International Journal of Research in Pharmacology & Pharmacotherapeutics (IJRPP)
IJRPP |Vol.15 | Issue 1 | Jan - Mar -2026
www.ijrpp.com
DOI : https://doi.org/10.61096/ijrpp.v15.iss1.2026.44-57
ISSN: 2278-2648

Recent Development in Fused Deposition Modeling-(FDM) Based 3D Printing

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Published by:
02.02.2026

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Abstract A popular additive manufacturing method modeling of fused deposition, or FDM, makes use of thermoplastic filaments to create three-dimensional structures layer after layer. It's been extensively utilized due to its benefits, such as affordability and ease of use, in a variety of industries, including health care, pharmaceuticals, aerospace, and automotive. of use , minimum material waste, and compatibility with a variety of polymers. Without the need for molds or tools, FDM Technology makes it possible to produce complex geometries, quick prototyping, and bespoke components. Recent developments in composite filaments, biocompatible polymers, multi-material printing, and process optimization have increased its uses despite drawbacks such anisotropic mechanical strength, roughness of the exterior, and a lack of high-performance materials. Enhancing mechanical qualities, thermal stability, biocompatibility, and The primary focus of current research is sustainable production. The creation, mechanisms, uses, and prospects of FDM-based 3D printing, highlighting its potential in advanced material development, industrial manufacturing, and customized medicine.

Keywords: Additive Manufacturing (AM); Fused Deposition Modeling the (FDM); and 3D printing; Thermoplastic Filaments (PLA, ABS, PETG, PCL); and Composite Filaments (Carbon Fiber, Nanoparticles)Layer-by-layer manufacturing; quick prototyping, personalized medical equipment, and pharmaceutical applications; CAD, STL, and slicing; process parameters (layer thickness, nozzle temperature, and raster angle); industrial applications (automotive, aerospace, and healthcare); biocompatible and biodegradable materials; future scope and mass customization; sustainability and environmentally friendly filaments.

INTRODUCTION:

One technique used Fused Deposition Modelling (FDM) is used in 3D printing. The approach used here is one of the production processes within Engineering for additive manufacturing class, increasing popularity in academia and business to study and improve. With less waste and other benefits over traditional production, additive manufacturing techniques are becoming increasingly well-liked since they can produce a wide range of intricate shapes and structures while effectively managing materials. Concerning manufacturing, the FDM technology is technically equivalent to injection molding. For example, mass customization. It involves making a series of personalized items, in order for each product to be errant while main- training low prices owing to mass production.

It doesn't need the added expenditures of manufacturing molds and tools for personalized goods. The basic principle of the FDM manufacturing method is simply melting the raw material and shaping it to produce new forms.

The substance is a lament arranged in a roll, pulled by a driving wheel, and then put into a temperature- heated to semiliquid and the nozzle head was under control. The nozzle precisely extrudes and directs materials in an Layer after layer of incredibly thin material to create layer-by-layer structures rural elements. This adheres to the specifications of the software-specific layer, usually CAD that has been incorporated into the FDM work system.

It doesn't need the extra expenses associated with making tools. And molds for customized products. The core idea of the FDM The fundamental the substance is only melted and formed. to form new shapes using manufacturing innovations.

The quick advancement of recent advancements in additive manufacturing (AM) technology has caused the emphasis to abandon traditional application techniques. Aerospace, automotive, and bioengineering are only a few of the manufacturing industries that employ 3D printing. Additive manufacturing (AM) has the advantage of generating items with complex shapes more quickly and affordably than traditional manufacturing techniques.

The AM technique is commonly applied on prototypes. in engineering applications, functional, and customized goods. Currently, several AM systems like the market offers Stereo and FDM lithography (SLA), selective laser sintering (SLS), ink selective laser melting and jet modeling. The quantity of space required for these systems varies, the price, the number of building layers, and the materials used.

BACK GROUND:

When SLA was initially introduced in the mid-1980s, rapidly prototyped items had much worse mechanical qualities than parts manufactured with other conventional production techniques.

In the early 1990s, Stratasys Inc., USA, commercialized the FDM method, which had been developed from the 1980s.

Because of its dependability, affordability in producing 3D objects with high resolution, dimensional stability, extensive material customization, and simple fabrication procedure (Plymill et al. 2016; Masood and Song 2004), and capacity to safely fabricate complex geometrical FDM has recently been widely used in AM technology to produce a range of things across many manufacturing sectors in a favorable environment.

FDM technology is extremely adaptable and simple to include into CAD tools, or computer-aided design. Thermo-plastic filament needs be melted before to the deposition process because it is a thermally controlled process, which restricts the materials that can be processed with this technique.

Just Some materials include acrylonitrile-butadiene and polylactic acid (PLA). Styrene (ABS), have the required Thermal (melting point, glass transition temperature) and rheological (Melt Flow Index (MFI), etc.) characteristics to be processed with ease utilizing this technique.

Most research had mostly concentrated on process parameter optimization and were interested in examining the connections between various process parameters and how they affect the finished product. Road width (Anitha et al. 2001, Duigou et al. 2016), raster orientation (Es-Said et al. 2000, Lee and Huang 2013, Hill and Haghi 2014, Garg et al. 2016), layer thickness (Lee et al. 2005, Wu and associates (2015) Tian et al. 2016), nozzle diameter, extrusion velocity, filler particle size, raster temperature (Sun et al. 2008). To enhance the FDM procedure and achieve the highest qualities—such as high quality, dimensional precision, decreased porosity, improved mechanical qualities and less distortion in the finished product—all of these aspects need to be controlled.

This research provides a thorough analysis of the development and optimization of various composite materials to enhance the FDM system's mechanical characteristics (tensile strength, fatigue, etc.). It further provides areas for further research and development (R&D) initiatives should focus in order to advance this technology and produce commodities with increased power and other favorable qualities.

THE PAST:

1988 – S. Scott Crump, co-founder of Stratasys Inc, pioneered Fused Deposition Modeling (FDM) technology. In 1989, Stratasys Inc. submitted a patent application for FDM technology. 1990 saw commercial distribution of the initial FDM printer. 2005– The RepRap project started the open-source 3D printing revolution, created by Dr. Adrian Bowyer at Bath University, 2009: The FDM technology patent expired. Considering the RepRap open-source initiative, inexpensive kits and fully finished devices become accessible. ABS and PLA polymers became widely used materials, 2009 – The Rap Man 3D printer kit (£750) was released to build a similar system to FDM. MakerBot introduced the Cupcake CNC products according to the RepRap-based Cupcake CNC products were introduced by MakerBot, 2011 – Ulti maker Ltd. released the first RepRap-based 3D printer, Ultimaker Original. Solidoodle also launched their Rep I Rap-based Solidoodle 3D printer, 2012 observed the Replicator's release 2 and 2X platforms by MakerBot Industries. This marked a change from open-source functionality to proprietary control.

The public's interest in 3D printing peaked in 2013. For FDM, a range of plastics polymers (PP, polyamide, PCL) and composites were created, 2014 saw the release of Markforged's Mark One, the first printer with continuous fiber reinforcement. Compared to standard printed materials, the parts were ten times stronger parts.

The first PEEK 3D printer was introduced by INDMATEC (Apium Additive Technologies) in 2015.

AIM:

BASIC FUSED DEPOSITION MODELING (FDM) PRINCIPLES AND THEIR MECHANISMS:

In the hot melt extrusion method, which deposits material layer by layer using 3D model data is the primary basis for fused deposition modeling until a whole object is produced. A circulating drive gear mechanism is typically utilized in the FDM method to feed a filament feedstock has a 1.75-inch diameter mm or 3.00 mm into a printer To supply the energy needed to move the film through the system, a stepper motor is connected to one of the drive gears. One or both of the drive gears may have a toothed or grooved surface to create enough friction for the gear to hold the filament and feed it to the liquefier without slipping.

The solid part at the back serves as a piston to push the molten substance through the print nozzle as the heated liquefier melts the filament.

In general, as long as the printer's configuration are adjusted, the choice of filament diameter won't affect printing quality. A larger-sized diameter (3 mm) generates a stronger filament, and consequently, the procedure requires more pressure but is slower in pushing the substance through the nozzle. Because to its improved rigidity, it inhibits any flexibility in the PTFE tube; thereby resulting in a smoother filament feeding process and minimizes the likelihood of filament breakage.

In contrast, a 1.75 mm filament provides several advantages over a 3 mm filament. For the same size of the nozzle, the application of a smaller diameter filament requires less pressure and consequently, the filament may be fed through faster. Furthermore, the 1.75 mm filament is far more adaptable, and as a result conducive to spooling and twisting via curved tubes toward an extruder. Diagrammatic illustration In the modeling procedure for fused deposition, in which the print head moves in the x-y plane and the platform falls layer per layer as it the z-axis. As seen

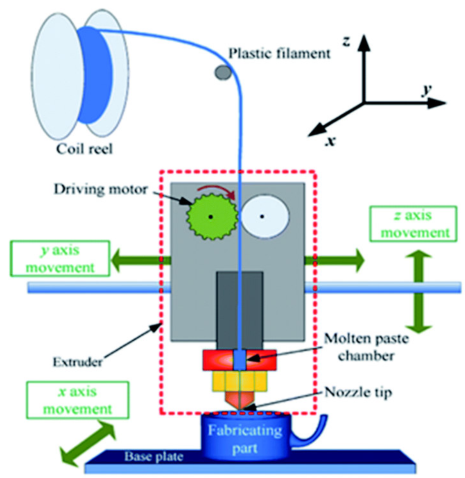

Figure 1: Diagrammatic representation of the modeling method for fused deposition.

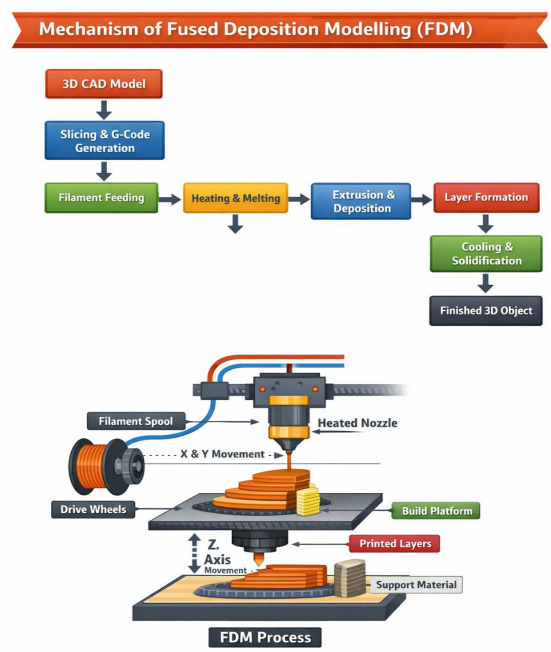

Figure 2: Mechanism of fused deposition modeling.

MODELING TECHNOLOGY FOR FUSED DEPOSITS OVERVIEW:

FDM technology is rapidly advancing and seems to have endless potential in a variety of sectors, such as the automotive, healthcare, and aviation industries. The layer-by-layer technology numerous prosthetics have been produced with FDM in medical purposes medical equipment, and organ models for preoperative surgery, human tissue, and personalized medicine because of its ability to create three-dimensional objects and designs for complex parts. With fresh advancements and enhancements, particularly in the areas of materials and printers, this technology's potential is continually expanding. As a dependable technique for freeform without the need for pricey molds with tools, the modeling technique of fused deposition provides numerous manufacturing benefits. The procedure is easy, user-friendly, and ensures efficient resource use, resulting in minimal material waste. The FDM technique's compatibility with one of its key benefits is a large selection of thermoplastic polymers. The most popular materials are ABS (acrylonitrile butadiene styrene) and PLA (polylactic acid) steady. Polymer other thermoplastics, such as polycarbonates (PC), polystyrene (PS), polyamide, polyetherimide (PEI), and polyetheretherketone (PEEK), have been proven to be printable by FDM printers thus far. Additionally, there is a need to create composite filaments by incorporating specific materials into polymer matrices because they provide better conductivity, biocompatibility, or mechanical qualities. However, using a syringe method instead of a printer 4 T. N. A. T. RAHIM ET AL. extruder can also produce a part formed of liquid or paste, such chocolate or clay.

Due to modifications in the raster orientation or build direction throughout the procedure, the printed parts also exhibit anisotropic behavior, displaying weak portions that are perpendicular to the created axes. Later in Section 9, a more thorough analysis of earlier research is covered. Additionally, FDM items are less accurate than parts made using traditional and alternative printing methods. The high dimensional inaccuracy (±0.1 mm) of FDM components may be brought about by the appearance of "vowelized" or "non-smooth" surfaces. The way the material flows determines this aspect; should the extrusion head not be moving constantly, the material will bump up and the printing process will be interrupted.

Additionally, the method exhibits a general slowness brought on by the slow printing speed, which necessitates a longer build time to print the entire structure. The biocompatibility of traditional another issue is the use of polymers like ABS in medicinal applications. The exact effects of ABS toxicity on human cells are really still being debated. ABS is typically regarded as being rather harmless because it is unknown to be harmful to humans or carcinogenic. Health because of this, ABS is widely used in the manufacturing of household products, surgical tools, toys (like Lego), and pharmaceutical processing applications. According to earlier research, AS is a stable thermoplastic polymer that doesn't release harmful substances or cause any anomalous behavior.

Recently, several ABS grades have also been deemed FDA food contact compliant, meaning the materials are suitable for contact with food. Long-term contact with the human body, such as with drug delivery devices or medical implants, is still unsuitable. This is because experts are worried that styrene, a a portion of the chemical structure of ABS, could lead to cancer in humans. Consequently, this content has not yet been included. in any medical implants., Furthermore, most consumers find the plastic to smell bad when heated between processing temperatures, and 0.50 mmol/h of volatile organic compounds (VOC) were measured.

Some researchers are investigating and creating a biocompatible FDM feedstock from Because of the shortcomings in conventional materials, polylactic acid (PLA) and polycaprolactone (PCL) are used in biomaterial applications. It has been found it scaffolds with many styles and controlled porosities can be made from these materials. They have also been found to be safe each of them in vitro and in vivo. Scaffolds are intended to provide temporary fixes for tissue engineering applications; their biological and mechanical requirements are intended to provide temporary fixes for tissue engineering applications; their biological and mechanical requirements have been effectively met and proven. However, because PLA may create lactate conjugates in a physiological setting, which subsequently change the surrounding pH, PLA Breakdown leads to more issues.

It should be mentioned that decreasing pH has a negative effect on cell attachment, differentiation, and proliferation. Additionally, By activating particular pathways, an acidic environment alters and begins an inflammatory program in cells. This causes inflammation, which can expose cells to secondary problems resemble an illness and gradually lessen the healing process. Many attempts have been made to functionalize PLA in order to change pH of it characteristics during breakdown. in order to manufacture PLA that breaks down in a pH-neutral manner. PLA fibers with micro gels and regulating the dispersion of micro gels to achieve more improvements with solution spinning.

In a Prior study, the mechanical and thermal characteristics of the zirconia-HA/polyamide 12 (PA12) composite were examined in an attempt to prolong the material's life while simultaneously enhancing its mechanical and thermal performance. New FDM-based biomaterial feedstocks made of polyamide composites were also looked into. As per the research, a modest quantity of filler content enhanced the mechanical properties of composites and thermal stability, which might render them appropriate for usage. as biomedical implant materials for non-load-bearing applications. As seen in Figure 3...

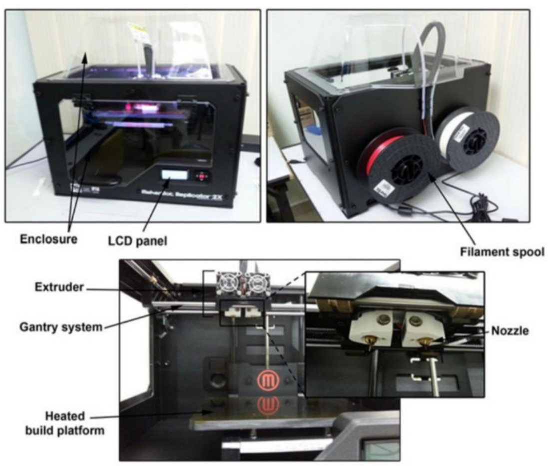

Figure 3: Overview of (FDM) machine

OBSERVATION:

A thermoplastic Fused deposition modeling, or A popular 3D printing method called FDM produces three-dimensional objects by melting in a filament a heated nozzle and Putting it in layer by layer. The create a platform that vanishes after each layer along the Z-axis as the print head travels in the X-Y direction. Complex forms and designs can be precisely fabricated with this technology.

Because FDM is inexpensive, simple to use, and appropriate for a variety of materials, including PETG, PLA, ABS, and medicinal polymers. FDM-based 3D printing is utilized in pharmaceutical practice to create customized medical devices, regulated medication administration methods, and customized dose forms. The printed item exhibits appropriate layer bonding, acceptable dimensional accuracy, and is appropriate for small-scale production and prototyping. Therefore, FDM combined 3D printing has a useful and adaptable technology with uses in industry, education, and healthcare.

INNOVATION FOR 3D PRINTING:

The method of utilizing a computer model to create a three-dimensional solid object of nearly any shape is referred to as 3D printing or additive manufacturing. Charles Hull's techniques for printing from 1980. These days, 3D printing is primarily used in the food and aviation industries to create artificial and other items. Currently, 3D printing technology may be used to generate substances like metal, ceramics, graphene-based materials, and conventional thermoplastics. The layer-by-layer creation of constructions in three dimensions (3D) utilizing 3D printing technology straight from computer-aided design (CAD) plans, including a steel bridge in Amsterdam, a heart pump, jewelry, a PGA rocket engine, and a 3D-printed cornea.

Since obtaining its initial patent in 1986, 3D printing has been applied to pharmaceutical printing, bio fabrication, and medications. Additionally, it might be integrated into the pharmaceutical industry's drug production process, which tends to shift toward both mass manufacturing and individualized medicine. The International Standards Organization (ISO) defined 3D printing (3DP), which i is the act of creating things by depositing a substance using a print head, nozzle, or other printing equipment.

The FDA approved the successful use of 3D printed implants and medical devices earlier this year. In 2012, the FDA approved utilizing printed tracheal splints. A customized 3D printed plate was approved for use in a patient's surgical skull surgery in February 2013. The seven subsections that comprise these technologies provide a comprehensive framework for categorizing printing processes in the present and the prospects.

ESSENTIAL OF 3D PRINTING:

The fundamental concept of 3D printing, also known as additive manufacturing, is to create three-dimensional things by layering digital models. This process 141 differs from traditional subtractive methods of production, which remove material from a solid block to achieve the desired form.

1. Stereolithography: Photo polymerization is a novel liquid phenomenon that takes place throughout the whole process. SLA is treated with a specific liquid called photosensitive resin. This resin solidifies or hardens significantly when subjected to ultraviolet (UV) electromagnetic radiation. SLA uses low-power UV radiation, which is a type of light that people are unable to see This light comes from a laser, namely a He-Cd or Nd:YVO4 laser. The highest operating power of this laser is 1000 milliwatts (mW), which is adequate to solidify the resin quickly. Among the most important elements of the SLA machine is platform movement. It holds the thing being made, somewhat like a small table. This platform is surrounded by a tank of liquid resin. The piece of art is produced layer by layer as the resin is struck by laser beams. Where and how long the laser should beams are determined by the computer that functions the laser source. The machine needs to be tidied after the 3D object has been created. The object is positioned in a UV oven after being cleaned. Shown in **FIGURE;4**

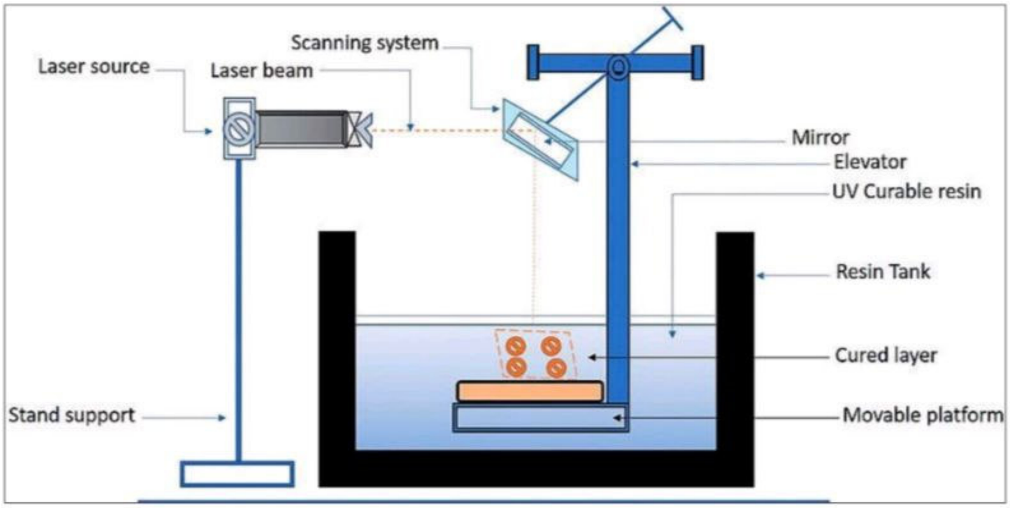

Figure 4: Principle of Stereo lithography.

2. Fused Deposition Modeling (FDM): This method involves melting plastic filament and stacking it to construct an item. A computer controls the extruder's activity to build the final product, already displayed in image

3. Selective laser melting: Using a laser to fuse the particles and produce a solid product "A powdered material melts using selective laser melting (SLM). The laser's frequency is controlled to control the melting process shown in figure 5.

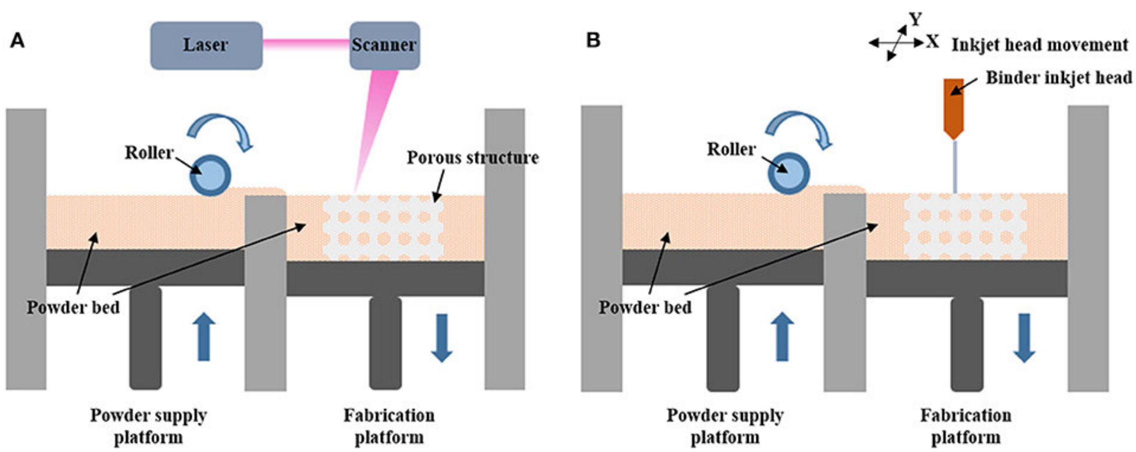

Figure 5: Selective laser melting principle.

4. Electronic beam melting: EBM creates strong metallic components in a vacuum by employing electron beams rather than lasers to Melt the metal powder. layer by layer, hence eliminating material stress 1+. Production of laminated objects: LOM's layers of materials, such as plastic or paper, are joined together and then laser-cut into the appropriate shapes. The final product may undergo more extensive modifications after printing. Shown in figure.6

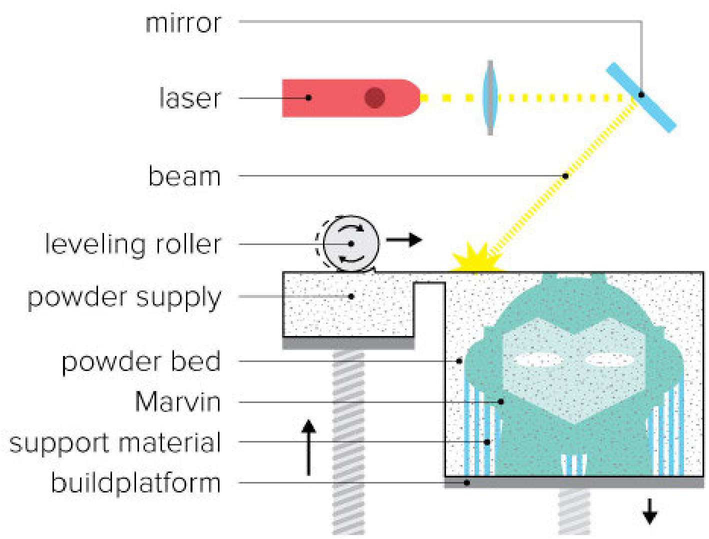

Figure 6: Electronic beam melting principle.

5. Fabrication of laminated objects: in LOM, layers of materials, such as plastic or paper, are bonded together before being laser-cut into the appropriate shapes. The final product may undergo more significant alteration following printing. Laser scanning system shown in **figure:7**

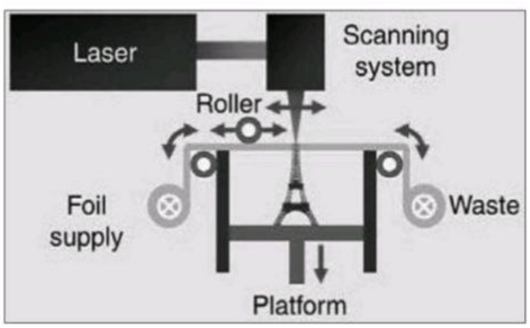

Figure 7: Concept of laminated object manufacture.

Classification of 3D printing:

There are seven different types of contemporary 3D printing technology are described by ASTM International, formerly known as American Standards and Testing Materials. it is mostly applied in therapeutic settings.

* Material jetting.

* Material extrusion.

* Binder jetting.

* Vat photo polymerization.

* Merging of powder beds.

* Focused deposition of energy

* Sheet lamination.

3D PRINTING MATERIALS:

* Plastics.

* Metals.

* Ceramics.

* Paper.

* Bio materials.

* Food.

* And others.

Application 3D manufacturing in the medical field:

Medical implants comprised of 3D printing devices are used in various parts of human anatomy. Losses and abnormalities that necessitate tissue or organ transplantation continue to be significant concerns in clinical medicine, as do problems with the application of contemporary techniques like auto transplantation, xenotransplantation, and the implantation of artificial mechanical organs.

The following are the four main areas of focus for current research on 3D printing technology for medical applications:

i) Research on the production of sick organ copies is used to evaluate techniques for surgery and preoperative planning.
ii) Examinations of the production of durable, non-bioactive implants.
iii) Research aimed at developing bioactive and biodegradable scaffolds locally.

iv) Research on the direct Producing of biological tissues and organs that important life functions.

CURRENT STATUS:

1. Industrial Adoption and Market Growth.

Quick market expansion: Forecasts indicate that the market for FDM 3D printing will considerably increase between 2025 and the early 2030s. The reported growth rates (CAGRs) range from approximately 21% to approximately 25%, indicating broad sectoral adoption. Transition from prototyping to production: In industries including automotive, aerospace, and healthcare, FDM is increasingly utilized for functional parts, tooling, jigs/fixtures, and even short-run end-use components. It was once mostly used for quick prototypes. Distributed manufacturing: To improve supply-chain resilience and shorten lead times, companies are setting up internal FDM "farms" to manufacture spare parts on demand.

2. Innovations in Technology Innovative Materials.

Diverse filaments: In addition to PLA and ABS, engineering-grade polymers like PEEK, ULTEM, nylon, PETG, and composite filaments (like carbon-fiber reinforced) are now offered for sale, allowing for stronger and more heat-resistant parts. Specialty & eco-materials: As sustainability becomes a priority, recycled and bio-based filaments are gaining traction.

Emerging research even investigates thermal-stable and space-grade filaments for harsh environments.

3. Software & Process Enhancements.

AI and cloud integration: Part complexity, efficiency, and quality control are being improved by intelligent monitoring, automated process management, and cloud-based generative design. Hybrid and multi-material systems: Modern machinery can handle several filaments and combine additive and subtractive techniques for items with mixed functions and increased precision.

Advanced hardware concepts: To improve print speed and dependability, research is being done on optimized components, such as nozzle geometry.

4. Use Cases in Industry Automotive. Prototypes, fixtures, and functional components are widely used, allowing for quicker design iterations and the fabrication of lightweight parts.

5. Healthcare & medications.

Although regulatory channels are still developing, FDM is being utilized more and more for anatomical models, custom surgical jigs, and research in dosage forms and polymer-based medications. Education & Consumer. Because of its relative price and accessibility, it continues to be a mainstay in education, quick product design, and low-volume consumer products customization.

6. Sustainability Priorities Process ustadecisions and material development are being impacted by sustainability;

Businesses are investigating closed-loop recycling systems;

The market is witnessing a rise in the application of recycled filament;

Bio-based and biodegradable materials are being introduced.

Types of FDM Fused deposition model:

1. Cartesian FDM 3D Printer.
2. Delta FDM 3D Printer.
3. Polar FDM 3D Printer.
4. Scare FDM 3D Printer.
5. Core-XY FDM 3D Printer.
6. H-Bot FDM 3D Printer.
7. Belt FDM 3D Printer.

1. Cartesian FDM 3D Printer:

Figure 8: Cartesian FDM 3d Printer.

Cartesian FDM 3D printers use Coordinates in Cartesian system, which allows for independent motion throughout the X, Y, and Z axes. Typically, the build platform travels along the Z-axis and the print head travels along the X-Y aircraft. Due to its simple design, precision, and ease of control, this type is the most popular. Benefits include

- Easy calibration;
- Simple construction; and
- High dimensional accuracy Applications include small-scale manufacturing, education, and prototyping education, and prototyping.

2. Delta FDM 3D Printer:

Figure 9: Delta FDM Printer.

Three vertical towers are linked to a single print head by lightweight arms in a parallel robotic mechanism used by Delta FDM printers. The nozzle is positioned in space by coordinated arm movements. These printers are renowned for their fluid action and rapid printing. Benefits include:

- Quick printing speed;
- Lightweight moving parts; and
- Fit for tall things. Limitations: Limited construction area close to edges and complicated

3. Polar FDM 3D Printer:

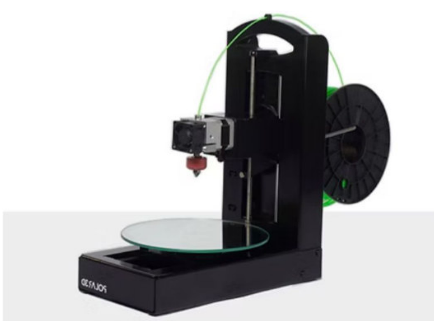

Figure 10: Polar FDM 3D Printer

In polar FDM printers, the print head travels both vertically and radially while the build platform rotates according to polar coordinates. Radius (r), angle (θ), and height (Z) are employed to regulate printing. Advantages

- Efficient for circular geometries;
- Fewer mechanical components Limitations: Limited commercial use and the requirement for certain software. include a large working envelope and a great degree of adaptability and reach.

4. Scara FDM 3D Printer:

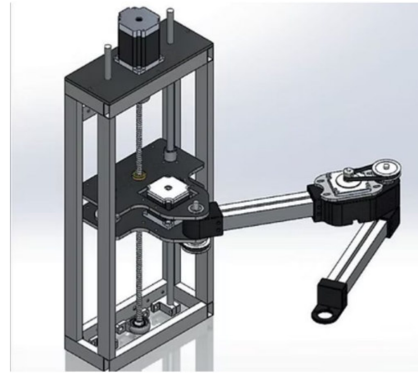

Figure 11: Scara FDM 3D Printer

Selective Compliance Assembly Robot Arm, or SCARA The print head of FDM printers is controlled by a robotic arm. The Arm motion is linear in the vertical direction while spinning in the horizontal plane. Benefit Add a sizable working envelope and a great degree of adaptability and 3D printing application on an experimental and industrial scale.

5. Core-XY FDM 3D Printer;

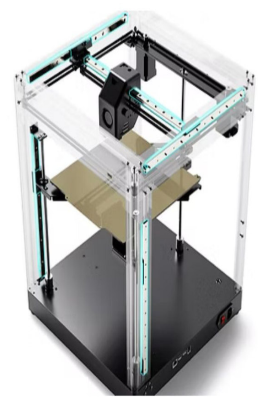

Figure 12: Core-XY FDM 3D Printer.

Core-XY printers employ a dual-motor belt system in which the To control movement in the two X and Y directions. Because the motors don't move, there is less moving mass. Benefits include:

- High printing speed;
- Improved stability and precision; and
- Less vibration Applications: Professional and desktop printers with high performance.

6. H-Bot FDM 3D Printer;

Like Core-XY systems, H-Bot printers employ a single continuous belt for X-Y motion. Incorrect belt tension might result in racking even though it is mechanically simpler. Benefits:

- Easy belt arrangement;
- Fewer parts Cons: Less stable than Core-XY.

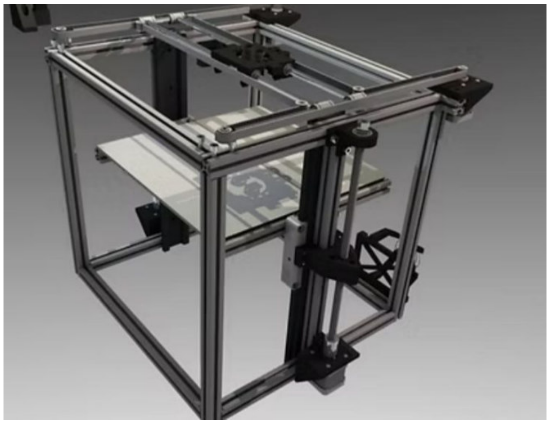

Figure 13: H-Bot FDM 3D Printer.

7. Belt FDM 3D Printer;

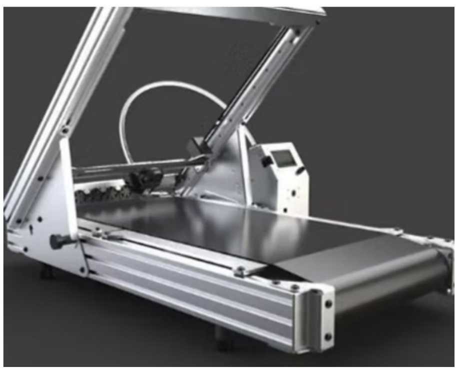

Figure 14: Belt FDM 3D Printer.

A continuous moving belt, usually oriented at a 45° angle, serves as the build platform in belt FDM printers. This enables theoretically limitless object length and continuous printing. Benefits include:

- Constant production;
- Perfect for batch manufacturing Applications include automated and industrial production systems.

MATERIAL UTILIZED IN FDM:

Modeling via Fused Deposition (FDM) is an additive manufacturing process that creates three-dimensional things by heating, extruding, and depositing thermoplastic filaments layer by layer majority of research literature divides FDM materials into three categories: composites, high-performance polymers, and thermoplastics.

1. Base Materials: Thermoplastic Polymers for in most cases, FDM procedures, these serve as the primary feedstock. They are offered as filaments and are selected according to end-use requirements, mechanical qualities, and printing ease. Material Features/Uses PLA (polylactic acid) is frequently used in instructional methods and prototyping since it is biodegradable, simple to print, and has a low warp. ABS (Butadiene Acrylonitrile Styrene) Powerful, heat resistant, common in functional prototypes; prone to warping without heated bed. Strength, superior printability, and chemical resistance are all combined in PETG (polyethylene terephthalate glycol). PC (polycarbonate) is employed in engineering applications due to its high power and heat resistance. Flexible and long-lasting, nylon (polyamide) works well for mechanical components. Thermoplastic Polyurethane and Elastomers (TPU/TPE) are elastic and pliable materials utilized for soft or wearable parts. Polyvinyl alcohol, or PVA, is a water-soluble support substance. Polycaprolactone, or PCL, is a low melting temperature polymer utilized in biodegradable and medicinal applications. The mechanical, rheological, given these polymers' thermal characteristics in FDM printing have been thoroughly investigated.

2. Polymers with High Performance Materials with enhanced thermal and mechanical stability are employed in demanding application of engineering

- Polyether Ether Ketone, or PEEK, is incredibly strong mechanically and chemically.
- PEI (Polyetherimide/ULTEM): excellent structural performance and heat resistance.
- ASA stands for acrylonitrile styrene acrylate. is comparable to ABS but has better weather and UV protection.

3. Modified Filaments and Polymer Composites Base polymers are frequently supplemented with fillers to improve performance (like conductivity and strength): Carbon-based Fillers.

- Using carbon fibers, carbon nanotubes (CNTs), or graphene into filaments increases their strength and stiffness. For instance, carbon fiber reinforced PLA or nylon has a significantly higher tensile strength than neat polymer.
- Nanoparticle-Enhanced Polymers: Metal nanoparticles (like titanium nitride) and oxide fillers are being investigated to provide additional properties like electrical conductivity or photo thermal reactions.

4. Specialized Materials for Biomedical and Functional Uses FDM materials are modified using biocompatible or dissolvable polymers for uses such as drug delivery or tissue engineering: Hydroxypropyl cellulose (HPC), polyethylene glycol (PEG), copolymers and poloxamers, and chitosan For biomedical scaffolds and controlled release systems, they are frequently combined with PLA, PVA, or TPU.

UTILIZATION OF FUSED DEPOSITION MODELING:

One popular additive manufacturing technique is fused deposition modeling, or FDM. Because of its ease of use, cost, and adaptability. Rapid prototyping, which uses FDM to swiftly create prototypes for assessing product design, dimensional correctness, and functional performance, is among its most important applications. This enables for numerous design changes prior to final manufacturing and drastically cuts down on the time and expense of product development. Prosthetics, orthotic devices, surgical guides, and patient-specific anatomical models are all made using FDM in the medical industry. These personalized models help surgeons with medical education and pre-operative preparation. For these kinds of applications, biocompatible and biodegradable polymers including PLA, PCL, and TPU are frequently utilized.

In the medical field industry, FDM has also drawn more interest, especially for the Oral dose forms printed in three dimensions. It supports the concept of customized medicine by developing it possible to manufacture tablets with unique sizes, shapes, and medication dosages. Pharmaceutical-grade polymers are used in FDM research to create sustained-release and controlled-release drug delivery systems. Functional parts, jigs, fixtures, tools, and low-volume end-use components are produced using FDM in engineering and industrial manufacturing. For industrial uses, materials including ABS, nylon, and polycarbonate offer adequate mechanical strength. On-demand spare part production is another application for FDM.

Furthermore, FDM is frequently utilized in research and educational institutes to teach design optimization, material science, and additive manufacturing fundamentals. It is appropriate for lab demonstrations and student projects because to its simplicity of use and inexpensive equipment. All things considered, FDM contributes significantly to contemporary manufacturing by facilitating quick, personalized, and economical production in numerous sectors, including engineering, medicine, and pharmaceutical science.

ADVANTAGES OF FDM:

1. Fused Deposition Modeling's (FDM) benefits1. When compared to other additive manufacturing techniques, FDM is an inexpensive 3D printing technology.
2. It is appropriate for novices and instructional use because it is simple to utilize and preserve.
3. Several types of thermoplastic materials, including PLA, ABS, PETG, nylon, and TPU, are supported by FDM.
4. It reduces the amount of time required for the product development by enabling quick prototyping.
5. FDM is capable of creating intricate and unique shapes
6. Because the material is deposited layer by layer, there is not very material waste.
7. FDM printers are easily accessible and just need basic post-processing.
8. It can be applied to engineering, pharmaceutical, and medical applications, including customized goods.

9. DISADVANTAGES OF FDM:

1. Because layer lines are visible, FDM printed objects frequently have a low surface polish.
2. In comparison to some other 3D printing methods and traditional production, it offers less mechanical strength.
3. There is anisotropic behavior, which indicates that strength varies in different directions.
4. Compared to other technologies, there are few options for materials to thermoplastic materials.
5. Shrinkage and warping can happen, particularly with materials like ABS.
6. Compared to SLA or SLS methods, accuracy and dimensional precision are lower.
7. Large or complicated portions print slowly.
8. To enhance surface quality, post-processing techniques like sanding or smoothing are frequently needed.

METHODOLOGY OF FDM:

1. 3D model design Computer-aided design (CAD) programs like SolidWorks or AutoCAD are employed in the original design of the item that will be generated.
2. STL File Conversion an STL (Standard Tessellation Language) file, which depicts the object's geometry in triangular facets, is produced using the model in CAD.
3. Slicing Models the figure is cut into thin horizontal layers and printing parameters like layer height, temperature, and infill are specified when The STL document is imported into the slicing program.
4. Feeding Materials A spool of thermoplastic filament, like PLA or ABS, is supplied to the heated extruder nozzle.
5. Extrusion and Melting the filament is extruded via the nozzle in a semi-molten state after being heated above its melting point.
6. Layer-by-Layer Deposition In accordance in the cut design, the molten material is applied

to the build layer upon layer of platform apparatus. Following deposition, every layer solidifies.

7. Movement of Platforms the build platform descends along the Z-axis after each layer is placed to make room for the layer that comes after.
8. Both Cooling and Solidification the last 3D object is created when the printed layers solidify and cool, joining with the preceding layers.
9. After-processing Support structures, if any, are removed after printing, and finishing procedures like polishing or sanding may be performed.

FUTURE SCOPE OF FDM:

Future prospects for FDM, or fused deposition modeling, is substantial because of developments in software optimization, printer technology, and materials. The creation of sophisticated, high-performing materials is one of FDM's main possible uses. To expand the application of FDM in the automobile industry, biomedical, and aerospace industries, research is concentrated on enhancing filament qualities including strength, heat resistance, conductivity, and biocompatibility. FDM is expected to be essential to personalized medicine in the pharmaceutical and medical industries. Customized implants, patient-specific medication dose forms, and biodegradable scaffolds for tissue engineering are examples of future innovations. According to regulatory-approved 3D-printed tablets, FDM in pharmaceutical manufacture is anticipated to increase dramatically in the future.

The application of FDM in mass customization and industrial manufacturing is another significant future potential. FDM may transition from prototyping to end-use part production with advancements in printing speed, accuracy, and automation. Smart manufacturing systems will be made possible by FDM's incorporation with Industry 4.0 technologies, including as artificial intelligence (AI) and the Internet of Things (IoT). Sustainable and sustainable production is another aspect of FDM's future. The creation of bio-based, Filaments that are biodegradable and recyclable will reduce their detrimental effects on the environment. is therefore a potential technique for environmentally friendly production.

Due to its low cost and ease of use, FDM will continue to be widely used in education and research for training, innovation, and experimental studies. As technology advances, FDM is anticipated to become more accurate, quicker, and appropriate for high-value applications. All things considered, the future scope of FDM is broad and promising, with strong potential in healthcare, pharmaceuticals, advanced manufacturing, and sustainable production.

CONCLUSION:

Fused Deposition Modeling (FDM) is a popular and adaptable 3D printing process that makes it possible to fabricate intricate, personalized objects quickly and affordably. Rapid prototyping, customized production, as well as the application of a variety of thermoplastic and materials that are composite are all made possible by its layer-by-layer deposition technique. Ongoing developments in materials, printer technology, and process optimization are greatly improving FDM performance despite certain drawbacks, such as reduced mechanical strength, problems with surface polish, and limited material options. Custom implants, prostheses, surgical models, and individualized drug delivery systems are just a a some of the technical medical, and pharmaceutical domains where FDM has already found use The technology has enormous potential for use in smart factories, industrial manufacturing, tailored medicine, and sustainable production in the future. Every things considered, FDM is still a dependable, flexible, and promising additive manufacturing method with growing uses in a variety of industries.

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