Chapter 34
Composites in Context to Additive Manufacturing

Mohd Shoeb, Lokesh Kumar, Abid Haleem, and Mohd Javaid

Abstract The very first application in the Additive Manufacturing (AM) is the development of prototypes, that too by using plastic in fused deposition modeling (FDM) 3D printing processes, Stereolithography, SLS and others. Apart from printing ordinary shaped objects, Additive Manufacturing is also able to produce composites by using different materials on a single production platform. Continuous research and development has improved Additive manufacturing capability to develop various composite materials including fiber-reinforced composite, Biocomposite, Nanocomposites, Polymer matrix composites and Polymers. The primary purpose of this work is the literature-based study on FDM printed composite materials. For this purpose, the keyword "FDM Composites" is used in SCOPUS search and research papers from reputed publishers and Journals were identified and studied. Further, discussed the methods for the development of composite using FDM, and different composite materials with their types which can be printed by using FDM are discussed in a tabular form. It is learned that FDM provides an extraordinary chance to develop typical AM parts with the use of composite materials. Exploration, expansion and commercialization of AM materials are a significant extent of the study in the field of a composite at present.

Keywords Additive manufacturing (AM) · Composites · Fused deposition modeling (FDM) 3D printing

34.1 Introduction

3D Printing is the rapid production technology for making 3D parts directly from CAD files [1]. This process can produce 3D parts without using the conventional technique. It made layer by layer deposition of materials. There are different ways to produce a layer by using different 3D printers which may be with the help of binders [2] or by using 3D lithographic method [3] or by sintering using laser [4] or by plastic

---

M. Shoeb (✉) · L. Kumar · A. Haleem · M. Javaid
Department of Mechanical Engineering, Jamia Millia Islamia, New Delhi 110025, India
e-mail: mshoeb1@jmi.ac.in

R. Pratap Singh et al. (eds.), *Proceedings of the International Conference on Industrial and Manufacturing Systems (CIMS-2020)*, Lecture Notes on Multidisciplinary Industrial Engineering, https://doi.org/10.1007/978-3-030-73495-4_34

filament deposition [5] or by the electron beam [6]. It observed that the FDM is most economic and suitable technology [7]. The broad dissemination of Additive Manufacturing and innovative performance necessities required advanced composite and multimaterial solutions [8]. Properties of composites generally depends on comparative quantities, production technique, geometry such as shape and size, distribution and positioning of reinforcement phase, phases properties and interfacial boundaries strength [9]. This work comprises the study of composite material printing with help of Fused Deposition Modeling method. In FDM 3D printing the thermoplastic filament is used for deposition in a reel form which passes through a hot head. The temperature in head is maintained above the filaments melting point and the melted filament is deposited in XY plane developing a solid material layers on build platform [10]. The Fused Deposition Modeling is found most commonly used method due to their advantages such as economical, reliable, dimensionally stable, high-quality resolution [8], customization of a variety of materials [9] easy fabrication method [10] and capability to develop common geometrical objects in friendly environment conditions. The highly flexible process simply incorporated with CAD packages. Researchers are working on the process parameters optimization and concentrate on the study to inter-relate the various parameters and their response to the final developed product [11].

The most common classification of the 3DP process is based on the initial state of materials and working principle [12] (Kindly see Table 34.1).

34.2 Reason to Embrace 3D Printing for Composites

The main reason for AM implementation and its industrial applications are Geometrical independence, Part functionality, economic and environmental sustainability [13]. The critical application of AM are in the field of energy, aerospace, biomedical, automotive and others [14, 15].

Composites are used in making light structures in different medical and industrial applications. In automobile sector, since 2015, it is observed that there is 5% increase in composites use [16].

34.3 Materials Used in 3D Printing Technologies

3D printing is considered as an important technology in the manufacturing sector worldwide. Its success mainly depends on the enhancement of the materials for the requirement of different applications. This enhancement includes the class, strength, cost and types of materials. There is a variety of materials that can be used in 3D printing according to the requirements of the market. The different types of materials used in 3D Printing are briefly discussed here [17]: *Nylon (Polyamide)*—Flexible, strong and durable. *Resin*—Delicate but rigid. *ABS*—Created by filament-like

Table 34.1 3DP process based on the initial state of materials and working principle

Materials initial state	Distinctive materials	Preparation of material	Process	Method of layer formation	Uses
Solid sheet	Metal, plastic, paper	Laser cutting	LOM	Sheets binding and feeding with the help of adhesives	Models casting and prototypes
Liquid	UV curable resin, ceramic suspension Ceramic paste	The resin in a vat Paste in nozzle	SLA Robocasting	Laser scanning Continuous extrusion	Casting patterns, Prototypes Functional parts
Powder	Polymer, ceramic powders Metal	Powder in bed Powder in bed Powder in bed	3DP SLM EBM	Drop-on-demand binder printing Laser scanning Electron beams scanning	Casting shells, Prototypes Tooling Tooling, functional parts Tooling, functional parts
Filament	Thermoplastics, waxes	Melted in nozzle	FDM	Continuous extrusion and deposition	Casting patterns, prototypes

spaghetti and many colour options. *Silver and Gold*—In the category of Strong materials. *Titanium*—In the category of strongest materials. *Gypsum*—Fragile and rigid known as rainbow ceramics or sandstone. *Ceramics*—Found in rigid form but delicate, obtained by printing and glazing the surface. *VisiJet CF-BK*—Black rubber-like material, appeared in rubber form, highly flexible good ability to absorbs impacts and shocks. *VisiJet FTX Materials*—Parts are micro-manufactured generally used for Jewelry items. *VisiJet CR-WT*—Rigid white ABS-like material, high-temperature resistance greater rigidity highly durable.

34.4 Methods Used for Composites Creation Using FDM

The following methods are briefly discussed here for composite creation using FDM technique:

34.4.1 Multi-Material Structures Creation Using an Element

By this method, multi-material structures are created by printing polymer material layers on wood, metal, ceramic or polymer materials surfaces. The elements obtained by this method have few materials, and built-in material inhabits much of total volume [18]. The main limitation is to break the prototype in parts alienated by comparable planes, successive printing stages to be identified and to resume printing without interrupting the steadiness of material.

34.4.2 Composite Structure Creation Using a Single Nozzle with Reinforcement Material

A composite structure is created by printing using a single nozzle on reinforcement material. The method is same as of multi-material structures creation. The multi-stage method used for composite creation, the amount of stages corresponds to reinforcement layers of the final element. Each stage is planned by the required division plate to enable discontinuing the printing and reinforcement phase deposition on print. Composite may reinforce with cloth and the fibre [19]. The restriction for reinforcement of material layers thickness is the disadvantage of this method. The approximately 0.5 mm layer thickness of reinforcement is generally found.

34.4.3 Composite Structure Creation Using a Single Nozzle with Specific Filament

This method creates composite structure by using different filament with the help of conventional 3D printing method, in addition to polymeric material has additives like microspheres, carbon fiber, wood flour, particles of glass etc. [20]. The limitation of this method is printing material availability.

34.4.4 Composite Creation Using Two Different Materials Alternatively

The process of printing by two materials alternatively is considered as modern and most commonly used 3D printing process. In this method, a head with two nozzles or a nozzle with changeable filament system is used. Alternate layers of different materials are possible in one printing step [21]. Disadvantages of this method are contamination due to problem of transition in filaments and fragments.

34.4.5 *Layered Composite Creation Using Two Different Materials*

This method is similar to the method using two materials method only they differ by way of deposition of materials [21]. In this method first, apply one material layer then apply the layer of other material.

34.4.6 *Skeletal Composite Creation Using Two Different Materials*

This method is similar to the method of creating a layered composite the only difference is that the material is a skeletal structure instead of solid. Reducing infills algorithm is used, which reduces materials consumption and time in the printing process. Commonly known skeletal structures are honeycomb, square cells, hexagonal cells and other self-designed structure can be used.

34.4.7 *Layered Composite Creation Using a Special Nozzle for Continuous Fiber Introduction*

The filaments used as matrix material and reinforcing fibers provided independently to the nozzle. The fiber is heated to increase the mixing capacity to thermoplastic materials and reinforcement phase before entering the nozzle [21]. Fibers supplied to printer head by filament motion automatically, and in printer head the plasticized filament is linked to reinforcement phase. The other stages of printing are the same as the standard 3D printing method.

34.5 Various Composites Printed by FDM 3D Printing

The various composite materials printed by FDM are arranged in tabular form (Table 34.2) based on types, constituents, findings and references.

34.6 Implications of This Study

The present state of manufacturing methods generally depends on composite, plastics and polymer because of high strength corresponding to weight ratio, lightweight and low cost. Various kinds of composites which are commonly used for research are discussed here. Researchers mainly focused on mechanical properties, rheological properties, process parameters optimization, stability, and finding new areas like dimensional accuracy and tissue engineering. Various composite materials for FDM use are studied and a brief discussion is arranged in tabular form based on types, constituents, findings and references.

Table 34.2 Composites by using FDM based on types, Constituents, findings and references

S. No.	Types of composites	Constituents	Findings	References
1	Fiber-reinforced composites	Fiber-reinforced thermoplastic composites	UTS 165 MPa for isotropic layers of carbon fiber and better fatigue performance	Alberto et al. [22]
		Carbon fiber—Nylon Glass fiber—Nylon Kevlar fiber—Nylon	Impact strength 82.26 kJ/m^2 Impact strength 280.95 kJ/m^2 Impact strength 184.76 kJ/m^2	Caminero et al. [23]
		Carbon fibers—Epoxy resin	792 MPa UTS and 161 GPa Young's modulus were found	Hao et al. [24]
		PLA—Carbon fiber	Impregnation advances on increasing melting temperature, mechanical properties increases, above 240^{0}C surface accuracy decreases	Tian et al. [25]
		PLA—Carbon fiber	Ellipsoid shaped holes observed by SEM. the orientation of extrusion coincide with a major axis and thus decreasing tensile strength	Hofstatter et al. [26]
		PLA—Bamboo fiber	At 160 °C, 273 MPa flexural strength and 6.8 GPa modulus are found. Strength increases at 160 °C and decreases after 180 °C while modulus increases at 140 °C	Ochi [27]

(continued)

Table 34.2 (continued)

S. No.	Types of composites	Constituents	Findings	References
2	Bio-composites	Woven cotton fabric—PLA	Fabrics with pore sizes 0.5 mm, 1.0 mm, 1.5 mm and concentrations of PLA, 0.01 g/mL, 0.03 g/mL, and 0.06 g/mL used to develop woven cotton fabric—PLA composite	Macha et al. [28]
		Cow Dung (CD)—Poly lactic acid (PLA)	Improvement in flexural properties and drop in tensile and impact strength with increasing CD loading	Yusef et al. [29]
		Wood bio-composite	Mechanical behaviour observed by changing the printing width, porosity increases by increasing the printing width	Duigou et al. [30]
		Blended TPS—ABS Biomass Alloys	Filaments flowing capability, organic emissions, mechanical, thermal and physical properties are found better than that of commercial ABS	Kuo et al. [31]
		Polyester scaffolds with PCL and PLA	Biocompatibility found increases by proliferation and adhesion on their surfaces	Sabino et al. [32]
		TCP-PLA	TCPmorphology depends on the process temperature and affects the biodegradability. Superior compactness and dimensional accuracy affect mechanical performance	Drummer et al. [33]

(continued)

Table 34.2 (continued)

S. No.	Types of composites	Constituents	Findings	References
3	Nano-composites	ABS-Carbon Nanotubes (CNT)	Optimal CNT content in the filament at 6 wt%, thermal, mechanical and electrical properties investigated	Dul et al. [34]
		Graphene-ABS	A significant reduction in deformation at tensile and breaking strength in the Z direction and small in X and Y directions. Filler content optimized to 4%, reduction in creep compliance and thermal coefficient	Dul et al. [35]
		Nano clay—ABS	Tensile strength and modulus increases with increase in loading weight from 5 to 10% but decreases if increases to 15%. For batch-loading, 5% to 10% hardness increases to 60.5% and compressive strength increases to 24.6% as compared to ABS material	Francis and Jain [36]
		CNT-PLA	Observed UTS—80 MPa Young's Modulus—1.99 GPa	Melenka et al. [37]
		Graphene in ABS and PLA	Higher mechanical strength achieved	Wei et al. [38]
4	Polymer matrix composites	Al_2O_3 powder with Nylon	Al_2O_3 significantly increases the wear resistance and length of the part greatly affects the dimensional accuracy	Singh et al. [39]

(continued)

Table 34.2 (continued)

S. No.	Types of composites	Constituents	Findings	References
		Fe-Nylon	Nearly alike influence of three parameters, extrusion temperature 20%, filler materials shares 25% and extrusion load 45%	Garg and Singh [40]
		Copper and Iron micro-scale in ABS	Observed UTS—15 MPa Young's modulus—0.23 GPa	Nikzad et al. [41]
		PA6-TiO_2	Excellent mechanical properties of PA6 at 30 weight per cent of TiO_2 obtained while 10 and 20 weight percentage shows reasonable. 30%TiO_2 shows minimum wear of PA6 at load 20 N and 10 min run time	Soundararajan et al. [42]
		Fe_3O_4 in P301 Nylon	UTS—4 MPa & Young's modulus—0.054 GPa	Masood [43]
5	Polymers	ABS	For impact loading, the tensile test shows brittle nature with moderate Elasticity Modulus	Owolabi et al. [44]
		PEEK	Comparatively best results are possible at 300 μm layer thickness and 0°/90° raster angle	Wu et al. [45]
		Nylon	Tensile strength increased at 77 °K	Cruz et al. [46]
		ABS-TPE, ABS-TiO_2. ABS-Jute fibre and Pure-ABS	Improvement in the surface finishes with TPE, improvement in ultimate tensile strength for ABS with TiO_2 in comparison to pure ABS, high roughness for ABS with jute fiber	Perez et al. [47]

(continued)

Table 34.2 (continued)

S. No.	Types of composites	Constituents	Findings	References
		ABS	Elastic behaviour of ABS parts is affected by the parameters like an air gap, raster angle and layer thickness	Lee et al. [48]

34.7 Future Opportunities

The developments in 3D printing have a greater impact on medical and industrial engineering field with different ink designs, enhanced depiction and ink assets modelling in deposition and improved ink deposition and better robotic control for smarter précised 3D printing. The capability of locally specify for both structure and composition is permitting better mechanism concluded the functionality and possessions of the subsequently developed materials.

34.8 Conclusions

This work presents a literature-based study on composite development with FDM technology. This has been done to identify the suitability of FDM for the development of different composite applications. For this research papers from reputed journals are selected and studied. Identified 3DP processes based on the initial state of materials and working principles. Also presents in tabular format the types of composites based on types, constituents and research findings with references. In this study, various materials like Fiber-reinforced composite, Biocomposites, Nanocomposites, Polymer matrix composites and Polymers have been studied and found that FDM seems most suitable for manufacturing parts with composites. Finally attaining challenges, prospects and future aspects of FDM provides a compelling way to blowout smooth technique in various areas like building construction, farming and biomedical fields.

References

1. Chua, K., Leong, F., Lim, S.: Rapid Prototyping: Principles and Applications 2nd edn. World Scientific (2003)
2. Upcraft, S., Fletcher, R.: The rapid prototyping technologies. Assembly Autom. **23**, 318–330 (2003)

3. Williams, M., Adewunmi, A., Schek, M., Flanagan, L., Krebsbach, H.: Bone tissue engineering using polycaprolactone scaffolds fabricated via selective laser sintering. Biomaterials **26**, 4817–4827 (2005)
4. Li, X., Wang, T., Zhang, G., Li, C.: Fabrication and characterization of porous Ti6Al4V parts for biomedical applications using electron beam melting process. Mater. Lett. **63**, 403–405 (2009)
5. Zhang, X., Jiang, N., Sun, C.: Micro-stereolithography of polymeric and ceramic microstructures. Sens. Actuat. **77**, 149–156 (1999)
6. Zein, I., Hutmacher, W., Tan, C., Teoh, H.: Fused deposition modeling of novel scaffold architectures for tissue engineering applications. Biomaterials **23**, 1169–1185 (2002)
7. Jones, R., Haufe, P., Sells, E., Iravani, P., Oliver, V.: RepRap—the replicating rapid prototype. Robotica **29**, 177–191 (2011)
8. Harun, W., Sharif, S., Idris, H., Kadirgama, K.: Characteristic studies of collapsibility of ABS patterns produced from FDM for investment casting. Mater. Res. Innov. **13**(3), 340–343 (2009)
9. Plymill, A., Minneci, R., Greeley, A., Gritton, J.: Graphene and carbon nano-tube PLA composite feedstock development for fused deposition modeling. University of Tennessee Honors Thesis Projects (2016)
10. Masood, H., Song, Q.: Development of new metal/ polymer materials for rapid tooling using fused deposition modeling. Mater. Des. **25**, 587–594 (2004)
11. Kruth, P.: Material increase manufacturing by rapid prototyping techniques. CIRP Ann. Manuf. Technol. **40**, 603–614 (1991)
12. Kruth, P., Leu, C., Nakagawa, T.: Progress in additive manufacturing and rapid prototyping. CIRP Ann. Manuf. Technol. **47**, 525–540 (1998)
13. Horn, J., Harrysson, L.: Overview of current additive manufacturing technologies and selected applications. Sci. Prog. **95**, 255–282 (2012)
14. Guo, N., Leu, C.: Additive manufacturing: technology, applications and research needs. Front. Mechan. Eng. **8**, 215–243 (2013)
15. Mellor, S., Hao, L., Zhang, D.: Additive manufacturing: a framework for implementation. Int. J. Prod. Econ. **149**, 194–201 (2014)
16. Yakout, M., Elbestawi, M.: Additive manufacturing of composite materials: an overview. In: 6th International Conference on Virtual Machining Process Technology (VMPT), Montréal, May 29th–June 2nd (2017)
17. Lipson, H., Kurman, M.: Fabricated: The New World of 3D Printing. Wiley, Indianapolis (2013)
18. Dudek, P.: FDM 3D printing technology in manufacturing composite elements. Arch. Metall. Mater. **58**(4), 1415–1418 (2013)
19. Katarzyna, B., Elżbieta, P., Paweł, S., Wojciech, Ś., Marek, P.: Polymer Composite Manufacturing by FDM 3D Printing Technology. MATEC Web of Conferences 237. https://doi.org/10.1051/matecconf/201823702006
20. Ning, W., Cong, W., Qiu, J., Wei, J., Wang, S.: Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modeling. Compos. B Eng. **80**, 369–378 (2015)
21. Kumar, S., Kruth, P.: Composites by rapid prototyping technology. Mater. Des. **31**, 850–856 (2010)
22. Pertuz, A.D. et.al.: Static and fatigue behaviour of continuous fibre reinforced thermoplastic composites manufactured by fused deposition modelling technique. Int. J. Fatig. **130**, 105275 (2020)
23. Caminero, A., Chac, J., Moreno, I., Rodriguez, G.: Impact damage resistance of 3D printed continuous fibre reinforced thermoplastic composites using fused deposition modeling. Compos. B Eng. **148**, 93–103 (2018)
24. Hao, W., Liu, Y., Zhou, H., Chen, H., Fang, D.: Preparation and characterization of 3D printed continuous carbon fiber reinforced thermosetting composites. Polym. Test. **65**, 29–34 (2018)
25. Tian, X., Liu, T., Yang, C., Wang, Q., Li, D.: Interface and performance of 3D printed continuous carbon fibre reinforced PLA composites. Compos. Part A: Appl. Sci. Manuf. **88**, 198–205 (2016)

26. Hofstätter, T., Gutmann, I., Koch, T., David, B.: Distribution and orientation of carbon fibres in polylactic acid parts produced by fused deposition modeling. In: Proceedings of ASPE summer topical meeting 2016: dimensional accuracy and surface finish in additive manufacturing. APSE—The American Society for Precision Engineering
27. Ochi, S.: Flexural properties of long bamboo fibre/PLA composites. Open J. Compos. Mater. **5**, 70–78 (2015). https://doi.org/10.4236/ojcm.2015.53010
28. Macha, J., Medard, M., Josephat, L.: In vitro study and characterization of cotton fabric PLA composite as a slow antibiotic delivery device for biomedical applications. J. Drug Deliv. Sci. Technol. **43**, 172–177 (2018)
29. Yusef, M., Khalid., M., Yasin, M.: Physico-mechanical properties of poly(lactic acid) biocomposites reinforced with cow dung. Mater. Res. Exp. **4**(2) (2017). https://doi.org/10.1088/2053-1591/aa5cdb
30. Duigou, A.L., Castro, M., Bevan, R., Martin, N.: 3D printing of wood fibre biocomposites: from mechanical to actuation functionality. Mater. Des. **96**, 110–114 (2016)
31. Kuo, C., Liu, C., Teng, W., Chang, H.: Preparation of starch/Acrylonitrile-Butadiene-Styrene copolymers (ABS) biomass alloys and their feasible evaluation for 3D printing applications. Compos. B Eng. **86**, 36–39 (2016)
32. Sabino, M., Fermín, Z., Marielys, L., Moret, J.: In vitro biocompatibility study of biodegradable polyester scaffolds constructed using fused deposition modeling. In: The International Federation of Automatic Control, Fortaleza, Brazil (2013)
33. Drummer, D., Cuellar, S.C., Rietzel, D.: Suitability of PLA/TCP for fused deposition modeling. Rapid Prototyp. J. **18**(6), 500–507 (2012). https://doi.org/10.1108/13552541211272045
34. Dul, S., Fambri, L., Pegoretti, A.: Filaments production and fused deposition modelling of ABS/carbon nanotubes composites. Nanomaterials **8**, 49 (2018). https://doi.org/10.3390/nano8010049
35. Dul, S., Fambri, L., Pegoretti, A.: Fused deposition modelling with ABS-graphene nanocomposites. Compos. Part A: Appl. Sci. Manuf. **85**, 181–191 (2016)
36. Francis, V., Jain, P.K.: Experimental investigations on fused deposition modelling of polymer-layered silicate nanocomposite. Virt. Phys. Prototyp. **11**(2), 109–121 (2016)
37. Melenka, W., Cheung, K., Schofield, J., Dawson, M., Carey, J.: Evaluation and prediction of the tensile properties of continuous fibre-reinforced 3D printed structures. Compos. Struct. **153**, 866–875 (2016)
38. Wei, X., Li, D., Jiang, W., Gu, Z., Wang, X., Zhang, Z., Sun, Z.: 3D printable graphene composite. Sci. Rep. 11181 (2015)
39. Singh, R., Singh, S., Fraternali, F.: Development of in-house composite wire-based feedstock filaments of fused deposition modelling for wear-resistant materials and structures. Compos. B Eng. **98**, 244–249 (2016)
40. Garg, H., Singh, R.: Investigations for melt flow index of Nylon6-Fe composite based hybrid FDM filament. Rapid Prototyp. J. **22**(2), 338–343 (2016)
41. Nikzad, M., Masood, H., Sbarski, I.: Thermo-mechanical properties of a highly filled polymeric composites for fused deposition modeling. Mater. Des. **32**(6), 3448–3456 (2011)
42. Soundararajan, R., Jayasuriya, N., Vishnu, R., Prasad, B., Pradeep, C.: Appraisal of mechanical and tribological properties on PA6-TiO2 composites through fused deposition modelling. ICMPC-2019 Materials Today: Proceedings (2019). https://doi.org/10.1016/j.ijfatigue.2019.105275
43. Masood, H., Song, Q.: Development of new metal/ polymer materials for rapid tooling using fused deposition modelling. Mater. Des. **25**, 587–594 (2004)
44. Owolabi, G., Peterson, A., Habtour, E., Riddick, J., Coatney, M.: Dynamic response of Acrylonitrile butadiene styrene under impact loading. Int. J. Mechan. Mater. Eng. **11**(1), 1–8 (2016)
45. Wu, W., Geng, P., Li, G.., Zhao, D., Zhang, H.: Influence of layer thickness and raster angle on the mechanical properties of 3D-printed PEEK and a comparative mechanical study between PEEK and ABS. Materials **8**(9), 5834–5846 (2015)

46. Cruz, P., Shoemake, E., Adam, P., Leachman, J.: Tensile strengths of polyamide-based 3D printed polymers in liquid nitrogen. IOP Publishing **102**(1), 1–6 (2015)
47. Perez, T., Roberson, A., Wicker, R.: Fracture surface analysis of 3D-Printed tensile specimens of novel ABS-based materials. J. Fail. Anal. Prev. **14**, 343–353 (2014)
48. Lee, H., Abdullah, J., Khan, Z.: Optimization of rapid prototyping parameters for production of flexible ABS object. J. Mater. Process. Technol. **169**, 54–61 (2005)