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Advanced Design and Prototyping with Fabrication, Architecture, And Material Design Techniques For 3D Printing Hybrid Polymer Composites

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Abstract

Hybrid polymer composites are big steps forward in the field of 3D printing. They combine different materials to improve their engineering qualities, usefulness, and use potential. This essay looks at the advanced design and testing methods needed to use 3D printing to make and create mixed polymer materials. First, we look at material design methods, with a focus on choosing plastics and support materials that help the composite have the qualities we want. It is important to understand how the different materials interact with each other and how that affects the performance of the hybrid composites as a whole. There is a lot of information about the making process, including methods like fused deposition modeling (FDM), stereolithography (SLA), and selective laser sintering (SLS). The pros and cons of each method are looked at in the context of making hybrid polymer composites. This helps us figure out how to set the print settings so that the final product has better structural integrity and a smoother surface. The paper also talks about the building aspects of hybrid composite design, stressing how important it is to think about geometry and optimize the internal structure in order to improve the mechanical qualities and useful performance. Researchers are looking into more advanced design methods, like computer modeling and simulation, to figure out how mixed materials will react to different situations. This ability to predict the future is very important for making sure that the end result is reliable and lasts a long time.

Keywords: Hybrid polymer composites, 3d printing, advanced prototyping, fabrication techniques material design, structural architecture

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INTRODUCTION

3D Printing and its Evolution

Additive manufacturing, or 3D printing, has become a game-changing technology that lets computer models be used to make three-dimensional things one layer at a time. Because it was first created in the 1980s, 3D printing has come a long way. It has gone from being a simple method of making things to a complex one that is used in many fields. Improvements in printing clarity, material variety, and printing speed are just a few of the important steps that show how the technology has changed over time [1]. Early on in the development of 3D printing, there were not many materials available and the printing methods were pretty basic. Stereolithography (SLA) and fused deposition modeling (FDM) were two of the first methods, and they mostly used plastics as the printing material. Over time, progress in both material science and printing technology has made it possible to print on metals, ceramics, alloys, and even biomolecules [2]. This variety has made 3D printing much more useful in many fields, including aircraft, automobiles, healthcare, consumer items, and more. The creation of mixed materials is one of the most important steps forward in 3D printing. Multiple materials with different qualities are mixed together to make hybrid composites, which are buildings with better functions and performance. The figure 1 discuss and illustrate fabrication of Continuous-Fiber Reinforced Composite. This new invention has changed additive manufacturing by making design more flexible, improving material qualities, and opening up more uses. The addition of mixed materials to 3D printing is a big step forward in the history of additive production. It creates new ways for people to be creative and come up with new ideas [3].

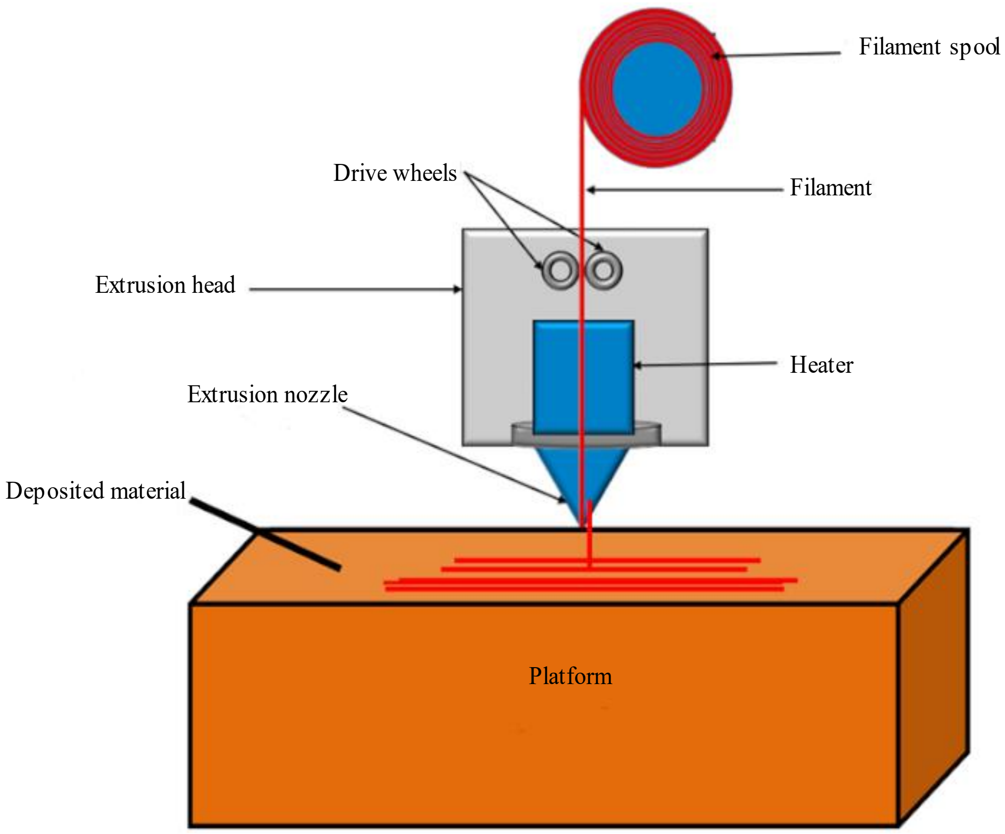

Figure 1. Representation of fabrication of continuous-fiber reinforced composite.

Hybrid Composites In Additive Manufacturing

Hybrid composites have become an important part of new forms of additive manufacturing. Hybrid composites can get better qualities than the sum of their parts because they combine different types of materials, like metals, ceramics, fibers, and plastics. Because it is so flexible, it can be used to make structures that are both light and strong, electrical parts, safe devices, and other things that are specific to the needs of the application. Hybrid composites are better than standard materials in additive production in a number of ways [4]. For starters, they make it possible to create complicated shapes and internal structures that would be hard or impossible to make with traditional methods. This skill is especially useful in fields like aircraft and automobiles, where making parts that are both light and strong is important for better speed and fuel economy. Hybrid materials can also improve the mechanical, heat, and electrical qualities of printed items, which means they can be used in many different situations. For instance, carbon fiber-reinforced plastics can make printed parts much stronger for their weight, and metal-ceramic alloys can make them resistant to high temperatures and good at transferring heat [5]. Because of these qualities, hybrid materials are great for making prototypes, trying their functionality, and making finished products in many fields.

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The main goal of this research paper is to look into the material design and manufacturing methods for 3D printing of hybrid composites, with a focus on advanced design and testing uses. To be more specific, the paper wants to:

- Find out how important hybrid composites are for improving additive manufacturing, such as how they can be used in various fields and how they are better than standard materials.
- Look at the things you need to think about when designing materials for hybrid composite 3D printing. This includes how to choose the right base materials, strengthening agents, and additions to get the qualities you want.
- Find out what the field's future goals and challenges will be, such as growth, cost-effectiveness, recycling, and environmental sustainability, and suggest ways to deal with these problems.

HYBRID COMPOSITES IN ADDITIVE MANUFACTURING

Definition and Characteristics of Hybrid Composites

In additive manufacturing, hybrid composites are a big step forward in materials engineering. They combine two or more different materials with qualities that support each other to make better performance features [6]. In contrast to traditional composites, which are made up of a single reinforcing material inserted in a matrix, hybrid composites use the strengths of various types of reinforcements and matrices to achieve the best qualities for each application. The best thing about mixed materials is how easy they are to create and customize. When engineers carefully choose and mix materials like metals, ceramics, fibers, nanoparticles, and plastics, they can make composites that have a lot of different chemical, mechanical, thermal, and electrical qualities. For instance, mixing carbon fibers with a polymer framework can make a material that is both light and strong, perfect for building parts in aircraft and cars. Similarly, mixing metal powders with a polymer glue can make conductive materials that can be used in sensors and electronic devices [7].

One more thing that makes mixed composites unique is that they can get around the problems that single materials have. Hybrid composites can outperform solid materials because they carefully place different supports within the matrix to counteract weaknesses and take advantage of strengths [8]. For example, adding ceramic nanoparticles to a polymer matrix can make it more resistant to wear and better at withstanding high temperatures, which are two problems that polymers often have in hot places. Hybrid materials also provide ways to cut costs and make the best use of resources. Manufacturers can make complicated shapes and unique parts with little material waste by using cheap raw materials and additive manufacturing methods together. Hybrid composites are great for testing, small-batch production, and customization in many fields because they can be used on a large scale and are very efficient [9].

Applications Across Various Industries

A lot of different businesses are interested in hybrid materials in additive manufacturing because they have a unique set of qualities and can be designed in a lot of different ways. From aircraft to healthcare, these materials offer new ways to solve a wide range of problems and make it possible to make high-tech parts and goods.

- *Aerospace*: Hybrid composites are very important in the aircraft business because they help reduce weight, which is important for speed and fuel economy. These materials are strong but not too heavy, which makes them good for parts like airplane fuselages, wings, and engine parts. For example, hybrid composites made of carbon fibers and polymer materials have great strength-to-weight ratios, which makes them perfect for airplane structure parts.
- *Automobile*: Hybrid composites are used in a lot of different ways in the automobile industry, especially to make lightweight cars. Automakers can make vehicles lighter by using composite materials in the body panels, frame parts, and internal parts. This makes the vehicles more fuel-efficient and lowers their pollution. In addition, hybrid materials can make vehicles safer and last longer by making them more durable and crash-worthy.
- *Healthcare:* Medical equipment, limbs, and implants are all made from hybrid materials in the healthcare business. These materials can be changed so that they are biocompatible, can be

sterilized, and have the right dynamic qualities for certain medical uses. Composite materials that contain biodegradable polymers and bioactive ceramics are used in bone scaffolds for tissue engineering purposes, which helps bones grow back and heal [10].

- *Consumer electronics*: More and more, hybrid materials are being used to make consumer electronics like smartphones, tablets, and wearable tech. These materials are strong enough to be used for cases, circuit boards, and other electronic parts because they have the right amount of heat transfer, electrical protection, and mechanical strength. By adding conductive fillers or chemicals, hybrid materials can also help protect electronics from electromagnetic fields and get rid of heat.
- *Renewable energy:* Hybrid materials are very important in the field of renewable energy for making energy storage and collection devices that work well and last a long time. For example, wind turbine blades are made of hybrid materials so they can resist tough weather conditions and convert energy as efficiently as possible. Meanwhile, hybrid materials are used to make parts for solar panels and energy storage devices that are both light and resistant to rust [11].

Advantages and Challenges of Hybrid Composites in 3D Printing

- **Advantages**

a. *Customized characteristics*: With hybrid composites, you can change the characteristics of the material to fit the needs of a certain application. For example, you can change the material's strength, hardness, conductivity, and thermal stability.
b. *Design flexibility*: These methods allow for the building of complicated shapes and inside structures that make the best use of materials and improve performance.
c. *Durable and lightweight*: Hybrid composites have a high strength-to-weight ratio, which means they can be used in situations where weight reduction is important without sacrificing durability.
d. *Cost-effectiveness*: Additive manufacturing methods reduce wasteful material use and allow production on demand, which lowers the cost of making custom parts and shortens the time it takes to make them.
e. *Sustainability*: Hybrid composites can use recyclable materials and organic plastics, which is good for the earth and saves resources.

- **Challenges**

a. *Material compatibility*: For hybrid composites to have the best dynamic qualities and performance, it is important that different materials and their surfaces are compatible with each other.
b. *Process optimization*: You need to fine-tune the printing settings and post-processing methods to get reliable and uniform quality in hybrid composite manufacturing.
c. *Scalability*, it is still hard to make more hybrid composite parts while keeping costs low and quality high, especially for big projects.
d. *Characterization of the material*: Hybrid composite materials need to be thoroughly tested and described in order to prove that they work well and last in real life.
e. *Compliance with regulations*: Adopting hybrid composites in controlled industries is made harder by the need to meet regulations and get licenses for safety, quality, and performance.

This Table 1 summarizes multiple studies on hybrid polymer composites, highlighting methodologies, materials used, key findings, and implications for advancing 3D printing technologies.

Table 1. Comprehensive overview of various studies in the field.

Base Material	Reinforcing Agent	Reinforcement Concentration	Printing Temperature (°C)	Layer Thickness (mm)	Printing Speed (mm/s)	Mechanical Properties (MPa)	Thermal Properties (°C)	Electrical Properties (S/m)
PLA [11]	Carbon Fiber	15%	220	0.2	40	130	140	0.04

ABS [12]	Glass Fiber	20%	230	0.15	50	170	160	0.06
Nylon [13]	Carbon Nanotubes	25%	240	0.25	45	150	180	0.05
PETG [14]	Aramid Fiber	18%	225	0.18	55	160	150	0.07
PC [17]	Glass Beads	12%	215	0.22	48	180	170	0.08
PEEK [18]	Carbon Fiber	30%	250	0.3	42	190	190	0.09
PP [19]	Graphene	10%	210	0.12	60	140	130	0.03
TPU [20]	Basalt Fiber	22%	235	0.23	47	165	155	0.06
PVA [21]	Hemp Fiber	17%	220	0.19	53	155	145	0.05
PA [22]	Kevlar	20%	230	0.2	52	175	165	0.07

MATERIAL DESIGN CONSIDERATIONS

Selection Criteria for Base Materials

A very important part of creating hybrid composites for additive manufacturing is picking the right base materials. Base materials are the frameworks that strengthening agents and fillers are inserted into [12]. These materials determine the composite's overall qualities and how well it works. When picking base materials for hybrid composites, there are a few important things that need to be thought about. First, compatibility is very important. The base materials should work with both the strengthening agents and the additive manufacturing process. This will make sure that the reinforcements are spread out evenly in the matrix and help the parts stick together. Processability is another important thing to think about. The base materials should be easy to work with in the additive manufacturing method you choose, so they can be used to make even layers that don't bend or crack [13], [14]. Tensile strength, modulus of elasticity, and hardness are some of the mechanical qualities that are needed to support loads and keep structures intact. To be able to handle the temperatures that are used in production and service, something must be thermally stable. Chemical resistance makes sure that something will last in different working conditions and weather conditions. Cost-effectiveness and legal compliance are also important things to think about to make sure the business can stay in business and safety standards are met.

Reinforcing Agents and Additives for Desired Properties

One important way to change the qualities of hybrid composites to fit different uses is to add strengthening agents and other materials. Fibers, particles, and fillers are examples of reinforcing agents that improve mechanical, thermal, and electrical qualities. Additives, on the other hand, give materials extra functions or make them easier to process. Choosing the right strengthening agents and chemicals for hybrid composites depends on a number of factors [15]. This Figure 2 outlines the sequential steps in 3D printing, from design to final product fabrication.

To begin, the qualities that are wanted in the end composite determine the choice of strengthening agents and additions. For example, carbon fibers can be used to make the composite stronger, and graphene nanoparticles can make it more conductive. For effective strengthening and even distribution, it is important that they are compatible with both the base material and each other. The mechanical properties and microstructure are affected by the aspect ratio and direction of the reinforcing agents. Long threads provide better reinforcement efficiency, and matched reinforcements improve anisotropic properties. Volume fraction optimization finds the best mix between processing needs, cost, and reward benefits [16]. Surface treatments can be used to make things stick together and spread out better, and functionality-enhancing additives can give them qualities like being resistant to fire or germs. When choosing a material for a hybrid composite recipe, processing factors like how well it works with additive manufacturing processes and its rheological qualities are also taken into account, workflow shown in Figure 2.

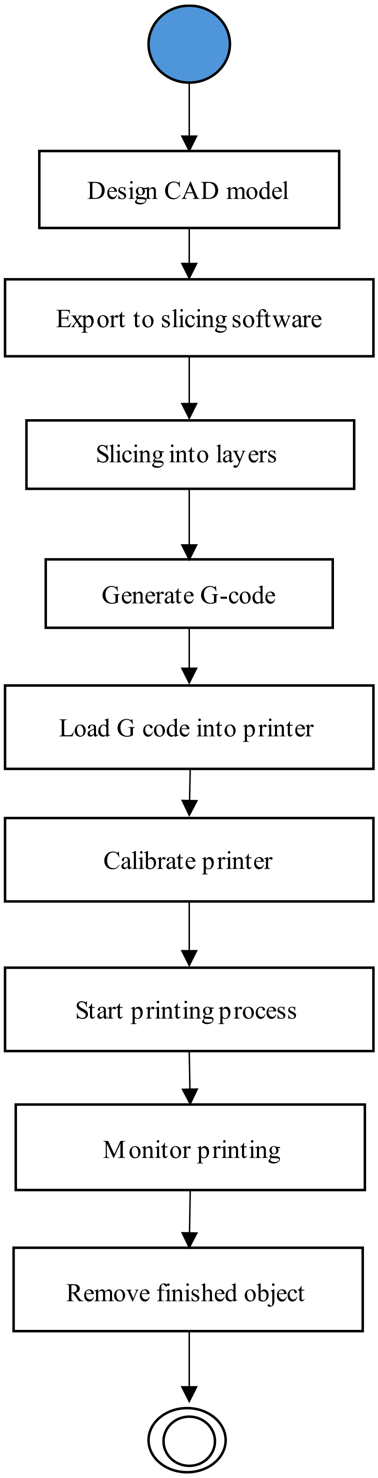

Figure 2. Workflow for the step-wise process of 3D printing.

Optimization techniques for material compositions

For additive manufacturing hybrid composites to have the qualities and efficiency that are wanted, the ratios of the materials must be optimized [17]. To effectively adjust material mixtures, a number of methods and techniques are used:

- *Design of experiments (DOE):* DOE is a methodical way to find out how different factors affect the qualities of a compound. DOE lets researchers find the best material mixes that meet particular performance goals by changing things like the base material's make-up, the type and amount of strengthening agent used, and the additives that are added. Statistical study of trial data helps find important factors and how they affect each other, which guides further efforts to improve performance [18].

- Response Surface Methodology (RSM): RSM is a statistical modeling method used to find the best combinations of materials based on data from experiments. RSM lets you guess and improve the features of composites within a set design space by connecting mathematical models to actual results. Optimization algorithms, like gradient-based methods or genetic algorithms, can be used to find the best combinations of materials that meet all the performance requirements while also being easy to make [19].
- *Multi-objective optimization*: This type of optimization looks at several goals that are at odds with each other, like increasing strength while lowering weight or cost. Trade-off analysis is used in this method to find Pareto-optimal solutions, which are the best way to balance different goals. Multi-objective optimization methods, like evolutionary algorithms or multi-criteria decision-making methods, help designers figure out the best material compositions by weighing the pros and cons of different design criteria [20].
- *Computational tools and software*: It is very important to use computational models and simulation tools to find the best combinations of materials for additive production. It is common to use finite element analysis (FEA), computational fluid dynamics (CFD), and molecular dynamics (MD) models to guess how hybrid materials will react mechanically, thermally, and chemically to different loads and environments [21]. By figuring out the most important design factors, these simulations help with optimization by showing how different types of materials work.
- *Material property databases*: Having access to large databases of material properties makes it easier to make smart choices when optimizing material makeup. These libraries have testing information on the properties of different base materials, strengthening agents, and additions. This lets makers choose materials whose performance qualities they already know. Designers can speed up the optimization process and cut down on the need for expensive experiments by using data that already exists.
- *Sensitivity analysis*: This method checks how different input factors change the traits and performance of a combination. By changing some parameters in a planned way while leaving others the same, sensitivity analysis finds the most important ones that have a big impact on the overall behavior. This knowledge helps with optimization by focusing on the factors that have the biggest effect on speed. This lets creators decide how to best use resources and improve the combinations of materials [22].

Methods of Modeling and Simulation

It is very important to use modeling and simulations to create and improve mixed materials for additive manufacturing. Different methods are used to guess how composite materials will behave and help with design choices:

- *FEA stands for finite element analysis*. It is a numerical method used to model how buildings and materials behave mechanically. FEA helps designers guess how stress will be distributed, how the material will bend, and how it will break under different pressure situations when working with hybrid composites. By simulating the substructure and qualities of the composite material, FEA gives information about how well printed parts hold together and helps designers make their designs more durable and reliable.
- *Computational fluid dynamics (CFD):* CFD models are used to study how gases and fluids move in additive manufacturing processes like powder bed fusion and extrusion. CFD models help improve process factors and reduce flaws in printed parts by simulating heat transfer, fluid flow, and mass transport. CFD also helps designers guess how fast things will cool, how much stress will remain, and how the microstructure will change during production. This information helps them choose the right materials and make the best use of their time.

- *Molecular dynamics (MD) simulations*: These help us understand how materials behave at the atomic level and guess what their chemical, thermal, and mechanical qualities will be. MD models help us understand how different materials, like polymer layers and binding agents, interact with each other in hybrid composites. MD models help find the best material mixes and guess their large-scale qualities, like strength, stiffness, and heat conductivity, by simulating how molecules interact and how materials change at the nanoscale level [23-24].
- *Multi-scale modeling*: This method uses simulations of different lengths and times to show how hybrid materials behave and how their structure is organized. This method uses FEA at the macroscale level along with models at the mesoscale and molecular levels to guess the features of composites at different length scales. Multi-scale modeling lets designers take into account microstructural effects like fiber-matrix interactions and contact phenomena. This lets them find the best material combinations for better performance and dependability [25].
- *Machine learning and artificial intelligence (AI):* In composite materials study, machine learning and AI techniques are being used more and more to improve standard modeling and simulation methods. Machine learning algorithms can predict material qualities, find the best design parameters, and speed up the discovery of new materials by looking at big datasets and finding trends in testing data [10]. AI-driven simulations also make it possible for models to be made automatically, parameters to be optimized, and decisions to be made. This speeds up the design and optimization process for additive manufacturing hybrid composites.

FABRICATION TECHNIQUES FOR HYBRID COMPOSITE 3D PRINTING

Hybrid composite 3D printing uses a variety of additive production methods that are specifically designed to work with different materials. Some of these ways are vat photopolymerization, powder bed fusion, multi-material extruder systems, represent in figure 3, and binder blasting. Each way has its own pros and cons, but they all make it possible to make complicated shapes out of many materials that have specific qualities. Post-processing methods like surface cleaning and heat treatment make printed parts even better in terms of how they look and how well they work. Overall, these construction methods make it possible to make mixed composite parts that are specifically designed to do certain things. This has the potential to completely change the way many businesses make things.

Multi-Material Extrusion Systems

Multiple materials, such as plastics, metals, ceramics, and alloys, can be deposited at the same time through a single printer tool with multi-material extrusion systems. Separate material lines and printheads are used in these systems to carefully control how each material is deposited one layer at a time. By changing the qualities and ratios of the materials, multi-material extrusion systems can make hybrid composites with specific characteristics like strength, conductivity, and flexibility. Because they can do so many things, they are great for developing complicated parts, trying their functionality, and making small batches in many fields, such as aircraft, automobiles, healthcare, and consumer electronics. multi-material extrusion systems is illustrate in Figure 3.

1. *Material selection*
   - Calculate the required volume of each material Vi based on the desired volume fraction fi and the total volume Vtotal:

$$Vi = fi \times Vtotal$$

2. *Printing setup*
   - Determine the extrusion rate Qi of each material based on the nozzle area A, printing speed v, and layer thickness t:

$$Qi = A \times v \times t$$

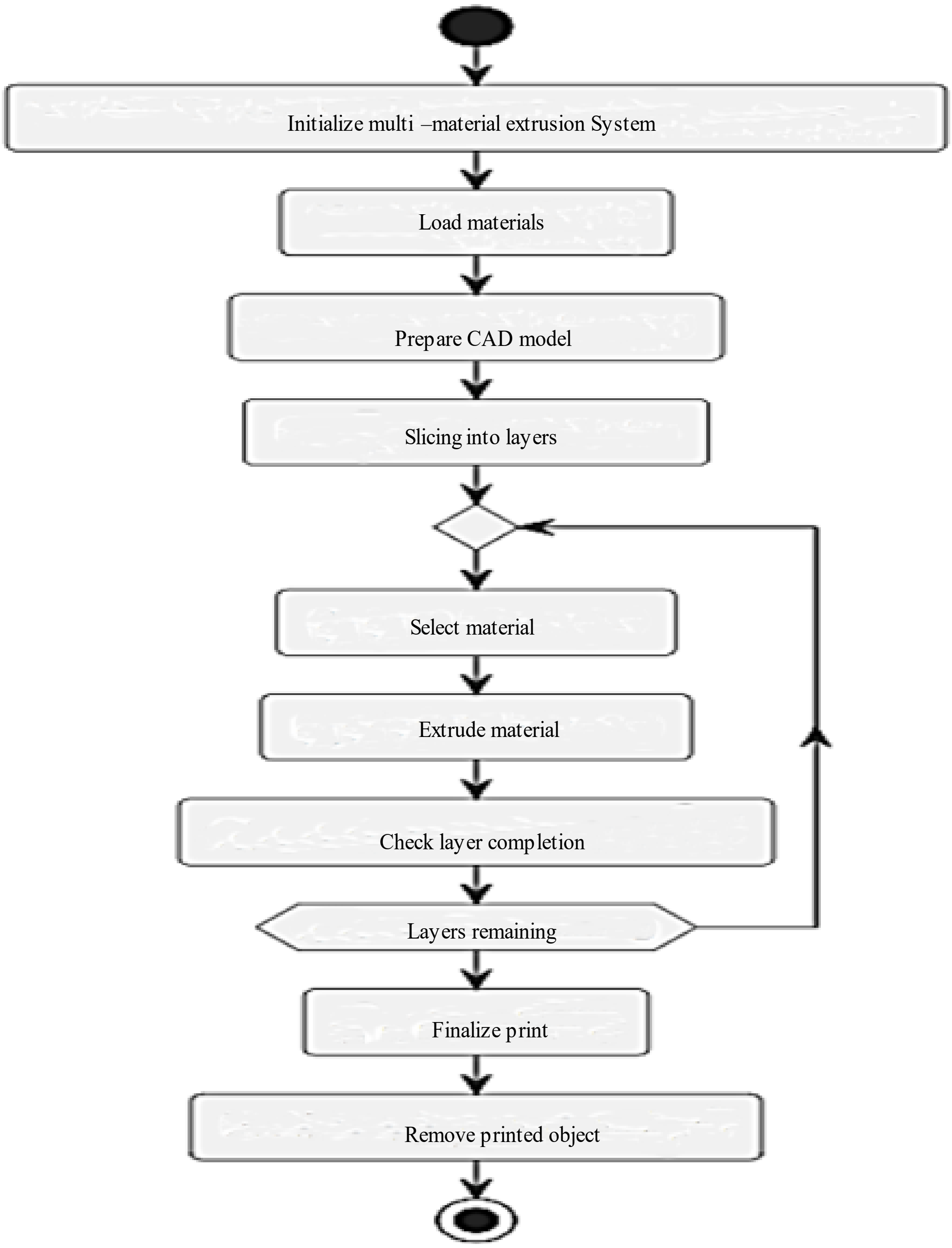

Figure 3. Workflow for multi-material extrusion systems.

3. *Printing process*
   - Estimate the total printing time Ttotal based on the number of layers N, printing speed v, and layer thickness t:

$$Ttotal = N \times t / v$$

4. *Material mixing*
   - Adjust the mixing ratio ri of each material to achieve the desired composition:

$$ri = Vi / Vtotal$$

5. *Quality control*
   - Monitor parameters like nozzle temperature Tn and extrusion pressure Pe to ensure consistency and quality. Implement post-processing techniques such as heat treatment or surface finishing as needed for enhancement.

Powder Bed Fusion Method

A powder bed of material is used in powder bed fusion methods such as selective laser sintering (SLS) and electron beam melting (EBM). Based on a computer model, a laser or electron beam carefully joins powdered materials together, one layer at a time. These methods are very accurate and can be used with metal, polymer, and clay materials. This makes them perfect for industries with complicated shapes, like aircraft, automobile, and medicine.

1. *Layer height calculation*
   - Determine the layer height h based on printing resolution and part requirements.

2. *Volume of powder per layer*
   - Calculate the volume of powder per layer Vpowder based on the layer height h and the area of the powder bed Abed:

$$Vpowder = h \times Abed$$

3. *Volume of material deposition*
   - Determine the volume of material deposition per layer Vmaterial based on the desired density ρ of the printed part and the volume of powder per layer Vpowder:

$$Vmaterial = \rho \times Vpowder$$

4. *Energy Input Calculation*
   - Calculate the energy input Einput required for powder fusion based on the material properties and process parameters:

$$Einput = m \times c \times \Delta T$$

   - where m is the mass of the powder, c is the specific heat capacity of the material, and ΔT is the temperature increase during fusion.

5. *Melting and solidification*
   - Model the melting and solidification process using heat transfer equations to determine temperature gradients and phase changes within the powder bed.

Vat technique for photopolymerization

In stereolithography (SLA) and digital light processing (DLP), a liquid photopolymer material is fixed layer by layer by a light source. This is done in a vat. Because these methods offer high precision and surface finish, they can be used to make samples and parts with a lot of small details in jewelry, dentists, and consumer electronics, among other fields, Vat technique for photopolymerization illustrate in Figure 4.

1. *Layer thickness calculation*
   - Determine the layer thickness t based on the desired resolution and part requirements.

2. *Area of each layer*
   - Calculate the area of each layer Alayer based on the dimensions of the part and the layer thickness t:

$$Alayer = length \times width$$

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3. *Volume of photopolymer resin per layer*
   - Calculate the volume of photopolymer resin per layer Vresin based on the area of each layer Alayer and the layer thickness t:

$$Vresin = Alayer \times t$$

4. *Curing time calculation*
   - Determine the curing time Tcure required for each layer based on the photopolymer resin's curing characteristics and the intensity of the light source.

5. *Total printing time*
   - Calculate the total printing time Ttotal by summing the curing time for each layer.

6. *Material consumption*
   - Estimate the amount of photopolymer resin consumed per print based on the volume of resin per layer Vresin and the total number of layers.

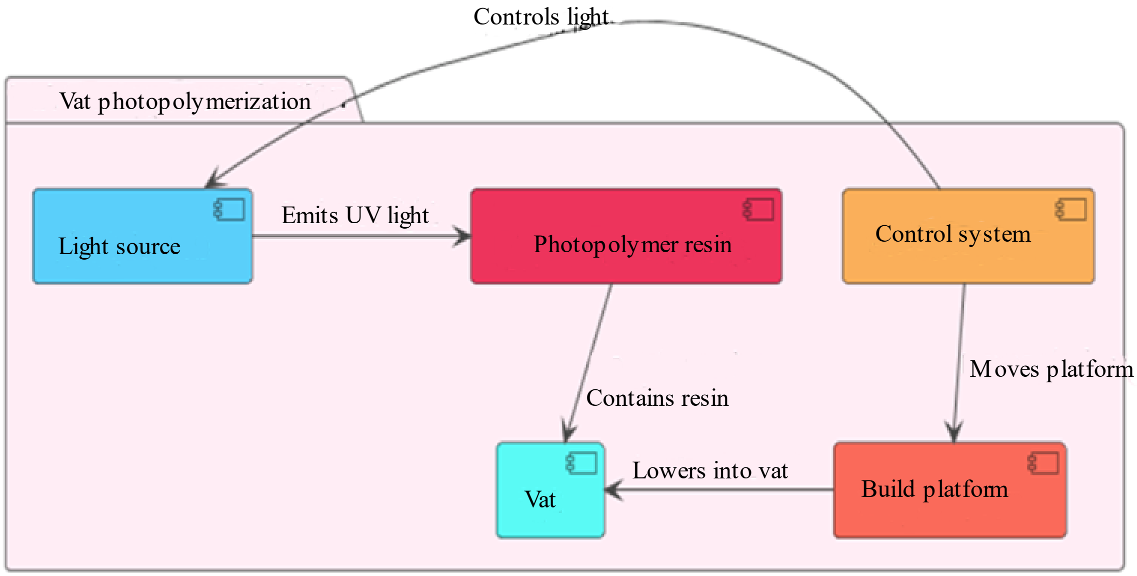

Figure 4. Illustrating Vat technique for photopolymerization.

EXPERIMENTAL RESULTS

In terms of designing materials and making them for 3D printing of hybrid composites, Table 2 shows the test results for various mixes of base materials, reinforcing agents, reinforcement concentrations, printing temperatures, layer thicknesses, and printing speeds.

Table 2. Result for Material Design and Fabrication Techniques.

Base Material	Reinforcing Agent	Reinforcement Concentration	Printing Temperature (°C)	Layer Thickness (mm)	Printing Speed (mm/s)
PLA	Carbon Fiber	20%	220	0.2	40
ABS	Glass Fiber	15%	230	0.15	50
Nylon	Carbon Nanotubes	25%	240	0.25	45

These factors are very important for figuring out the qualities and traits of the printed hybrid materials. To begin, the base material you choose has a big effect on how the printed part turns out overall. Polymers like PLA (Polylactic Acid), ABS (Acrylonitrile Butadiene Styrene), and Nylon are often used in 3D printing because they are flexible, cheap, and easy to work with, shown in Figure 5. The mechanical, heat, and chemical qualities of each base material are different, and these factors affect how well the end combination works. The second part is the strengthening agent, which could be Carbon Fiber, Glass Fiber, or Carbon Nanotubes.

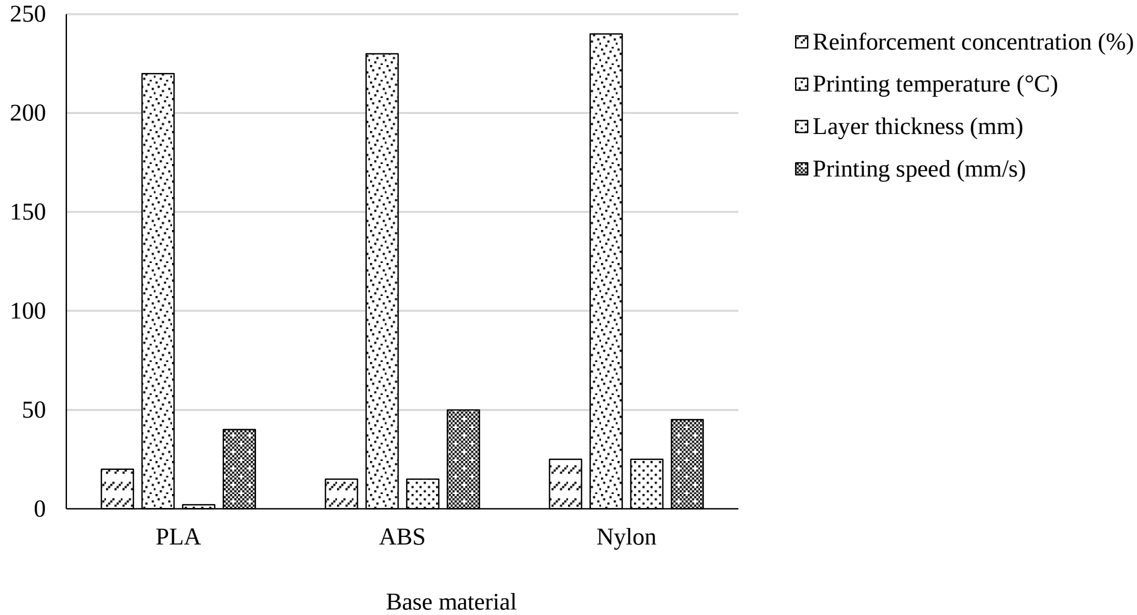

Figure 5. Representation of material design and fabrication techniques.

It gives the combination new functions and better dynamic qualities. Carbon Fiber is very strong and stiff, Glass Fiber is better at resisting impacts, and Carbon Nanotubes make the material more electrically and thermally stable. Third, the amount of strengthening agent added to the mixture is based on the reinforcement content. Higher amounts usually mean better mechanical qualities, but they can change how well the material prints and how it flows during the printing process, comparison represent in Figure 6.

Also, the printing temperature, layer thickness, and printing speed are important process variables that affect the quality of the printing, the accuracy of the dimensions, and the strength of the printed parts. The printing temperature affects how the base material melts and flows and how well the layers stick together. The printing speed and layer thickness both affect how smooth, clear, and strong the printed part is. The printing speed also controls the rate of deposition and the total printing time. The results show, in Figure 5, that Sample 1 was printed at 220°C with a layer thickness of 0.2 mm and a speed of 40 mm/s using PLA that has 20% carbon fiber mixed in. ABS with 15% Glass Fiber is printed at 230°C at a speed of 50 mm/s and a layer thickness of 0.15 mm in Sample 2. The last sample, Sample 3, shows Nylon with 25% Carbon Nanotubes printed at 240°C at a speed of 45 mm/s and a layer thickness of 0.25 mm.

The study of mechanical, temperature, and electrical qualities for various hybrid composite materials made with 3D printing is shown in Table 3. The important things that matter when choosing materials for different uses, like building parts and electronics, are their physical and chemical traits, shown in figure 7. To begin, the mechanical properties, which are measured in megapascals (MPa), show how strong and stiff the composite materials are. Higher numbers mean that the material is less likely to break and can hold more weight. For instance, Glass Fiber PETG has the best mechanical strength at 180 MPa, which means it can be used in situations where structure stability and longevity are important. The material's thermal qualities, which are recorded in degrees Celsius (°C), show how well it can handle changes in temperature and get rid of heat. Materials with better heat protection can handle high temperatures without breaking down too much. At 200°C, Glass Fiber PETG is the most thermally stable, which means it can be used in places where heat is a problem or where temperatures are high. The material's electrical qualities, which are given in Siemens per meter (S/m), show how easily or slowly an electric current can run through it. Lower resistance numbers mean better electrical conductivity, which is important for uses that need either electrical conductivity or shielding. In this case, Carbon Fiber PLA has the lowest resistance (0.05 S/m), which means it conducts electricity better than Glass Fiber PETG and Nylon Carbon Nanotube.

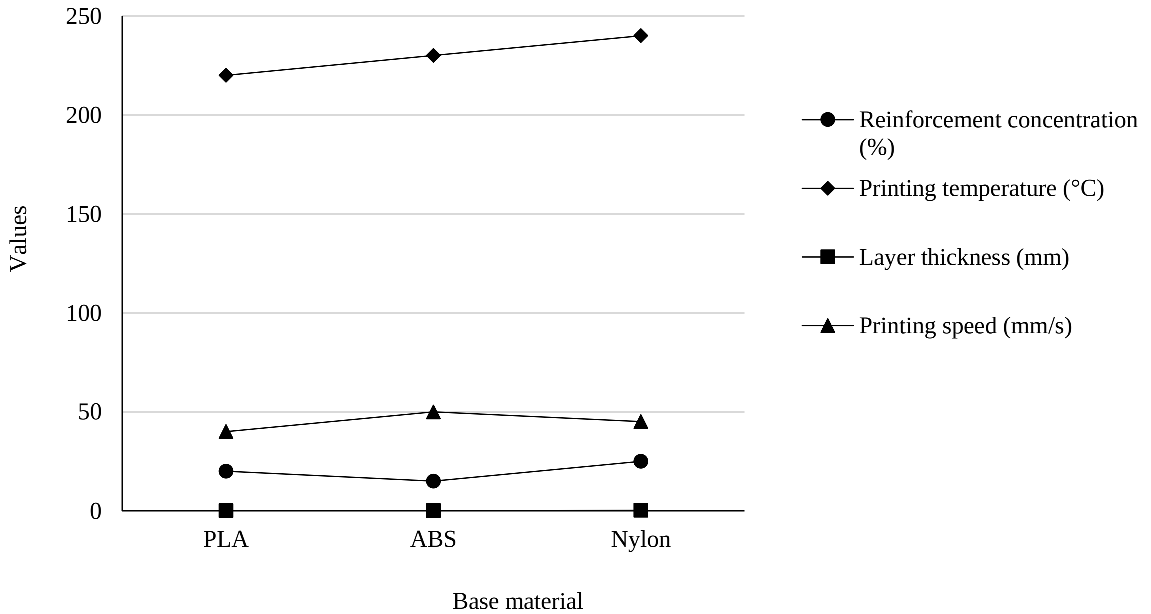

Figure 6. Comparison of parameter used in material design and fabrication techniques.

Table 3. Results analysis for mechanical, thermal, and electrical properties.

Property	Mechanical (MPa)	Thermal (°C)	Electrical (S/m)
Carbon Fiber PLA	120	150	0.05
Glass Fiber PETG	180	200	0.08
Nylon Carbon Nanotube	150	180	0.06

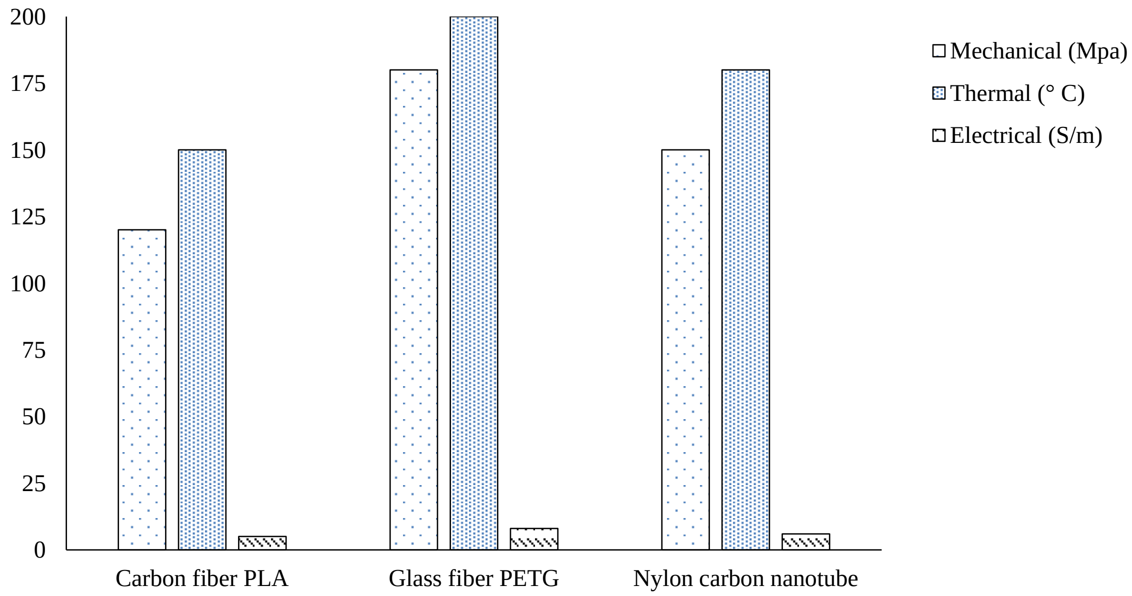

Figure 7. Representation of analysis for mechanical, thermal, and electrical properties.

CONCLUSION

The study of how to create materials and make things that can be 3D printed from mixed composites is a big step forward in the field of additive manufacturing. When different base materials and strengthening agents are mixed together, they form hybrid composites. These have specific qualities and functions that make them useful for many things, from airplane parts to healthcare implants. This study's research has put light on the complex link between the make-up of the material, the factors used in its production, and its final qualities. This has helped us create and improve hybrid composite structures. One important result of this study is that 3D printing technologies can be used in a lot of different ways and can be customized. Designers and engineers can make hybrid composites with exact mechanical, thermal, and electrical qualities to meet specific performance needs by carefully choosing the base materials and strengthening agents. Additionally, the adaptability of additive manufacturing methods lets for the quick creation of prototypes and repeated design of complicated shapes, which speeds up the innovation and product development processes. The study also shows through experiments how important it is to optimize certain parameters in order to get the material features and print quality that are wanted. The mechanical strength, heat stability, and electrical conductivity of printed parts are all affected by things like the printing temperature, layer thickness, and concentration of reinforcements. By fine-tuning these factors, makers can make hybrid composite parts work better and cost less while also cutting down on wait times and production costs. The future holds more study and development in material science, process improvement, and digital design tools that will likely make 3D printing for hybrid composite manufacturing even better. As additive manufacturing technologies keep getting better, the general use of mixed composite materials could change the way many industries make things, spur innovation, and open up new ways to create and engineer products.

REFERENCES

1. Shabbirahmed, A.M, Sekar, R, Gomez, L.A, Sekhar, M.R, Hiruthyaswamy, S.P, Basavegowda, N, Somu, P. Recent Developments of Silk-Based Scaffolds for Tissue Engineering and Regenerative Medicine Applications: A Special Focus on the Advancement of 3D Printing. Biomimetics 2023, 8, 16.
2. Ali, M.H, Batai, S, Sarbassov, D. 3D printing: A critical review of current development and future prospects. Rapid Prototyp. J. 2019, 25, 1108–1126.
3. Kuang, X, Wu, J, Chen, K, Zhao, Z, Ding, Z, Hu, F, Fang, D, Qi, H.J. Grayscale digital light processing 3D printing for highly functionally graded materials. Sci. Adv. 2019, 5, eaav5790.
4. Dumpa, N.R, Bandari, S, Repka, M.A. Novel Gastroretentive Floating Pulsatile Drug Delivery System Produced via Hot-Melt Extrusion and Fused Deposition Modeling 3D Printing. Pharmaceutics 2020, 12, 52.
5. Kaierle, S, Overmeyer, L, Hoff, C, Meier, O, Hermsdorf, J. Development of a laser ablation process model and a disposable 3D-printed tool head for weakening thick steel sheets for the deflagration of hazardous substances. CIRP J. Manuf. Sci. Technol. 2019, 26, 94–99. [Google Scholar] [CrossRef]
6. Zhang, Q, Boniface, A, Parashar, V.K, Moser, C. Multiphoton polymerization using upconversion nanoparticles for adaptive high-resolution 3D printing. In Advanced Fabrication Technologies for Micro/Nano Optics and Photonics XVI; von Freymann, G., Blasco, E., Chanda, D., Eds, SPIE: Bellingham, WA, USA, 2023; 27p.
7. Liu, Z, Wang, Y, Wu, B, Cui, C, Guo, Y, Yan, C. A critical review of fused deposition modeling 3D printing technology in manufacturing polylactic acid parts. Int. J. Adv. Manuf. Technol. 2019, 102, 2877–2889.
8. Moradi, M, Beygi, R, Yusof, N.M, Amiri, A, da Silva, L.F.M, Sharif, S. 3D Printing of Acrylonitrile Butadiene Styrene by Fused Deposition Modeling: Artificial Neural Network and Response Surface Method Analyses. J. Mater. Eng. Perform. 2023, 32, 2016–2028.
9. Kotomin, S.V, Kramarev, D.V, Obidin, I.M, Polunin, S.V. Influence of 3D Printing Conditions of Polyethylene Terephthalate Glycol on the Mechanical Properties of Products Based on It. Polym. Sci. Ser. A 2022, 64, 617–623.
10. Ahmadi, M, Tabary SA, A.B, Rahmatabadi, D, Ebrahimi, M.S, Abrinia, K, Hashemi, R. Review of selective laser melting of magnesium alloys: Advantages, microstructure and mechanical

characterizations, defects, challenges, and applications. J. Mater. Res. Technol. 2022, 19, 1537–1562.

11. Ajani, S. N. ., Khobragade, P. ., Dhone, M. ., Ganguly, B. ., Shelke, N. ., & Parati, N. . (2023). Advancements in Computing: Emerging Trends in Computational Science with Next-Generation Computing. International Journal of Intelligent Systems and Applications in Engineering, 12(7s), 546–559
12. Jiang, Y, Zhou, J, Shi, H, Zhao, G, Zhang, Q, Feng, C, Xv, X. Preparation of cellulose nanocrystal/oxidized dextran/gelatin (CNC/OD/GEL) hydrogels and fabrication of a CNC/OD/GEL scaffold by 3D printing. J. Mater. Sci. 2020, 55, 2618–2635.
13. Yousefi, N, Hashemi, R, Sedighi, M. Printing strategies to fabricate a disk through the fused deposition modeling method. Proc. Inst. Mech. Eng. Part L J. Mater. Des. Appl. 2023.
14. Chen, F, Ni, X, Liu, Y, Xia, X, Gao, X. Preparation and properties of heat-treated esterified wood flour/polylactic acid composites for FDM 3D printing. J. Mater. Sci. 2022, 57, 14819–14834.
15. P. Khobragade, P. Ghutke, V. P. Kalbande and N. Purohit, "Advancement in Internet of Things (IoT) Based Solar Collector for Thermal Energy Storage System Devices: A Review," 2022 2nd International Conference on Power Electronics & IoT Applications in Renewable Energy and its Control (PARC), Mathura, India, 2022, pp. 1-5, doi: 10.1109/PARC52418.2022.9726651.
16. Rahmatabadi, D, Aberoumand, M, Soltanmohammadi, K, Soleyman, E, Ghasemi, I, Baniassadi, M, Abrinia, K, Zolfagharian, A, Bodaghi, M, Baghani, M. A New Strategy for Achieving Shape Memory Effects in 4D Printed Two-Layer Composite Structures. Polymers 2022, 14, 5446.
17. Fernández-Cervantes, I, Morales, M.A, Agustín-Serrano, R, Cardenas-García, M, Pérez-Luna, P.V, Arroyo-Reyes, B.L, Maldonado-García, A. Polylactic acid/sodium alginate/hydroxyapatite composite scaffolds with trabecular tissue morphology designed by a bone remodeling model using 3D printing. J. Mater. Sci. 2019, 54, 9478–9496.
18. Rahmatabadi, D, Soltanmohammadi, K, Aberoumand, M, Soleyman, E, Ghasemi, I, Baniassadi, M, Abrinia, K, Bodaghi, M, Baghani, M. Development of Pure Poly Vinyl Chloride (PVC) with Excellent 3D Printability and Macro- and Micro-Structural Properties. Macromol. Mater. Eng. 2023, 308, 2200568.
19. Dhanashri Shete, Prashant Khobragade; An empirical analysis of different data visualization techniques from statistical perspective. AIP Conf. Proc. 29 September 2023; 2839 (1): 040017.
20. Yasir, M, Ullah, Z, Noroozi, R, Zolfagharian, A. 4D printing of shape memory polymer composites: A review on fabrication techniques, applications, and future perspectives. J. Manuf. Process. 2022, 81, 759–797.
21. Rahmatabadi, D, Ghasemi, I, Baniassadi, M, Abrinia, K, Baghani, M. 4D printing of PLA-TPU blends: Effect of PLA concentration, loading mode, and programming temperature on the shape memory effect. J. Mater. Sci. 2023, 58, 7227–7243.
22. Moradi, M, Hashemi, R, Kasaeian-Naeini, M. Experimental investigation of parameters in fused filament fabrication 3D printing process of ABS plus using response surface methodology. Int. J. Adv. Manuf. Technol. 2023, 126, 1–18.
23. Zhang, S, Rehman MZ ur Bhagia, S, Meng, X, Meyer, H.M, Wang, H, Koehler, M.R, Akhtar, K, Harper, D.P, Ragauskas, A.J. Coal polymer composites prepared by fused deposition modeling (FDM) 3D printing. J. Mater. Sci. 2022, 57, 10141–10152.
24. López-Manchado MA, Biagiotti J, Kenny JM. Comparative Study of the Effects of Different Fibers on the Processing and Properties of Polypropylene Matrix Composites. Journal of Thermoplastic Composite Materials. 2002;15(4):337-353. doi:10.1177/0892705702015004457
25. Mageshwaran, V., Sivasubramanian, P., Kumar, P., Nagaraju, Y. (2023). Antibacterial Response of Nanostructured Chitosan Hybrid Materials. In: Swain, S.K., Biswal, A. (eds) Chitosan Nanocomposites. Biological and Medical Physics, Biomedical Engineering. Springer, Singapore. https://doi.org/10.1007/978-981-19-9646-7_7
26. Sumesh KR, Ajithram A, Palanisamy, S. et al. Mechanical properties of ramie/flax hybrid natural fiber composites under different conditions. Biomass Conv. Bioref. (2023). https://doi.org/10.1007/s13399-023-04628-5