy to work with, and has a smooth surface. It is good for making prototypes, models for learning, and functional parts that don't need a lot of load[31].

3.1.2 Acrylonitrile Butadiene Styrene (ABS)

Compared to PLA, ABS is tougher, more resistant to impacts, and more stable in size. It is often used for working prototypes, consumer items, and applications that don't need very high mechanical performance[32].

3.1.3 Polyethylene Terephthalate Glycol (PETG)

PETG combines strength, flexibility, and chemical resistance. Its balanced properties make it suitable for industrial components, containers, and applications where moderate mechanical and thermal performance is required[33].

3.1.4 Polycarbonate (PC)

PC provides excellent toughness, heat resistance, and dimensional stability. It is widely used for engineering parts, protective housings, and components subjected to higher mechanical or thermal loads.

3.1.5 Polyether Ether Ketone (PEEK)

PEEK is a high-performance polymer known for exceptional mechanical strength, chemical resistance, and thermal stability. It is ideal for aerospace, medical implants, and demanding industrial applications.

3.2 Reinforcements Used in Thermoplastic Composites

In order to make the mechanical, thermal, and functional properties of thermoplastic matrix composites used in 3D printing better, they need reinforcements. Adding fibres, nanoparticles, or hybrid fillers to the base polymer makes the composites stronger in both tension and flexion, makes them more resistant to impacts, and makes them more stable at high temperatures. This makes them good for both structural and functional uses. Some of the most common types of reinforcements are short fibres, continuous fibres, and particle fillers. Carbon fibres are stronger than glass fibres, stiffer, and more stable in terms of size. On the other hand, glass fibres are better and cheaper than other materials for reinforcing. Natural fibres like jute, hemp, and bamboo are good for the environment and have great mechanical properties. Nanoparticles such as graphene, silica, or metal oxides enhance surface adhesion, improve thermal conductivity, and increase barrier strength. This means that you can develop composites that can accomplish many different things. Hybrid fillers, which are made up of fibres and nanoparticles, work together to improve the performance of composites[34], [35]. The features, size, form, and alignment of the reinforcements have a big effect on the load distribution, failure mechanisms, and anisotropic properties of printed parts. Also, in 3D printing, you need to keep the material moving and make sure it is properly aligned to minimise weak spots, warping, and delamination. By making the properties of reinforcement better, it is possible to develop composites that are specifically designed for the aerospace, automotive, medical, and industrial sectors. These composites strike a balance between strength, durability, and usefulness[36].

3.3 Processing Techniques for 3D Printing

Fused deposition modelling (FDM), fused filament fabrication (FFF), and pellet-based extrusion are the three basic approaches to produce thermoplastic composites for 3D printing. FDM is popular because it is easy to use, affordable, and works with fiber-reinforced filaments. This lets you construct complicated designs by regulating how the layers are deposited. FFF, which is a kind of FDM, puts open-source frameworks and bespoke filaments at the top of the list[37], [38]. Researchers can test out alternative materials and reinforcing loads to see how they can improve the way things work. Pellet-based extrusion is good for making things in factories because it lets you add more filler, use resources better, and grow. Nozzle temperature, print speed, layer height, and infill density are all important process variables that affect the quality, dimensional accuracy, and mechanical qualities of printed parts in all methods. Effective optimisation reduces defects like warping, delamination, and voids. This makes sure that thermoplastic composites have the right strength, thermal stability, and surface polish for use in many industries for both functional and structural purposes[39], [40].

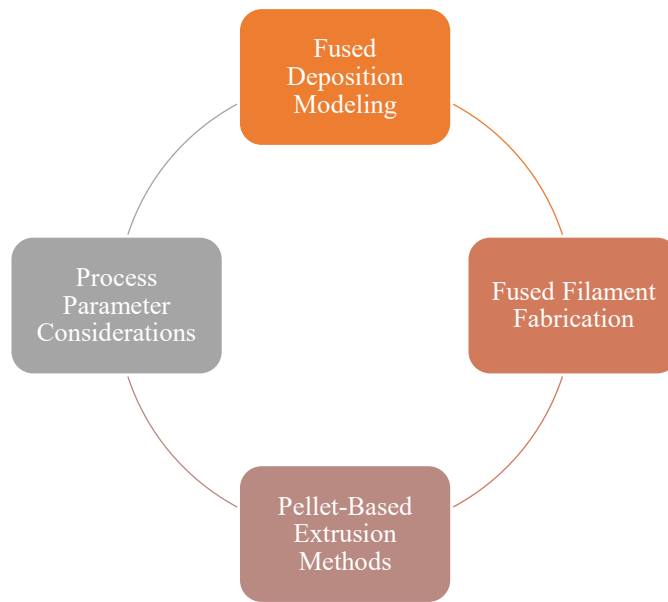


Figure 5 Process Parameter Considerations

3.3.1 Fused Deposition Modeling (FDM)

FDM is the most common way to 3D print thermoplastic composites because it is flexible, easy to use, and cheap. The process involves melting a thermoplastic filament and pushing it through a heated nozzle, which lays down layers of material to slowly build up the final three-dimensional shape. This layer-by-layer deposition makes it easy to precisely control the geometry of the part, the thickness of the walls, and the patterns of the infill. This makes it possible to make complex shapes and functional parts that would be hard or impossible to make using traditional methods. FDM works with a lot of different reinforced filaments, like short or long fibres, nanoparticles, or hybrid fillers. These things make the material more effective at keeping heat. It's easy to get at and use, thereby rendering it perfect for quick testing, school projects, and miniature industrial uses, especially where durability and resilience aren't extremely important. To make sure that results are of high calibre and have fewer faults, it is very important to get the FDM parameters right, such as the nozzle setting, layer height, or print speed.

3.3.2 Fused Filament Fabrication (FFF)

Fused Filament manufacture (FFF) is a kind of 3D printing technique that is like Fused Deposition Animation (FDM). Both technologies function by putting a thermoplastic thread through the heated nozzle in order to slowly build up things. FFF talks a lot about open-source platforms for software and hardware. These make it easy to pick, change, and test a variety of filament. You can employ a lot of different thermoplastic matrices, such PLA, ABS, PETG, and powerful polyethylene, together with microscopic particles, fibres, and hybrid additives to make the material stronger, more flexible, and more useful.[41], [42]. FFF is very helpful for research and development since it lets you look at new combinations of materials and composite structures that aren't on the market yet. FFF also lets researchers quickly develop and test prototypes, which helps them understand more about how materials behave, how well

they stick to one other, and how well they spread out reinforcing. This enables them build better composites for application in technology, medicine, and industry[43].

3.3.3 Pellet-Based Extrusion Methods

In pellet-based extrusion, thermoplastic polymer pellets, sometimes combined with reinforcements like fibres or nanoparticles, are put into an extruder. The pellets are turned into a liquid and then used in layers to make the part that is needed. This technology allows for the addition of more filler than filament-based methods, which improves the mechanical and thermal qualities. It is also cheaper since raw polymer pellets cost less than pre-extruded filaments. Pellet extrusion gives you more control over making composites, and it's especially useful for industrial uses that need bigger, stronger, and longer-lasting parts for functional or structural reasons[44].

3.3.4 Process Parameter Considerations

As 3D printing thermoplastic composites, a number of process parameters have a big effect on the quality and performance of the parts that are made. Nozzle temperature, print speed, layer thickness, and infill density are all important elements that have a big effect on surface polish, dimensional accuracy, and mechanical qualities. It is very important to carefully control the temperature of the nozzle to ensure that the polymer melts properly and that the layers stick together properly. Too much heat can cause the polymer or reinforcement to break down. The speed of the print impacts how well the layers stick together and how strong the structure is. If the speed is too high, the layers could not stick together well or fuse completely[45]. The thickness of the layers affects the smoothness and strength of the surface. Thinner layers give better resolution but take longer to print. The infill density determines the part's interior structure, mass, and stiffness. You can fix problems like warping, splitting, or void formation by changing these parameters. This ensures that parts made using 3D printing are always of good quality and may be used for both structural and functional purposes.[46].

3.4 Mechanical and Thermal Properties

Thermoplastic matrix composites are far better at handling heat and stress than unreinforced polymers. This makes them suitable for 3D-printed items that are both functional and structural. Adding things like fibres, nanoparticles or hybrid fillers to the material makes it stronger in tension, bends, and impact, as well as harder so it can withstand more weight and stress.[47]. The thermal qualities are better, which implies that parts can stay strong even when it's hot and after a long time of use. The type, size, setup, and alignment of reinforcement, as well as the strength of the bond within the matrix and filler, are all key aspects that determine how well the composite performs as a whole. Carbon fibre- reinforcement PLA or ABS is more stiffer, stronger, and more resistant to heat than regular PLA or ABS. This makes them great for models that need to bear weight and survive a long period.[48], [49]. Adding fibres from glass makes things stronger and less likely to deform, while adding small particles like carbon or silica makes things better at conducting heat and blocking it. Reinforcements that are properly aligned and spread out regularly eliminate weak spots, stop anisotropic actions, and stop tearing or breaking during printing. Thermoplastic compounds that are manufactured just for

aeronautical, automotive, healthcare and industrial uses are achievable when the properties that comprise the matrix and reinforcements are improved. These composites are light, cheap to make, and work well.

3.5 Applications of Thermoplastic Composites in 3D Printing

Thermoplastic composites are widely used in the automotive, aerospace, medical, consumer, and industrial industries because they are strong, long-lasting, and light. In the automotive industry, ABS and PLA reinforced with carbon or glass fibres make it easier to make high-performance brackets, panels, and structural parts. This improves fuel efficiency and speeds up prototyping. PEEK and carbon fibre composites are used in aerospace for UAV frames and structural parts because they have great strength-to-weight ratios and are stable at high temperatures. Reinforced PEEK composites are used in medicine for prosthetics, implants, and surgical guides because they are safe for the body and dependable[50]. These composites are used in consumer and industrial products to make strong tools, enclosures, and precision jigs that combine usefulness with the flexibility of additive manufacturing.

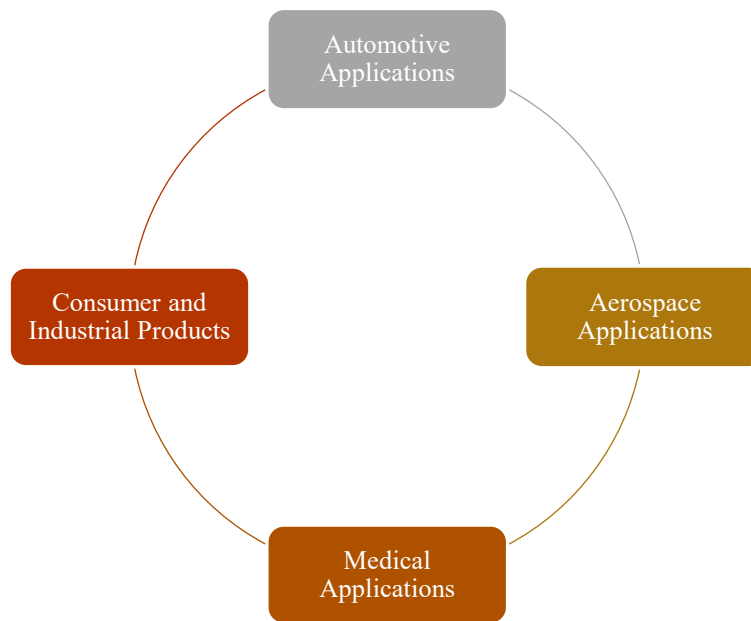


Figure 6 Applications of Thermoplastic Composites in 3D Printing

3.5.1 Automotive Applications

Thermoplastic composites are extensively used in the automotive industry to produce lightweight, durable, and high-performance components. Materials such as carbon fiber or glass fiber-reinforced ABS and PLA are utilized for brackets, interior panels, and structural elements. These composites provide enhanced tensile and impact strength, reduce overall vehicle weight, and improve fuel efficiency. Their ability to be 3D printed allows for rapid prototyping and the fabrication of customized components tailored to specific design requirements[51].

3.5.2 Aerospace Applications

In aerospace, reinforced thermoplastic composites like PEEK and carbon fiber/PLA are used for drone frames, UAV components, and lightweight structural parts. Their high strength-to-weight ratio, thermal resistance, and dimensional stability make them suitable for components exposed to mechanical stress, vibration, and fluctuating temperatures. Additive manufacturing enables efficient production of complex geometries that are otherwise difficult to achieve with traditional methods[52].

3.5.3 Medical Applications

Thermoplastic composites are applied in the medical field for prosthetics, surgical guides, implants, and biomedical devices. PEEK composites with carbon or ceramic reinforcements are particularly valued for their biocompatibility, chemical resistance, and mechanical reliability, ensuring safe, long-lasting, and functional medical components[52].

3.5.4 Consumer and Industrial Products

Consumer goods, such as electronics housings, sporting equipment, and household tools, leverage reinforced thermoplastic composites for durability and performance. In industrial applications, composites are used in tooling, jigs, and fixtures, where thermal stability and dimensional accuracy are critical.

4. Trends and Emerging Applications

Recent progress in thermoplastic and thermosetting composites focusses on creating new materials that combine several types and improve their performance. Adding nanoparticles or fibres to high-performance polymers like PEEK and PEI makes them stronger, more stable under heat, and more useful. Functional composites have properties like electrical conductivity, the ability to heal themselves, or antimicrobial properties. Hybrid composites, on the other hand, use different fillers to get synergistic benefits. The use of technologies like FDM, FFF, and pellet extrusion makes it easier to make complex, lightweight, and unique parts. These changes make it possible to use these technologies in more places, like aviation, cars, medical devices, electronics, and consumer goods[64], [65]. They also improve efficiency, sustainability, and high-performance solutions in growing industrial and technological fields.

4.1 Innovations in Composite Materials

Recent research on thermoplastic and thermosetting composites focusses on making their mechanical, thermal, and functional properties better by using new materials. High-performance thermoplastics like PEEK, PEI, and PPS are being used more and more in tough situations since they are very strong and can withstand heat. To make polymers stiffer, stronger, better at conducting heat and electricity, and more resistant to wear and tear, nanoparticles like graphene, carbon nanotubes, silica, and metal oxides are added to them. Engineers are making bio-based and recyclable polymers that are better for the environment while still working[66]. Also, advanced processing methods improve the adhesion between the matrix and the reinforcement, which reduces voids and flaws that could harm performance. These improvements in materials make composites able to handle extreme conditions, heavy loads, and changes in temperature[67], [68]. This makes them more useful in the aerospace,

automotive, electronics, and biomedical fields, and it also makes it easier to make lightweight, strong, and high-performance 3D-printed parts.

4.2 Hybrid and Functional Composites

Hybrid composites combine different types of reinforcements, like carbon fibres and nanoparticles, to make them stronger, tougher, and stiffer. Functional composites are made to have better properties including electrical conductivity, temperature control, the ability to heal themselves, and antibacterial properties. These make them good for smart devices, wearable electronics, and biomedical implants. Designers can adapt composites to fit specific operating needs by carefully choosing combinations of matrix and reinforcement[69]. This makes the plastics more flexible and improves how well they work mechanically. It is easier to control the shape of the inside of a framework, the direction of the fibres, and the placement of fillers with additive manufacturing. This makes the building more robust and useful. More and more, hybrid and functional materials are being employed in high-performance applications like lightweight aeroplane parts, antiviral medical implants, and car parts that need to be strong and conduct electricity. This shows how adaptable and helpful they could be in future technology.

4.3 Integration with Additive Manufacturing Technologies

The way things are manufactured is changing because of the mix of sophisticated composites and 3D printing methods like FDM, FFF, and pellet extrusion. Additive manufacturing makes it easier to produce unique parts, lightweight structures, and intricate shapes that are hard to make with traditional processes. It is able to accurately deposit reinforced thermoplastic and hybrid composites in layers, with controlled fibre orientation, layer thickness, and infill density. This makes the materials stronger and better at handling heat. This combination makes it possible to swiftly develop prototypes, test how they work, and make products in the aerospace, automotive, medical, and electronics areas, whether they are small or large[70]. New technologies like multi-material printing, gradient composites, and smart architectures make it easy to incorporate sensors, conductive channels, or self-healing characteristics to a single part. The utilisation of advanced composites and additive manufacturing together is coming up with new ideas, making things more efficient, and giving businesses more options.

5. Results and Discussion

5.1 Key Findings from the Literature

The systematic literature review demonstrates that thermoplastic and thermosetting reinforced polymer composites play a vital role in advancing 3D printing technologies. Thermoplastic composites, including PLA, ABS, PETG, and high-performance polymers such as PEEK and PEI, are widely adopted due to their ease of processing, recyclability, and design versatility. Thermosetting composites, on the other hand, offer superior mechanical strength, stiffness, and thermal stability, making them suitable for load-bearing and structural applications. The inclusion of reinforcements such as carbon fibers, glass fibers, natural fibers, and nanoparticles (graphene, silica, metal oxides) significantly enhances tensile strength, impact resistance, and thermal behavior. Hybrid composites and functionalized polymers expand the scope of applications by adding electrical conductivity, thermal management, or antibacterial properties,

enabling their use in aerospace, automotive, medical devices, consumer products, and tooling. Optimization of process parameters such as nozzle temperature, layer height, print speed, and infill density is consistently highlighted as critical to achieving high-quality, defect-free 3D-printed parts. Collectively, the literature emphasizes the synergistic role of material selection, reinforcement type, and process control in maximizing performance and application potential.

5.2 Gaps Identified in Current Research

Despite extensive research, several gaps persist. Standardized testing protocols and performance benchmarks for 3D-printed composites are limited, making cross-study comparisons challenging. Long-term durability studies, including fatigue, creep, and thermal cycling, are often lacking. The interfacial bonding between matrix and reinforcement, which significantly affects mechanical and thermal properties, requires deeper investigation, particularly in hybrid and nanocomposite systems. Research on sustainable, recyclable, and bio-based composites remains insufficient, even though environmental concerns are increasingly critical. Additionally, industrial-scale adoption faces challenges due to variability in print quality, material behavior under high filler loading, and complex geometry optimization. There is also a limited focus on multi-functional composites, such as electrically conductive or self-healing materials, for advanced applications. Addressing these gaps will strengthen both the academic understanding and practical implementation of 3D-printed composite materials.

5.3 Implications for Future Research and Industry

The findings suggest that future research should prioritize high-performance, multifunctional composites, exploring hybrid materials and nanofiller integration for enhanced mechanical, thermal, and functional properties. Standardization of process parameters, testing methods, and material characterization will ensure consistency and reliability. Environmental sustainability should be integrated, promoting recyclable, biodegradable, or bio-based polymers in additive manufacturing. For industry, the insights highlight opportunities to produce lightweight, durable, and custom-designed components for aerospace, automotive, medical, and consumer applications. Collaboration between academia, research institutions, and manufacturers is essential to translate laboratory findings into scalable, industrial solutions, leveraging the potential of advanced composites for both functional and structural applications while minimizing costs and maximizing performance.

Table 1: Comparative Analysis of Thermoplastic and Thermosetting Polymer Composites

Authors/year	Comparison Criteria	Thermoplastic Composites	Thermosetting Composites	Remarks / Applications
Musa/2025 [53]	Basalt Fiber Reinforcement	NC-grafted BFRP improves bonding, strength, and	NC-grafted BFRP improves bonding,	NC-grafted BFRP improves bonding,

		performance effectively.	strength, and performance effectively.	strength, and performance effectively.
Abebe/2025 [54]	Nanoparticle Reinforcement	Improves toughness and impact resistance; processing flexibility	Nano-alumina enhanced polyester/wool-glass composites; high strength and rigidity	Ideal for lightweight, high-strength structural applications in automotive and construction industries
Sachini/2025 [55]	3D Printing Applicability	3D Printing Applicability	3D Printing Applicability	3D Printing Applicability
Niu/2025 [56]	Fiber Hybridization	Flax-basalt intra-yarn hybridization improves strength, impact resistance, and recyclability	Limited fiber integration, less flexibility, and poor recyclability under thermal stress	Ideal for high-strength, lightweight structures in automotive, furniture, and structural applications
Feng/2025 [57]	Creep Performance	Exhibits excellent long-term creep resistance and high tensile stability over extended durations	Shows moderate creep resistance but lower long-term performance under sustained stress	Ideal for prestressed concrete, bridges, and long-service civil infrastructure applications
Pizzorni/2025 [58]	Additive Manufacturing Flexibility	Enables FDM 3D printing of complex shapes, functional assemblies, and repairs	Limited adaptability; requires molds and curing, less suitable for intricate geometries	Limited adaptability; requires molds and curing, less suitable for intricate geometries

Alzahrani/2025 [59]	Defense Applications	Lightweight, impact-resistant, and adaptable for complex geometries	High-strength, rigid, excellent energy absorption, but limited recyclability	Ideal for ballistic protection, helmets, aircraft, and advanced military equipment
Radzi/2022 [60]	Natural Fiber Integration	Bamboo fibers improve biodegradability, light weight, and cost-efficiency	Strong, durable, and rigid, but less eco-friendly and harder to recycle	Suitable for sustainable construction, automotive panels, and low-cost structural applications
He/2021 [61]	3D Printing Capability	Limited by melt-processability, requires rapid solidification	Can be processed with direct-ink-writing, UV or thermal curing, enabling complex structures	Suitable for 3D/4D printing, biomedical devices, and functional composite components
Alshammari/2021 [62]	Carbon Fiber Reinforcement	Recyclable, flexible, easily processed, short production time, high strength	Rigid, strong, durable, longer curing time, limited recyclability	Ideal for aerospace, automation, renewable energy, and high-performance industrial applications
Armstrong/2020 [63]	3D Printing with PIP	Limited compatibility; matrix infiltration challenging, requires careful thermal control	Compatible with binder jetting and multiple PIP cycles; improves density,	Suitable for high-temperature, porous-resistant components in aerospace,

			strength, and thermal properties	energy, and industrial applications
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6. Conclusion

The comprehensive evaluation of thermoplastic matrix and thermosetting reinforced polymer composites in 3D printing underscores their critical role in advancing additive manufacturing technologies. Thermoplastic composites like PLA, ABS, PETG, and high-performance polymers like PEEK and PEI are good for making prototypes quickly and for parts that need to work. They are easy to recycle, process, and are flexible. Thermosetting composites are better for structural uses because they are stronger, more stable at high temperatures, and more resistant to chemicals. Adding reinforcements like carbon, glass, natural fibres, and nanoparticles greatly improves tensile, impact, and thermal properties. Hybrid and functional composites, on the other hand, make it easier for electricity to flow, heal themselves, and fight germs. Advanced 3D printing methods including FDM, FFF, SLA, and pellet extrusion allow for precise control over fibre orientation, layer thickness, and infill density. This improves the quality and performance of the parts. Despite these developments, challenges remain, including interfacial bonding issues, anisotropic mechanical properties, thermal degradation, and the lack of standardised testing methodologies, which impede widespread industrial adoption. Shortcomings in sustainable and recyclable materials, multifunctional composites, and long-term durability studies underscore prospective directions for more research. Future research must focus on the amalgamation of hybrid and nano-reinforcements, the standardisation of process parameters, and the exploration of environmentally sustainable materials. These composites give businesses the chance to make strong, lightweight, and custom-designed parts for use in aerospace, cars, medicine, and everyday items. Reinforced polymer composites in 3D printing are a revolutionary new way to make superior functional and structural parts by combining new materials with the flexibility of additive manufacturing.

References

[1] E. Rogha *et al.*, “Flexural properties of additively manufactured continuous fibre reinforced thermoplastic polymers after exposure to elevated temperatures,” *Compos. Commun.*, vol. 54, no. September 2024, p. 102279, 2025, doi: 10.1016/j.coco.2025.102279.

[2] Y. Lyu, A. Li, J. Wu, and D. Yang, “3D printing of continuous carbon fibre reinforced high-temperature epoxy composites,” *Compos. Commun.*, vol. 56, no. March, p. 102397, 2025, doi: 10.1016/j.coco.2025.102397.

[3] T. A. Abualbandora, M. G. Alshneeqat, and A. H. I. Mourad, “Impact of 3D printing parameters of short carbon fiber reinforced polymer CFRP on the mechanical and failure performance: Review and future perspective,” *Next Mater.*, vol. 8, no. December 2024, p. 100645, 2025, doi: 10.1016/j.nxmater.2025.100645.

[4] H. Sharma *et al.*, “From composition to performance: Structural insights into polymer composites,” *Next Mater.*, vol. 8, no. December 2024, p. 100852, 2025, doi:

10.1016/j.nxmate.2025.100852.

- [5] A. A. Shamsuri, S. N. A. Siti Nurul, M. A. Zarin, and K. Abdan, "Properties and potential applications of polymer composites containing secondary fillers," *Rev. Adv. Mater. Sci.*, vol. 64, no. 1, 2025, doi: 10.1515/rams-2025-0105.
- [6] B. Dochev, D. Dimova, F. Ublekov, M. Zagorski, and N. Tomanov, "Development of composites based on thermosetting polymers with cenospheres fillers," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1532, no. 1, 2025, doi: 10.1088/1755-1315/1532/1/012036.
- [7] R. I. Antor, A. M. Bithi, and A. M. Nahin, "Variation in Mechanical Properties of Polymer Composites With Reinforcements From Different Animal Origins—A Comprehensive Review," *Int. J. Polym. Sci.*, vol. 2025, no. 1, 2025, doi: 10.1155/ijps/4184239.
- [8] R. Bernardy and Y. Liu, "Three-Dimensional Printing of Polymer Composites: Manufacturing and Mechanics," *J. Compos. Sci.*, vol. 9, no. 1, 2025, doi: 10.3390/jcs9010033.
- [9] Y. Wang, Y. Ding, K. Yu, and G. Dong, "Advancing High-Performance Composites in Additive Manufacturing (AM) Through Pre-Impregnation and Direct Ink Writing for Scalable 3D Printing," *J. Compos. Sci.*, vol. 9, no. 5, 2025, doi: 10.3390/jcs9050218.
- [10] J. C. Clark, W. G. Davids, R. A. Lopez-Anido, A. P. Schanck, and C. A. Sheltra, "Continuously Formed Fiber-Reinforced Thermoplastic Composite Rebar for Concrete Reinforcement," *J. Compos. Sci.*, vol. 9, no. 7, pp. 1–20, 2025, doi: 10.3390/jcs9070378.
- [11] N. H. Padmaraj, V. Siddish, G. T. Mahesha, I. V. Thara Reshma, and S. Hegde, "Development of sustainable thermoplastic and thermoset based Areca Husk and Coir Fiber reinforced composites for acoustic applications," *Mater. Res. Express*, vol. 12, no. 7, 2025, doi: 10.1088/2053-1591/ade41.
- [12] A. Gupta, "Processing, Characterization and Engineering Applications of Fiber-Reinforced Thermoplastic Polymer Composites," *Polymers (Basel)*, vol. 17, no. 11, 2025, doi: 10.3390/polym17111511.
- [13] H. Zheng *et al.*, "3D Printing Continuous Fiber Reinforced Polymers: A Review of Material Selection, Process, and Mechanics-Function Integration for Targeted Applications," *Polymers (Basel)*, vol. 17, no. 12, pp. 1–32, 2025, doi: 10.3390/polym17121601.
- [14] C. Yang, K. Wang, J. Zhang, and A. Codolini, "Additive Manufacturing of Fibre-Reinforced Polymer Composites," *Polymers (Basel)*, vol. 17, no. 12, pp. 1–7, 2025, doi: 10.3390/polym17121652.
- [15] N. Diaz Armas, G. Bhandari, S. Kodra, J. Zhang, D. Kazmer, and J. Mead, "Additive Manufacturing of Thermoset Elastomer–Thermoplastic Composites Using Dual-Extrusion Printing," *Polymers (Basel)*, vol. 17, no. 13, 2025, doi: 10.3390/polym17131800.

- [16] M. Bukvić, S. Milojević, S. Gajević, M. Đorđević, and B. Stojanović, “Production Technologies and Application of Polymer Composites in Engineering: A Review,” *Polymers (Basel)*, vol. 17, no. 16, pp. 1–28, 2025, doi: 10.3390/polym17162187.
- [17] Y. Long, Z. Zhang, Z. Bi, K. Fu, and Y. Li, “3D-Printed Continuous Flax Fiber-Reinforced Composites Based on a Dual-Resin System,” *Polymers (Basel)*, vol. 17, no. 18, pp. 1–18, 2025, doi: 10.3390/polym17182515.
- [18] M. Andreozzi *et al.*, “Sustainability assessment of autoclave and 3D printed composites with thermosetting and thermoplastic matrices,” *Int. J. Adv. Manuf. Technol.*, vol. 138, no. 7, pp. 3221–3237, 2025, doi: 10.1007/s00170-025-15689-3.
- [19] C. F. Dojan, M. Ziaee, A. Masoumipour, S. J. Radosevich, and M. Yourdkhani, “Additive manufacturing of carbon fiber-reinforced thermoset composites via in-situ thermal curing,” *Nat. Commun.*, vol. 16, no. 1, pp. 1–10, 2025, doi: 10.1038/s41467-025-59848-2.
- [20] S. Islam, F. E. Karim, M. R. Islam, M. A. Saeed, K. A. Alam, and M. M. Khatun, “Thermoset and thermoplastic polymer composite with date palm fiber and its behavior: A review,” *SPE Polym.*, vol. 6, no. 1, pp. 1–31, 2025, doi: 10.1002/pls2.10157.
- [21] S. Islam *et al.*, “Thermoset and thermoplastic polymer composites reinforced with flax fiber: Properties and application—A review,” *SPE Polym.*, vol. 6, no. 1, pp. 1–33, 2025, doi: 10.1002/pls2.10172.
- [22] W. Sharuzi, W. Harun, and F. Ahmad, “The Nexus of Sustainability and Energy Technology Journal Sustainable Additive Manufacturing of Polymer Composites : A Review Sustainable Additive Manufacturing of Polymer Composites : A Review,” vol. 1, no. 2, 2025.
- [23] A. E. Ali, mohammed . . abdellah, M. Gronfula, and G. T. Abdel-Gaber, “Reinforcing Polymers with Date Palm Seeds: A Path to Greener Composites – A Review,” *SVU-International J. Eng. Sci. Appl.*, vol. 6, no. 2, pp. 1–16, 2025, doi: 10.21608/svusrc.2025.359294.1271.
- [24] D. Behera, S. S. Pattnaik, D. Nanda, P. P. Mishra, S. Manna, and A. K. Behera, “A review on bamboo fiber reinforced composites and their potential applications,” *Emergent Mater.*, vol. 8, no. 1, pp. 157–172, 2025, doi: 10.1007/s42247-024-00832-9.
- [25] V. Shanmugam, K. Babu, G. Kannan, R. A. Mensah, S. K. Samantaray, and O. Das, “The thermal properties of FDM printed polymeric materials: A review,” *Polym. Degrad. Stab.*, vol. 228, no. April, p. 110902, 2024, doi: 10.1016/j.polymdegradstab.2024.110902.
- [26] Y. S. Kim *et al.*, “Novel thermoplastic matrix resin with low processing temperature and good interfacial strength for carbon fiber-reinforced polyethersulfone,” *Compos. Part B Eng.*, vol. 281, no. April, p. 111503, 2024, doi: 10.1016/j.compositesb.2024.111503.
- [27] T. Shahnaz *et al.*, “Graphene-based nanoarchitecture as a potent cushioning/filler in

- polymer composites and their applications,” *J. Mater. Res. Technol.*, vol. 28, no. October 2023, pp. 2671–2698, 2024, doi: 10.1016/j.jmrt.2023.12.108.
- [28] A. J. G. dos Santos *et al.*, “Morphological, chemical and mechanical properties of hybrid polyester composites reinforced with bamboo fibers and kaolin waste,” *J. Mater. Res. Technol.*, vol. 30, no. February, pp. 1–15, 2024, doi: 10.1016/j.jmrt.2024.03.003.
- [29] D. Periasamy *et al.*, “Assessing the recycling potential of thermosetting polymer waste in high-density polyethylene composites for safety helmet applications,” *E-Polymers*, vol. 24, no. 1, pp. 1–11, 2024, doi: 10.1515/epoly-2023-0080.
- [30] S. Khanjar, S. Barui, K. Kate, and K. P. K. Ajjarapu, “An Investigation into Mechanical Properties of 3D Printed Thermoplastic-Thermoset Mixed-Matrix Composites: Synergistic Effects of Thermoplastic Skeletal Lattice Geometries and Thermoset Properties,” *Materials (Basel)*, vol. 17, no. 17, 2024, doi: 10.3390/ma17174426.
- [31] M. A. Jamal, O. R. Shah, U. Ghafoor, Y. Qureshi, and M. R. Bhutta, “Additive Manufacturing of Continuous Fiber-Reinforced Polymer Composites via Fused Deposition Modelling: A Comprehensive Review,” *Polymers (Basel)*, vol. 16, no. 12, 2024, doi: 10.3390/polym16121622.
- [32] U. Continuous, C. F. Thermoset, and R. Printing, “Mechanical Characterization and Production of Various Shapes,” 2024.
- [33] B. Hong, K. Wang, Y. Li, S. Ren, and P. Gu, “Solid State Additive Manufacturing of Thermoset Composites,” *Polymers (Basel)*, vol. 16, no. 17, pp. 1–13, 2024, doi: 10.3390/polym16172416.
- [34] M. A. Rahman, L. Gibbon, M. Z. Islam, E. Hall, and C. A. Ulven, “Adjustment of Mechanical Properties of 3D Printed Continuous Carbon Fiber-Reinforced Thermoset Composites by Print Parameter Adjustments,” *Polymers (Basel)*, vol. 16, no. 21, 2024, doi: 10.3390/polym16212996.
- [35] M. Ichim, E. I. Muresan, and E. Codau, “Natural-Fiber-Reinforced Polymer Composites for Furniture Applications,” *Polymers (Basel)*, vol. 16, no. 22, 2024, doi: 10.3390/polym16223113.
- [36] M. N. Alam and V. Kumar, “Multi-Functional and Multi-Scale Aspects in Polymer Composites,” *Polymers (Basel)*, vol. 16, no. 24, pp. 16–18, 2024, doi: 10.3390/polym16243475.
- [37] Z. Liao *et al.*, “Investigation into the Reinforcement Modification of Natural Plant Fibers and the Sustainable Development of Thermoplastic Natural Plant Fiber Composites,” *Polymers (Basel)*, vol. 16, no. 24, 2024, doi: 10.3390/polym16243568.
- [38] M. Andreozzi *et al.*, “Effect of moisture content on the mechanical performance of 3D printed continuous reinforced two-matrix composite,” *Int. J. Adv. Manuf. Technol.*, vol. 133, no. 11–12, pp. 5117–5126, 2024, doi: 10.1007/s00170-024-14041-5.
- [39] M. Siegl, B. Jungbauer, J. Gebhardt, A. Judenmann, and I. Ehrlich, “Winding process of

- fibre-reinforced thermoplastic tubes with integrated tape production through in-situ roving impregnation and infrared consolidation,” *Int. J. Adv. Manuf. Technol.*, vol. 135, no. 5–6, pp. 2847–2870, 2024, doi: 10.1007/s00170-024-14628-y.
- [40] R. Setter and K. Wudy, “Additive manufacturing and mechanical analysis of multi-material polymer parts combining thermosets and thermoplastics,” *Adv. Compos. Hybrid Mater.*, vol. 7, no. 4, pp. 1–19, 2024, doi: 10.1007/s42114-024-00935-1.
- [41] C. Zhang and K. Fu, “Additively manufactured 3D short carbon fiber scaffold for thermoset composites,” *MRS Commun.*, vol. 14, no. 4, pp. 520–526, 2024, doi: 10.1557/s43579-024-00548-1.
- [42] T. Cionita *et al.*, “Overview of Jute Fibre as Thermoplastic Matrix Polymer Reinforcement,” *J. Renew. Mater.*, vol. 12, no. 3, pp. 457–483, 2024, doi: 10.32604/jrm.2024.045814.
- [43] M. S. Hassan *et al.*, “Additive Manufacturing of Carbon Fiber Reinforced Epoxy Thermoset with Improved Thermomechanical Properties,” *J. Compos. Sci.*, vol. 7, no. 4, 2023, doi: 10.3390/jcs7040171.
- [44] T. R. Vijaybabu *et al.*, “High Thermal Conductivity Polymer Composites Fabrication through Conventional and 3D Printing Processes: State-of-the-Art and Future Trends,” *Macromol. Mater. Eng.*, vol. 308, no. 7, pp. 1–19, 2023, doi: 10.1002/mame.202300001.
- [45] Y. Qiao, L. D. Fring, M. R. Pallaka, and K. L. Simmons, “A review of the fabrication methods and mechanical behavior of continuous thermoplastic polymer fiber–thermoplastic polymer matrix composites,” *Polym. Compos.*, vol. 44, no. 2, pp. 694–733, 2023, doi: 10.1002/pc.27139.
- [46] M. A. Rahman, E. Hall, L. Gibbon, M. Z. Islam, C. A. Ulven, and J. J. La Scala, “A Mechanical Performance Study of Dual Cured Thermoset Resin Systems 3D-Printed with Continuous Carbon Fiber Reinforcement,” *Polymers (Basel)*, vol. 15, no. 6, 2023, doi: 10.3390/polym15061384.
- [47] X. Tian *et al.*, “3D Printing of Continuous Fiber Reinforced Polymer Composites: Development, Application, and Prospective,” *Chinese J. Mech. Eng. Addit. Manuf. Front.*, vol. 1, no. 1, p. 100016, 2022, doi: 10.1016/j.cjmeam.2022.100016.
- [48] H. Zhang *et al.*, “3D printing of continuous carbon fibre reinforced powder-based epoxy composites,” *Compos. Commun.*, vol. 33, no. June, pp. 0–6, 2022, doi: 10.1016/j.coco.2022.101239.
- [49] S. Park, W. Shou, L. Makatura, W. Matusik, and K. (Kelvin) Fu, “3D printing of polymer composites: Materials, processes, and applications,” *Matter*, vol. 5, no. 1, pp. 43–76, 2022, doi: 10.1016/j.matt.2021.10.018.
- [50] M. S. Hassan *et al.*, “Selective Laser Sintering of High-Temperature Thermoset Polymer,” *J. Compos. Sci.*, vol. 6, no. 2, 2022, doi: 10.3390/jcs6020041.
- [51] S. Dhanasekar *et al.*, “Study of Polymer Matrix Composites for Electronics

- Applications,” *J. Nanomater.*, vol. 2022, 2022, doi: 10.1155/2022/8605099.
- [52] H. Zhang *et al.*, “Hybrid Printing Method of Polymer and Continuous Fiber-Reinforced Thermoplastic Composites (CFRTPCs) for Pipes through Double-Nozzle Five-Axis Printer,” *Polymers (Basel)*., vol. 14, no. 4, 2022, doi: 10.3390/polym14040819.
- [53] A. A. Musa, J. Park, G. Hong, S. H. Yoon, A. P. Onwualu, and M. Kim, “Development of high-performance basalt fiber-reinforced polymer composite using a nanocellulose-based surface modification strategy,” *Compos. Part A Appl. Sci. Manuf.*, vol. 199, no. July, p. 109191, 2025, doi: 10.1016/j.compositesa.2025.109191.
- [54] Y. Abebe, S. Palani, and B. Sirahbizu, “Effect of Al₂O₃ nanoparticle on mechanical properties of polyester/ glass-wool fiber reinforced polymer composites,” *Hybrid Adv.*, vol. 10, no. December 2024, p. 100472, 2025, doi: 10.1016/j.hybadv.2025.100472.
- [55] S. Wickramasinghe *et al.*, “Advancing polymer composites in civil infrastructure through 3D printing,” *Autom. Constr.*, vol. 177, no. May, 2025, doi: 10.1016/j.autcon.2025.106311.
- [56] Z. Niu, W. Li, Y. Huang, Y. Liu, W. Xu, and Y. Ouyang, “Preparation and improved mechanical properties of three-dimensional woven fabrics reinforced thermoplastic composites based on intra-yarn hybrid flax/basalt fibers,” *Ind. Crops Prod.*, vol. 236, no. August, p. 121957, 2025, doi: 10.1016/j.indcrop.2025.121957.
- [57] S. Z. Feng, S. S. Xie, J. J. Zeng, J. K. Zhou, B. Zhao, and Y. Zhuge, “Tensile and creep performance of thermoplastic fiber reinforced polymer reinforcing bars,” *Constr. Build. Mater.*, vol. 490, no. May, p. 142337, 2025, doi: 10.1016/j.conbuildmat.2025.142337.
- [58] M. Pizzorni, M. Benvenuto, E. Lertora, and C. Mandolino, “Adhesive bonding of CFRP with a 3D-printed short-fiber composite: An experimental study on the effects of geometry and adhesive system on joint performance,” *Compos. Part B Eng.*, vol. 294, no. December 2024, p. 112155, 2025, doi: 10.1016/j.compositesb.2025.112155.
- [59] M. M. Alzahrani, K. A. Alamry, and M. A. Hussein, “Recent advances of Fiber-reinforced polymer composites for defense innovations,” *Results Chem.*, vol. 15, no. December 2024, p. 102199, 2025, doi: 10.1016/j.rechem.2025.102199.
- [60] A. . Radzi *et al.*, “Bamboo-Fiber-Reinforced Thermoset and Thermoplastic Potential Applications,” *Polymers (Basel)*., vol. 14, p. 1387, 2022.
- [61] X. He *et al.*, “3D printing of continuous fiber-reinforced thermoset composites,” *Addit. Manuf.*, vol. 40, no. November 2020, 2021, doi: 10.1016/j.addma.2021.101921.
- [62] B. A. Alshammari *et al.*, “Comprehensive review of the properties and modifications of carbon fiber-reinforced thermoplastic composites,” *Polymers (Basel)*., vol. 13, no. 15, pp. 1–32, 2021, doi: 10.3390/polym13152474.
- [63] C. L. Cramer *et al.*, “Processing and properties of SiC composites made via binder jet 3D printing and infiltration and pyrolysis of preceramic polymer,” *Int. J. Ceram. Eng. Sci.*, vol. 2, no. 6, pp. 320–331, 2020, doi: 10.1002/ces2.10070.

- [64] S. H. R. Sanei and D. Popescu, “3d-printed carbon fiber reinforced polymer composites: A systematic review,” *J. Compos. Sci.*, vol. 4, no. 3, 2020, doi: 10.3390/jcs4030098.
- [65] Y. Ming, Y. Duan, B. Wang, H. Xiao, and X. Zhang, “A novel route to fabricate high-performance 3D printed continuous fiber-reinforced thermosetting polymer composites,” *Materials (Basel)*., vol. 12, no. 9, 2019, doi: 10.3390/ma12091369.
- [66] A. Adumitroaie, F. Antonov, A. Khaziev, A. Azarov, M. Golubev, and V. V. Vasiliev, “Novel continuous fiber bi-matrix composite 3-D printing technology,” *Materials (Basel)*., vol. 12, no. 18, pp. 1–10, 2019, doi: 10.3390/ma12183011.
- [67] F. Brites *et al.*, “Cork Plastic Composite Optimization for 3D Printing Applications,” *Procedia Manuf.*, vol. 12, no. December 2016, pp. 156–165, 2017, doi: 10.1016/j.promfg.2017.08.020.
- [68] D. Yang, K. Wu, L. Wan, and Y. Sheng, “A particle element approach for modelling the 3d printing process of fibre reinforced polymer composites,” *J. Manuf. Mater. Process.*, vol. 1, no. 1, 2017, doi: 10.3390/jmmp1010010.
- [69] M. Invernizzi, G. Natale, M. Levi, S. Turri, and G. Griffini, “UV-assisted 3D printing of glass and carbon fiber-reinforced dual-cure polymer composites,” *Materials (Basel)*., vol. 9, no. 7, 2016, doi: 10.3390/MA9070583.
- [70] I. Pleșa, P. V. Noțingher, S. Schlögl, C. Sumereder, and M. Muhr, “Properties of polymer composites used in high-voltage applications,” *Polymers (Basel)*., vol. 8, no. 5, 2016, doi: 10.3390/polym8050173.