A Comprehensive Review on 3D Printer Composite Filament Used in Fused Deposition Modeling

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Abstract: The aim of this paper is to present give a review about the composite filament which is used in Fused Deposition Modeling (FDM) 3D Printer. This paper offers a comprehensive review of the existing literature on 3D printer composite filament, the objective of the paper is aimed at providing guidance on different types of filament or materials that can be used to improve the strength. This research targets to find new paths that can be used for further the development of the filament in different materials.

***Index Terms* – Composite Filament, Fused Deposition Modeling, FDM, 3D Printer.**

1. INTRODUCTION

3-D printing is an added additive manufacturing (AM) procedure for manufacturing an extensive variety of structures and complex geometries from Three-dimensional information or model data. The procedure comprises of printing successive layers of materials that are framed over each other. Originally the technology was developed by Charles Hull in 1986 known as stereolithography, which was trailed by resulting developments, for example, powder bed combination, Fused Deposition Modeling (FDM), inkjet printing and contour creating. [1]

3-D printing, which includes different techniques, materials and hardware, has advanced throughout the years and can convert to manufacturing and logistics processes. Additive manufacturing has been broadly connected in various industries, including construction, prototyping and biomechanical. [1]

Additive manufacturing is characterized as "a method of joining materials to make objects from 3D prototypical information, usually layer upon layer, different than subtractive manufacturing technology". AM technologies make it conceivable to construct a large variety of models or practical component with complex geometries those can't or possibly hard to be produced by conventional techniques. As compared to conventional techniques, AM can reduce the cycle time and production cost and increase the competitiveness. [2]

The preliminary AM technology is normally used to manufacture the pure plastic parts which are fundamentally utilized as quick models for practical testing. AM methods include stereolithography mechanical assembly from photopolymer liquid, Fused Deposition Modeling from plastic fibers, laminated object manufacturing from plastic laminations, and selective laser sintering from plastic powders. [3]

Generally, FDM is more preferable method among all the AM techniques for creating pure plastic parts with low cost, minimal wastage, furthermore, ease of material change. Before FDM-manufacturing process commence, the STL document is created by the CAD software is cut into flat layers or sliced and the thickness of each layer can be set depending on the demands of clients. [3]

1.1 Composite Material

Composites are made up of individual materials referred to as constituent materials. There are two main categories of constituent materials: matrix(binder) and reinforcement. At least one portion of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions.

Figure 1 Combination of Composite Material

1.2 Classification of Composite

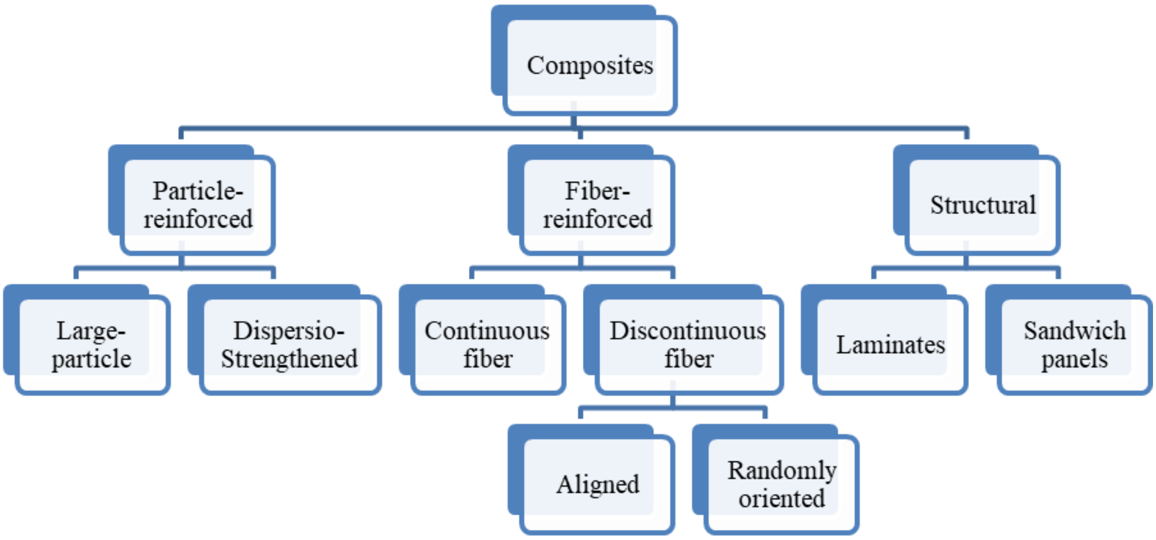

Figure 2 Classification of Composite

Particle Reinforced: Composites materials comprising of at least two individual constituents. The reinforcing constitutes is installed in a matrix to frame the composite. One type of composites is particulate reinforced composites with concrete being a good sample. The total of coarse shake or rock is implanted in a network of bond. The total gives stiffness and strength while the bond goes as the cover to hold the structure together.

Fiber Reinforced: A fiber- reinforced composite (FRC) is a composite building material that comprises of three segments: (I) the fibers as the irregular or scattered stage, (ii) the matrix as the continuous stage, and (iii) the fine interphase region, otherwise called the interface. This is a type of innovative composite group, which influences utilization of rice husk, to rice hull, and plastic as fixings. This innovation includes a strategy for refining, mixing, and compounding natural fibers from cellulosic waste streams to shape a high-quality fiber composite material in a polymer matrix.

Structural: Reinforced composite materials open up absolutely new skylines in a variety of modern applications, compared with conventional materials. At whatever point excellent performance, light weight, speed and extraordinary mechanical and chemical properties are basic, it merits thinking about the utilization of composite material structures and segments or components.

1.3 Application of Composite Material

- Higher specific strength than metals, non-metals and even alloys.
- Lower specific gravity in general.
- Improved stiffness of materials.
- Composite maintain their weight even at high temperatures.
- Toughness is improved
- Fabrication or Production is cheaper.
- Corrosion and oxidation resistance.
- In Automobile industries, marine and aeronautical application also for safety equipment.

II. EVOLUTIONS OF COMPOSITE MATERIAL

The history of composite materials in manufacturing predates manufacturing as we know it today. From B.C. to the present, different types of composites were developed and used for a wide variety of applications.

Ancient Times:

The times B.C. marked the beginning of types of composites materials used in daily applications.

- The first known use of composites is credited to the Mesopotamians. These ancient people glued wood strips at different angles to create plywood in 3400 B.C.
- between 2181 and 2055 B.C., Egyptians used Cartonnage and layers of linen or papyrus soaked in plaster to make death masks.

1200's:

In around 1200 AD, Mongols developed the principal composite bows produced using a mix of wood, bamboo, bone, horns, bamboo and silk fused with characteristic pine liquid.

1800's:

From the 1870's through the 1890's, a chemical revolution changed composite improvement. New engineered pitches were changed from a fluid to solid state in a cross-connected sub-atomic structure utilizing a technique known as polymerization.

1900's:

In the primary 1900's, chemical advances drove the improvement of plastics. Materials, for example, vinyl, polystyrene, phenolic and polyester were made and reinforcement was required to give strength and rigidity.

1930's:

Recognized as the most critical decade in the composites manufacturing, the 1930s saw the improvement of resins still utilized today. In 1935, Owens Corning presented the primary glass fiber and launched the fiber reinforcement polymer (FRP) industry. In 1936, unsaturated polyester resins were registered. In 1938, other higher execution resin frameworks like also became available.

1940's:

The necessities of World War II took the FRP business from research to generation. In adding to high-strength to-weight properties, scientific experts educated that fiberglass composites are transparent to radio frequencies. By 1947, a completely composite body car was prototyped and verified, important to the advancement of the 1953 Corvette. Fiberglass preforms impregnated with resin and formed in corresponding metal dies the dust was utilized to manufacture this classic car. Two strategies, pressure molding of sheet moulding compound (SMC) and bulk moulding compound (BMC), developed as the dominant forms of moulding for the car and different businesses.

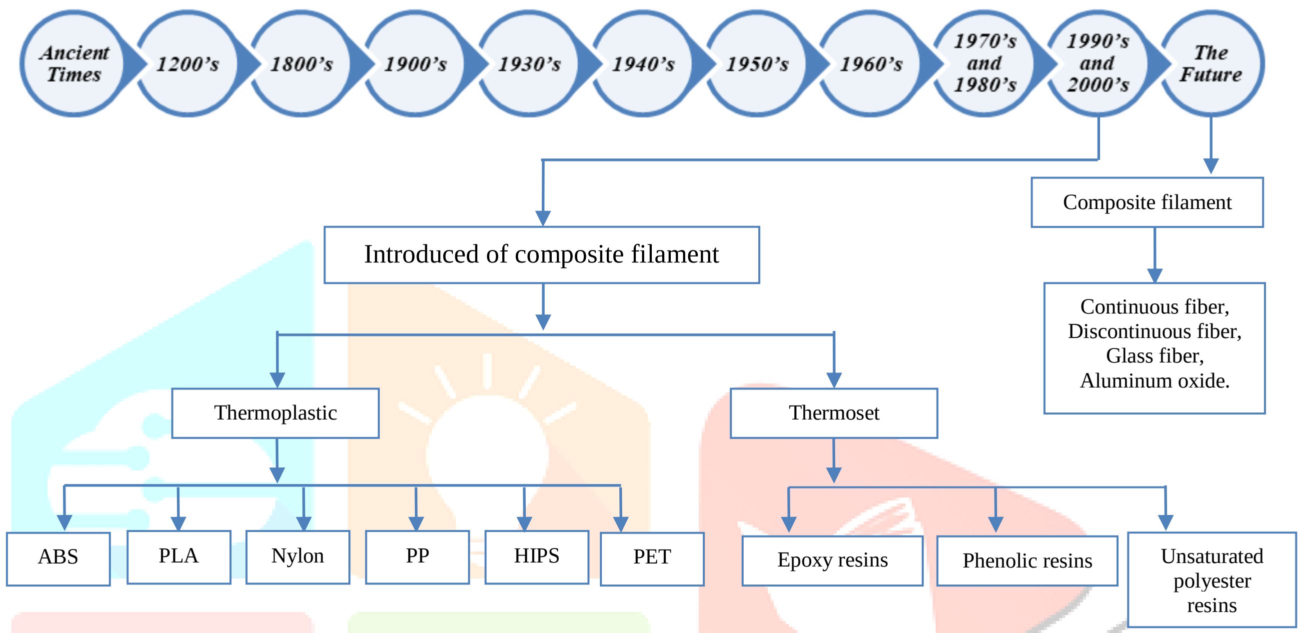

Figure 3 Evolution of Composite

1950's:

In the primary 1950's, fabricating advancement proceeded with the improvements of pultrusion, vacuum bag molding, and large-scale filament winding. These composites keep on finding applications today. It turned into the reason for large scale rocket engines that moved investigation of room in the 1960's and past.

1960's:

In 1961, the main carbon fiber was registered and quite a long while later, turned out to be economically available. Carbon fibers improved thermoset part stiffness to weight ratios, for use in much more applications, for example, aerospace, car, sporting goods, and customer products. In the 1960's, the marine market was the largest consumer of composite materials.

1970's and 1980's:

Throughout the following twenty years, the composite materials market developed. In the 1970's, the car market surpassed marine as the main market – a position it holds today.

1990's and 2000's:

By the middle 1990's, composite materials turned out to be more typical in standard manufacturing and development. As a financially exchange to normal materials like metal and built thermoplastics, thermoset composites were basic segments inside the apparatus, development, electrical and transportation businesses.

The Future:

Today, composites investigation pulls in pays from governments, manufacturers and colleges. These investments enable advancement to get faster. Particular organizations, for example, aerospace composite organization, will find a place in the industry's, will discover a place in the professional.

III. LITERATURE REVIEW

Table 1 Literature review on composite filament

Sr. No.	Title	Author	Publisher and year	Journal	Materials	Problem Discussed & Outcome
1	About the Use of Recycled or Biodegradable Filaments for Sustainability of 3D Printing	Jukka Pakkanenv et al.[1]	Springer (2017)	Sustainable Design and Manufacturing	ABS, PLA, Polycarbonate, HDPE.	Authors discussed development and use of recycled or biodegradable filament in 3D printing and analyzed mechanical properties of a filament such as Ultimate tensile strength, Young modulus, Elongation.
2	Tensile Strength of Commercial Polymer Materials for Fused Filament Fabrication 3D Printing	Nagendra G. et al.[2]	ELSEVIER (2017)	Additive Manufacturing	ABS, HIPS, Polycarbonate, Nylon, Semi Flex.	The part of tensile strength and strongest materials are to tested. Tested strength have ASTM D638 type fabricate. Results: tensile strength of Nylon materials were stronger than Semi Flex, and much more flexible than ABS, HIPS and polycarbonate, which provides a good balance between strength and flexibility.
3	Modified polylactide filaments for 3D printing with improved mechanical properties	Janez Slapnik et al.[3]	ELSEVIER (2017)	Contemporary Materials	Polylactic Acid (PLA), Core-shell Rubber.	The PLA filament was improved 10% by addition of core shell rubber the results show that that the injection molded specimens & 3D printed specimens increase the impact strength. PLA/ core-shell rubber specimens did not break during flexural test and improved toughness.
4	3D–printing of materials with anisotropic heat distribution using conductive polylactic acid composites	Yuan Zhuanga et al.[4]	ELSEVIER (2017)	Materials- & Design	Graphene doped Polylactic Acid, PLA	The higher content of the G-PLA led to a lower resistance and a smaller heat effect when an electric field was applied on the object. This one process is beneficial for the developing Poly. materials for the Arch. Engg., Mech. Engg., Electrical.Engg.
5	Sustainable composite fused deposition modelling filament using recycled preconsumer polypropylene	David Stoof et al.[5]	ELSEVIER (2017)	Composite	Recycled polypropylene, Hemp fibre, Harakeke Fibre	The most successful filaments contains 30 wt% harakeke fibres and had a tensile strength and Young's modulus of 39 MPa and 2.8 GPa compared to those of plain PP filament of 74% and 214% respectively 30 wt% harakeke filaments also underwent the least shrinkage of 0.34% corresponding to a net reduction of 84% relative to plain PP.
6	Preparation and characterization of 3D printed continuous carbon fiber reinforced thermosetting composites	Ye Liua et al.[6]	ELSEVIER (2017)	Polymer Testing	Thermosetting composites, Continuous Carbon Fiber	The tensile strength and elastic modulus is higher than compare to flexural strength and elastic modulus. The mechanical properties of these novel printed thermosetting composites were better than similar printed reinforced thermoplastic composites and 3D printed short carbon fiber reinforced composites.
7	Fabrication of continuous carbon, glass and Kevlar fibre reinforced polymer composites using additive manufacturing	Andrew N. Dickson et al.[7]	ELSEVIER (2017)	Additive Manufacturing	Nylon, Continuous carbon, Glass and Kevlar fibre	In this paper the part fabricated using carbon fibre for yielded the largest increase in mechanical strength. Result: A maximum efficiency in tensile strength was observed in glass specimen as fibre content approached 18%, with higher fibre contents (up to 33%), yielding only minor increases in strength.
	Effects of Part	S. H.	Springer	Progress	Polylactic	Parameter: X, Y and 45◦ Orientations.

8	Build Orientations on Fatigue Behavior of FDM-Processed PLA Material	Masood et al.[8]	(2016)	Additive Manufacturing	Acid (PLA)	Result: Part build in X direction shows higher tensile strength, and at 45◦ to X and Y direction shows highest fatigue strength.
9	Recycling and Remanufacturing of 3D Printed Continuous Carbon Fiber Reinforced PLA composites	Xiaoyong Tian et al.[9]	ELSEVIER (2016)	Journal of Cleaner Production	Polylactic Acid (PLA), Continuous - carbon fiber	Remanufacturing has been demonstrated by recycling the carbon fiber and PLA. also, Also, few tests have been on test has been carried out tensile and flexural strength. Result: Higher result can be achieved in flexural strength (25%). From this experiment we observed that the recovery rates for both carbon fiber and PLA matrix were directly achieved due to CFRTPCs.
10	Rapid Prototyping of Continuous Carbon Fiber Reinforced Polylactic Acid Composites by 3D Printing	N. Li et al.[10]	ELSEVIER (2016)	Journal of Materials Processing Technology	Polylactic Acid (PLA), Continuous - carbon fiber	The experimental results indicated that the tensile strength and flexural strengths are modified the carbon fiber reinforced. Result: The Scanning Electron Microscope (SEM) scan results indicated the preferable bonding for modified carbon fiber.
11	3D printing of polymer matrix composites: A review and prospective	Xin Wang et al.[11]	ELSEVIER (2016)	Composites Part B	ABS, PLA, Continuous carbon, Carbon fiber, photopolymer	This paper presents the overview of 3D printing techniques of polymer composite materials and the properties of material and also shown the applications of the different fields like biomedical, electronics and aerospace engineering.
12	Investigation for dimensional accuracy of AMC prepared by FDM assisted investment casting using nylon-6 waste based reinforced filament	Rupinder Singh et al.[12]	ELSEVIER (2015)	Measurement	Nylon-6 waste	Nylon-6 industrial waste has recycled the development of FDM filament. Parameter: dimensional accuracy Result: The Al and Al2O3 were considered as abrasive mediums for filament development.
13	Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modeling	Fuda Ning at al.[13]	ELSEVIER (2015)	Composites Part B	ABS, Carbon fibers.	In this paper the two tests have been carried out such as tensile test and flexural test. Result: The tensile strength and Young's modulus of fabricated specimen with 5 wt% carbon fiber content could increase 22.5% and 30.5%, respectively. CFRP composite specimen with 5 wt% carbon fiber content had larger flexural stress, flexural modulus, and flexural toughness with an increase of 11.82%, 16.82%, and 21.86%, respectively.
14	Development of Nylon Based FDM Filament for Rapid Tooling Application	R. Singh et al.[14]	Springer (2014)	Journal of The Institution of Engineers (India): Series C	Nylon, Aluminium Oxide	In this research work, they found two strengths, tensile and elongation. Parameter: Barrel Temp. and Screw head speed. Result: for tensile strength barrel temperature-56.34 %, screw head speed-24.52 % and Al2O3 proportion

						2.22 %. for elongation barrel temperature- 53.88 %, screw head speed-25.72 % and Al2O3 proportion 6.92 %.
15	Preparation and Performance of Long Carbon Fiber Reinforced Polyamide 6 Composites Injection Molded from Core/Shell Structured Pellets	Sandeep Rauta et al. [15]	ELSEVIER (2014)	Procedia Engineering	Long Carbon Fiber, Polyamide 6	In this paper the process is assisted by the single screw extrusion and injection molding and also applied in mass production. Result: The LCF/PA6 composite showed the highest tensile and flexural strength and also, analyzed the tensile strength of carbon fibers , which was much higher than the short carbon fiber.
16	Dieless forming of carbon fibre reinforced plastic parts using 3D printer	Ken-ichiro Mori et al.[16]	ELSEVIER (2014)	Procedia Engineering	ABS, Carbon fibres.	The inclusion of carbon fibers in the plastic increases the strength of specimens and it also increases the amount of carbon fibers for bonding between carbon fiber and plastic.
17	Experimental Characterization and Analytical Modelling of the Mechanical Behaviour of Fused Deposition Processed Parts Made of ABS-M30	Dario Croccolo et al.[17]	ELSEVIER (2013)	Acrylonitrile butadiene styrene (ABS)	Acrylonitrile butadiene styrene (ABS)	Greater contour is used to increase their stiffness and strength. It also increases the brittle behavior of the part. Result: The effectiveness of the theoretical model has been verified by comparison of significant number using experimental results.
18	Analysis of thermal properties and impact strength of PP/SRT, PP/EPDM and PP/SRT/EPDM mixtures in single screw extruder	V. Ramos et al.[18]	ELSEVIER (2006)	Polymer Testing	Scrap rubber tires (SRT) and polypropylene (PP), Ethylene–propylene–diene terpolymer (EPDM) and PP.	Improving the impact of toughness and stiffness of PP is important practical for extending the range. Parameter: melting temp. Result: The show that the thermal properties of SRT and EPDM have same behavior when it was mixed with PP at that time heat of crystallization and melting temp. were reduced.
19	Anisotropic Material Properties of Fused Deposition Modeling ABS	Sung-Hoon Ahn et al.[19]	Emerald - Insight (2002)	Rapid Prototyping Journal	Acrylonitrile butadiene styrene (ABS)	In this paper the authors analyzed the tensile strength and compressive strength for FDM printed specimens. Parameter: Air gap, Raster orientation, Bead Temp. Result: the tensile strength range is between 65 and 72% and the compressive strength ranged from 80 to 90%.
20	Short fiber reinforced composites for fused deposition modeling	Fan Li et al.[20]	ELSEVIER (2000)	Materials Science and Engineering	Acrylonitrile Butadiene Styrene (ABS), Short glass fiber.	In this paper ABS have composites value cause of the feedstock filament in FDM. Result: We can increase the strength of ABS filament by reducing flexibility and handle ability of glass fiber.

This table provides insights into current status of widely used of various composite filament in FDM based 3D Printer and from the literature it is observed that use of composite filament in FDM based 3D Printer is increased in China, USA and Germany but the status in India is still in primary stage. The table provides and overview of Implementation of composite filament in FDM based 3D Printer in various industries regardless of types and materials.

Table 2: Distribution of Reviewed paper in various journals and conference

Sr. No.	Journal	Number of References	%
1	Materials and Design	5	8.20%
2	Procedia CIRP	5	8.20%
3	Additive Manufacturing	4	6.56%
4	Composites Part A: Applied Science and Manufacturing	3	4.92%
5	Journal of Manufacturing Systems	2	3.28%
6	Journal of Materials Science	2	3.28%
7	2015 4th International Conference on Informatics, Electronics and Vision, ICIEV 2015	1	1.64%
8	2015 First International Conference on Reliability Systems Engineering (ICRSE)	1	1.64%
9	2015 International Conference on Informatics, Electronics & Vision (ICIEV)	1	1.64%
10	2016 Loughborough Antennas and Propagation Conference, LAPC 2016	1	1.64%
11	3D Printing in Medicine	1	1.64%
12	Applied Materials Today	1	1.64%
13	Applied Surface Science	1	1.64%
14	Archives of Civil and Mechanical Engineering	1	1.64%
15	Building and Environment	1	1.64%
16	Chemical and Petroleum Engineering	1	1.64%
17	Chemical Engineering Science	1	1.64%
18	CIRP Journal of Manufacturing Science and Technology	1	1.64%
19	Computational Materials Science	1	1.64%
20	Computers and Graphics (Pergamon)	1	1.64%
21	IECON Proceedings (Industrial Electronics Conference)	1	1.64%
22	IEEE Antennas and Propagation Society, AP-S International Symposium (Digest)	1	1.64%
23	IEEE Transactions on Dielectrics and Electrical Insulation	1	1.64%
24	International Journal of Advanced Manufacturing Technology	1	1.64%
25	International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering	1	1.64%
26	International Journal of Pharmaceutics	1	1.64%
27	Journal of Advanced Ceramics	1	1.64%
28	Journal of Chemical and Pharmaceutical Research	1	1.64%
29	Journal of Cleaner Production	1	1.64%
30	Journal of Cultural Heritage	1	1.64%
31	Journal of Failure Analysis and Prevention	1	1.64%
32	Journal of Food Engineering	1	1.64%
33	Journal of Intelligent Manufacturing	1	1.64%
34	Journal of Manufacturing Processes	1	1.64%
35	Journal of Materials Processing Technology	1	1.64%
36	Journal of Membrane Science	1	1.64%
37	Journal of Prosthetic Dentistry	1	1.64%

38	Journal of The Institution of Engineers (India): Series C	1	1.64%
39	Measurement: Journal of the International Measurement Confederation	1	1.64%
40	Measurement: Journal of the International Measurement Confederation	1	1.64%
41	Polymer (United Kingdom)	1	1.64%
42	Polymer Degradation and Stability	1	1.64%
43	Procedia Engineering	1	1.64%
44	Proceedings - 32nd Southern Biomedical Engineering Conference, SBEC 2016	1	1.64%
45	Proceedings of the IEEE International Conference on Industrial Technology	1	1.64%
46	Progress in Additive Manufacturing	1	1.64%
47	Resources, Conservation and Recycling	1	1.64%
	Total Number of Paper	**62**	**100%**

Total 62 paper reviewed from 20 international journals over period of 2010 to 2017.

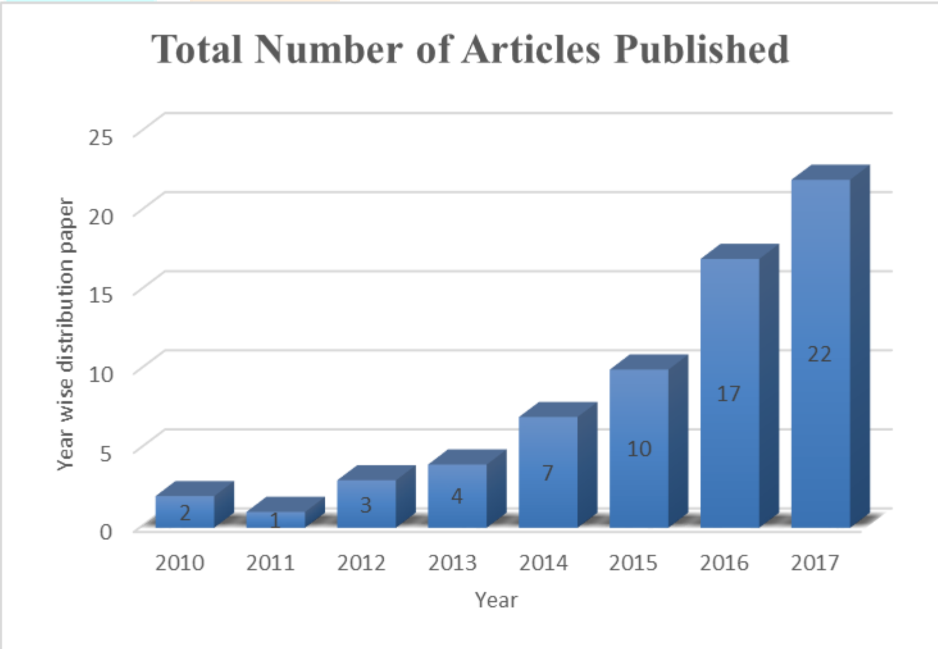

Figure 4: Year Wise Distribution of Article Published

Table 3 Composite materials used in Additive Manufacturing

Composite materials used in AM	Polymer Matrix	Granules	ABS
			PLA
			HIPS
			PET
			HDPE
			Nylon
			Polyamide 6
			Polycarbonate
			LLDPE
			Polypropylene
	Reinforcement Materials	Fibers	Continuous - carbon fiber
			Discontinuous - carbon fiber
			Glass and Kevlar fibre
			Carbon fiber
			Aluminum Oxide
			Ethylene–propylene–diene terpolymer
			Short glass fiber
			Fiber glass
	Composite Materials	Matrix & Reinforcement Mixing	ABS, Carbon fibres, Continuous carbon
			Polylactic Acid (PLA), Core-shell Rubber.
			Long Carbon Fiber, Polyamide 6
			Thermosetting composites, Continuous Carbon Fiber
			Polylactic Acid (PLA), Continuous - carbon fiber
			Graphene doped Polylactic Acid, PLA

IV. CONCLUSIONS

Review of the literature suggests that 3D printing has been very popular research domain for researchers as well as from practitioners in recent years. Application of composite material specifically in Fused Depotion Modeling based 3D Printer has shown positive results in terms of cost effectiveness and mechanical properties. There are some vast possibilities in the development and application of composite material in 3D printing for sustainable manufacturing of prototypes and functional parts. The review presented in this paper explores the fact that composite filament with continuous fiber, discontinuous fiber, carbon fiber, Core-shell Rubber, glass fiber reinforced material along with matrix and mix material using ABS, PLA, HIPS, Nylon and etc. are also used in FDM application.

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REFERENCES

[1] J. Pakkanen, D. Manfredi, P. Minetola, and L. Iuliano, "About the Use of Recycled or Biodegradable Filaments for Sustainability of 3D Printing," in Sustainable Design and Manufacturing 2017: Selected papers on Sustainable Design and Manufacturing, G. Campana, R. J. Howlett, R. Setchi, and B. Cimatti, Eds. Cham: Springer International Publishing, 2017, pp. 776–785.

[2] N. G. Tanikella, B. Wittbrodt, and J. M. Pearce, "Tensile strength of commercial polymer materials for fused filament fabrication 3D printing," Addit. Manuf., vol. 15, no. Supplement C, pp. 40–47, 2017.

[3] J. Slapnik, R. Bobovnik, M. Mešl, and S. Bolka, "Modified Polylactide Filaments for 3D Printing With Improved Mechanical Properties," vol. 2, pp. 142–150, 2016.

[4] Y. Zhuang et al., "3D–printing of materials with anisotropic heat distribution using conductive polylactic acid composites," Mater. Des., vol. 126, no. March, pp. 135–140, 2017.

[5] D. Stoof and K. Pickering, "Sustainable composite fused deposition modelling filament using recycled pre-consumer polypropylene," Compos. Part B Eng., vol. 135, pp. 110–118, 2018.

[6] W. Hao, Y. Liu, H. Zhou, H. Chen, and D. Fang, "Preparation and characterization of 3D printed continuous carbon fiber reinforced thermosetting composites," Polym. Test., vol. 65, no. September 2017, pp. 29–34, 2018.

[7] A. N. Dickson, J. N. Barry, K. A. McDonnell, and D. P. Dowling, "Fabrication of continuous carbon, glass and Kevlar fibre reinforced polymer composites using additive manufacturing," Addit. Manuf., vol. 16, pp. 146–152, 2017.

[8] M. F. Afrose, S. H. Masood, P. Iovenitti, M. Nikzad, and I. Sbarski, "Effects of part build orientations on fatigue behaviour of

FDM-processed PLA material," Prog. Addit. Manuf., vol. 1, no. 1–2, pp. 21–28, 2016.
[9] X. Tian, T. Liu, Q. Wang, A. Dilmurat, D. Li, and G. Ziegmann, "Recycling and remanufacturing of 3D printed continuous carbon fiber reinforced PLA composites," J. Clean. Prod., vol. 142, no. Part 4, pp. 1609–1618, 2017.
[10] N. Li, Y. Li, and S. Liu, "Rapid prototyping of continuous carbon fiber reinforced polylactic acid composites by 3D printing," J. Mater. Process. Technol., vol. 238, no. Supplement C, pp. 218–225, 2016.
[11] X. Wang, M. Jiang, Z. Zhou, J. Gou, and D. Hui, "3D printing of polymer matrix composites: A review and prospective," Compos. Part B Eng., vol. 110, pp. 442–458, 2017.
[12] R. Singh, J. Singh, and S. Singh, "Investigation for dimensional accuracy of AMC prepared by FDM assisted investment casting using nylon-6 waste based reinforced filament," Measurement, vol. 78, no. Supplement C, pp. 253–259, 2016.
[13] F. Ning, W. Cong, J. Qiu, J. Wei, and S. Wang, "Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modeling," Compos. Part B Eng., vol. 80, pp. 369–378, 2015.
[14] R. Singh and S. Singh, "Development of Nylon Based FDM Filament for Rapid Tooling Application," J. Inst. Eng. Ser. C, vol. 95, no. 2, pp. 103–108, 2014.
[15] H. Luo, G. Xiong, C. Ma, D. Li, and Y. Wan, "Preparation and performance of long carbon fiber reinforced polyamide 6 composites injection-molded from core/shell structured pellets," Mater. Des., vol. 64, no. Supplement C, pp. 294–300, 2014.
[16] K. Mori, T. Maeno, and Y. Nakagawa, "Dieless Forming of Carbon Fibre Reinforced Plastic Parts Using 3D Printer," Procedia Eng., vol. 81, no. Supplement C, pp. 1595–1600, 2014.
[17] D. Croccolo, M. De Agostinis, and G. Olmi, "Experimental characterization and analytical modelling of the mechanical behaviour of fused deposition processed parts made of ABS-M30," Comput. Mater. Sci., vol. 79, no. November 2013, pp. 506–518, 2013.
[18] H. M. da Costa, V. D. Ramos, and M. C. G. Rocha, "Analysis of thermal properties and impact strength of PP/SRT, PP/EPDM and PP/SRT/EPDM mixtures in single screw extruder," Polym. Test., vol. 25, no. 4, pp. 498–503, 2006.
[19] C. Mendonsa, K. V Naveen, and P. Upadhyaya, "Characteristic Study of Rapid Prototyped Parts at Different Build Orientation," vol. 4, no. 3, pp. 2013–2016, 2015.
[20] W. Zhong, F. Li, Z. Zhang, L. Song, and Z. Li, "Short fiber reinforced composites for fused deposition modeling," Mater. Sci. Eng. A, vol. 301, no. 2, pp. 125–130, 2001.
[21] S. Ahn, M. Montero, D. Odell, S. Roundy, and P. K. Wright, "Anisotropic material properties of fused deposition modeling ABS," Rapid Prototyp. J., vol. 8, no. 4, pp. 248–257, 2002.
[22] T. D. Ngo, A. Kashani, G. Imbalzano, K. T. Q. Nguyen, and D. Hui, "Additive manufacturing (3D printing): A review of materials, methods, applications and challenges," Compos. Part B Eng., 2018.
[23] R. Sharma, R. Singh, R. Penna, and F. Fraternali, "Investigations for mechanical properties of Hap, PVC and PP based 3D porous structures obtained through biocompatible FDM filaments," Compos. Part B Eng., vol. 132, pp. 237–243, 2018.
[24] P. Parandoush and D. Lin, "A review on additive manufacturing of polymer-fiber composites," Compos. Struct., vol. 182, no. August, pp. 36–53, 2017.
[25] B. Brenken, E. Barocio, A. Favaloro, V. Kunc, and R. B. Pipes, "Fused Filament Fabrication of Friber-Reinforced Polymers: A Review (submitted)," Addit. Manuf., no. 2010, 2017.
[26] W. Liu, N. Wu, and K. Pochiraju, "Shape Recovery Characteristics of SiC/C/PLA Composite Filaments and 3D Printed Parts," Compos. Part A Appl. Sci. Manuf., no. February, 2018.
[27] J. Justo, L. Távara, L. García-Guzmán, and F. París, "Characterization of 3D printed long fibre reinforced composites," Compos. Struct., vol. 185, pp. 537–548, 2018.
[28] L. M. Galantucci, I. Bodi, J. Kacani, and F. Lavecchia, "Analysis of dimensional performance for a 3D open-source printer based on fused deposition modeling technique," Procedia CIRP, vol. 28, pp. 82–87, 2015.
[29] A. M. Phatak and S. S. Pande, "Optimum part orientation in Rapid Prototyping using genetic algorithm," J. Manuf. Syst., vol. 31, no. 4, pp. 395–402, 2012.
[30] G. Moroni, W. P. Syam, and S. Petrò, "Functionality-based part orientation for additive manufacturing," Procedia CIRP, vol. 36, pp. 217–222, 2015.
[31] Y. Arbaoui et al., "3D printed ferromagnetic composites for microwave applications," J. Mater. Sci., vol. 52, no. 9, pp. 4988–4996, 2017.
[32] J. Li, T. Monaghan, T. T. Nguyen, R. W. Kay, R. J. Friel, and R. A. Harris, "Multifunctional metal matrix composites with embedded printed electrical materials fabricated by ultrasonic additive manufacturing," Compos. Part B Eng., vol. 113, pp. 342–354, 2017.
[33] R. Melcher, N. Travitzky, C. Zollfrank, and P. Greil, "3D printing of Al2O3/Cu-O interpenetrating phase composite," J. Mater. Sci., vol. 46, no. 5, pp. 1203–1210, 2011.
[34] R. Matsuzaki et al., "Three-dimensional printing of continuous-fiber composites by in-nozzle impregnation," Sci. Rep., vol. 6, no. 1, p. 23058, 2016.
[35] C. C. Spackman, C. R. Frank, K. C. Picha, and J. Samuel, "3D printing of fiber-reinforced soft composites: Process study and material characterization," J. Manuf. Process., vol. 23, pp. 296–305, 2016.
[36] K. P. Motaparti, "Effect of build parameters on mechanical properties of ultem 9085 parts by fused deposition modeling," pp. 964–977, 2016.
[37] M. P. Zwier and W. W. Wits, "Design for Additive Manufacturing: Automated Build Orientation Selection and Optimization," Procedia CIRP, vol. 55, pp. 128–133, 2016.
[38] L. Witek, Y. Shi, and J. Smay, "Controlling calcium and phosphate ion release of 3D printed bioactive ceramic scaffolds: An in vitro study," J. Adv. Ceram., vol. 6, no. 2, pp. 157–164, 2017.
[39] K. Gnanasekaran et al., "3D printing of CNT- and graphene-based conductive polymer nanocomposites by fused deposition modeling," Appl. Mater. Today, vol. 9, pp. 21–28, 2017.
[40] C. Le Tohic et al., "Effect of 3D printing on the structure and textural properties of processed cheese," J. Food Eng., 2016.
[41] W. S. Tan, S. R. Suwarno, J. An, C. K. Chua, A. G. Fane, and T. H. Chong, "Comparison of solid, liquid and powder forms

of 3D printing techniques in membrane spacer fabrication," J. Memb. Sci., vol. 537, pp. 283–296, 2017.
[42] J. F. Christ, N. Aliheidari, A. Ameli, and P. Pötschke, "3D printed highly elastic strain sensors of multiwalled carbon nanotube/thermoplastic polyurethane nanocomposites," Mater. Des., vol. 131, pp. 394–401, 2017.
[43] J. M. G. Farstad, O. Netland, and T. Welo, "Surface Friction of Rapidly Prototyped Wheels from 3D-Printed Thermoplastic Elastomers: An Experimental Study," Procedia CIRP, vol. 60, pp. 247–252, 2017.
[44] A. Abilgaziyev, T. Kulzhan, N. Raissov, M. H. Ali, W. L. K. O. Match, and N. Mir-Nasiri, "Design and development of multi-nozzle extrusion system for 3D printer," 2015 4th Int. Conf. Informatics, Electron. Vision, ICIEV 2015, pp. 3–7, 2015.
[45] N. Alharbi, R. Osman, and D. Wismeijer, "Effects of build direction on the mechanical properties of 3D-printed complete coverage interim dental restorations," J. Prosthet. Dent., vol. 115, no. 6, pp. 760–767, 2016.
[46] M. Bienia et al., "Inkjet printing of ceramic colloidal suspensions: Filament growth and breakup," Chem. Eng. Sci., vol. 149, pp. 1–13, 2016.
[47] C. Balletti, M. Ballarin, and F. Guerra, "3D printing: State of the art and future perspectives," J. Cult. Herit., vol. 26, pp. 172–182, 2017.
[48] B. Biemacki, S. Zhang, and W. Whittow, "3D printed substrates with graded dielectric properties and their application to patch antennas," 2016 Loughbrgh. Antennas Propag. Conf. LAPC 2016, 2017.
[49] A. Qiong Pan, Z. Fan Huang, R. Guo, and J. Liu, "Effect of FDM Process on Adhesive Strength of Polylactic Acid(PLA) Filament," Key Eng. Mater., vol. 667, pp. 181–186, 2015
[50] F. Decuir, K. Phelan, and B. C. Hollins, "Mechanical strength of 3-D printed filaments," Proc. - 32nd South. Biomed. Eng. Conf. SBEC 2016, pp. 47–48, 2016.
[51] Y. Deng, S. J. Cao, A. Chen, and Y. Guo, "The impact of manufacturing parameters on submicron particle emissions from a desktop 3D printer in the perspective of emission reduction," Build. Environ., vol. 104, pp. 311–319, 2016.
[52] B. Ezair, F. Massarwi, and G. Elber, "Orientation analysis of 3D objects toward minimal support volume in 3D-printing," Comput. Graph., vol. 51, pp. 117–124, 2015.
[53] A. Goyanes, A. B. M. Buanz, A. W. Basit, and S. Gaisford, "Fused-filament 3D printing (3DP) for fabrication of tablets," Int. J. Pharm., vol. 476, no. 1, pp. 88–92, 2014.
[54] Y. Guo et al., "Engineering flame retardant biodegradable polymer nanocomposites and their application in 3D printing," Polym. Degrad. Stab., vol. 137, pp. 205–215, 2017.
[55] E. J. Hunt, C. Zhang, N. Anzalone, and J. M. Pearce, "Polymer recycling codes for distributed manufacturing with 3-D printers," Resour. Conserv. Recycl., vol. 97, pp. 24–30, 2015.
[56] C. Kim et al., "3D Printing of Low Melting Temperature Alloys by Fused Deposition Modeling," 2015 First Int. Conf. Reliab. Syst. Eng., vol. 56, pp. 389–394, 2015.
[57] K. G. Kovalenko, V. I. Sivetskii, and A. L. Sokol'skii, "Design of an Extrusion Die for Plastic Profiles," Chem. Pet. Eng., vol. 49, no. 9–10, pp. 675–678, 2014.
[58] M. Kurimoto, H. Ozaki, Y. Yamashita, T. Funabashi, T. Kato, and Y. Suzuoki, "Dielectric properties and 3D printing of UV-cured acrylic composite with alumina microfiller," IEEE Trans. Dielectr. Electr. Insul., vol. 23, no. 5, pp. 2985–2992, 2016.
[59] A. Kęsy and J. Kotliński, "Mechanical properties of parts produced by using polymer jetting technology," Arch. Civ. Mech. Eng., vol. 10, no. 3, pp. 37–50, 2010.
[60] B. Leutenecker-Twelsiek, C. Klahn, and M. Meboldt, "Considering Part Orientation in Design for Additive Manufacturing," Procedia CIRP, vol. 50, pp. 408–413, 2016.
[61] N. Mir-Nasiri, H. Ali, and S. Kurokawa, "Development of 3D Printer with Integrated Temperature Control System," 2015 Int. Conf. Informatics, Electron. Vis., pp. 1–5, 2015.
[62] M. Mirzaee, S. Noghanian, L. Wiest, and I. Chang, "Developing flexible 3D printed antenna using conductive ABS materials," IEEE Antennas Propag. Soc. AP-S Int. Symp., vol. 2015–Octob, pp. 1308–1309, 2015.