A review on advances of fused deposition modeling techniques of additive manufacturing

Ashish Phogat

Department of Mechanical Engineering, University Institute of Engineering and Technology, Maharshi Dayanand University, Rohtak, Haryana, India

ABSTRACT

A digital fabrication process with the help of design softwares in computersrefered as fused filament fabrication, creates natural objects out of geometric models by layering materials on top of one another. The use of 3D printing is a rapidly growing industry and in almost every sector, whether it is the medical industry or aerospace industry. The use of 3D printing has become widespread in recent years because of its easy operation and low cost. In the agricultural, healthcare, automotive, and locomotive industries, 3D printing is rapidly used for mass modification and production of open-source designs. A three-dimensional object can be constructed using 3D printing technology layer by layer, starting with a CAD model as a base. The numerous forms of AM techniques, materials used& applications in various fields are covered in this paper.

INTRODUCTION

AM is a "process of adding the material layer by layer to form 3D parts, as a resist to traditional manufacturing and developmental manufacturing techniques"[1]. Additive manufacturing is the process in which an object is made by adding the material in layers recognized as rapid manufacturing [2]. The development of AM technology initiated in the 1980s [3]. FDM is also known as Fused Filament Fabrication used in 3D printing. Fused Deposition Modeling uses the thermoplastic polymers like - ABS, PLA, polyethylene terephthalate glycol, Nylon, etc. Thermoplastic polymer/composites are manufactured using the cost-effective additive manufacturing method known as FDM [4-9]. The top layer roughness, which depends on the printer's minimum thickness, is this technology's main flaw [10].According to certain writers, the air void and raster orientation significantly affect tensile strengthfabricated prototypes using RP processes (3D printer, nanocomposite deposition system (NCDs), and FDM) [11-22]. They used different process parameters and measured the compressive strength and perform the experiments in the axial direction, transverse direction and diagonal. FDM and NCDS specimens were made axial and transverse, whereas, 3Dprinter specimens were made diagonal [23-36].

Types of Additive Manufacturing/3DPrinting
1. STEREOLITHOGRAPHY
2. SLS
3. FDM

Stereolithography
The Stereolithography was patented on 11 March 1986, and it was touted in Hull [37]. With the help of UV laser and photosensitive monomer, Stereolithography builds 1line at once (figure 2). Then, the build plate is lowered to coat the part. The part is left to solidify to make sure the even surface previous to the next layer [38]. The support can be removed manually when the part is built. The limitation of the Stereolithography was the product size and the cost. The availability of the material in comparison to other additive manufacturing processes is limited [39].

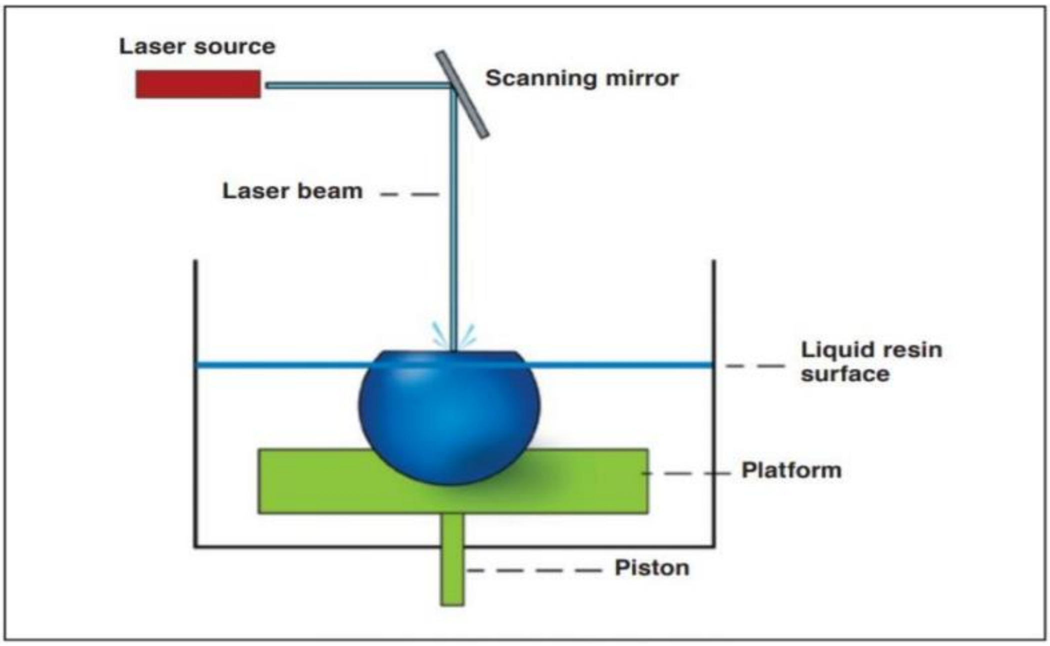

Fig 2 Stereolithography.

Selective Laser Sintering

It was patented on 5 September 1989, but it was previously described in Deckard and Beman [40,41]. It uses huge energy to merge small particles of the filament. To ease the fusion and to reduce the thermal misrepresentation powder bed is fiery just down its melting point (figure 3). Using the laser every veneer is drawn on to the powder bed to sinter the filament. This process is complicated. The feasible surface finish is not fine as it was of stereolithography and the material transition is also challengeable [42].

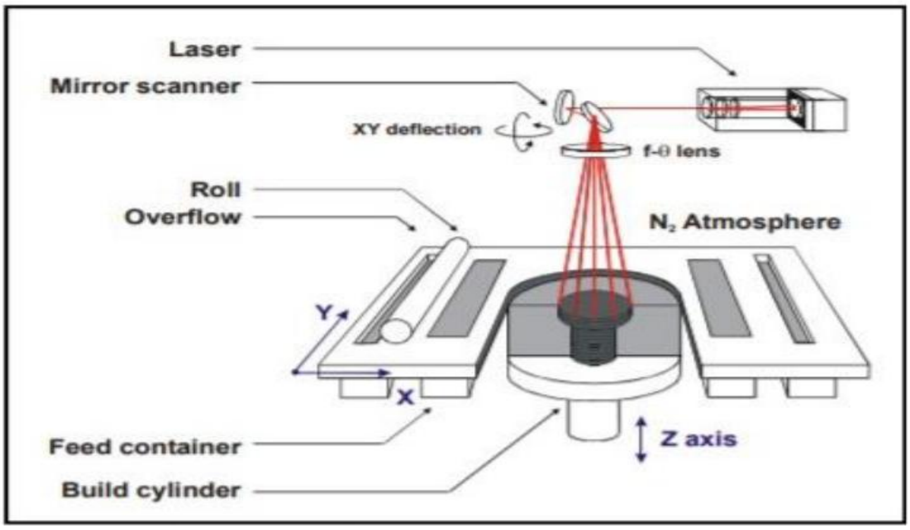

Fig 3 Selective Laser Sintering

Fused Deposition Modeling

The FDM technology was patented on 9 June 1992, but it was construed previous in Crump [43]. The Filament is extruded in semi-liquid form through the portable FDM head and deposited in layers (figure 4). The filament temperature is set to one degree above its melting temperature so that the filament stiffens just after the ouster onto the earlier layer. The materialthat dissipated to wax, TPE, and metals [44]. With a good quality of the filament, the accuracy of the part can reach ± 0.05mm. FDM uses less space because of dense size and preservation cost is minimized. The materialis fed to the nozzle, through the Bowden extruder with the help of stepper motor, where the filament is heated in the hot end and ejected through the nozzle on the heated bed, and then solidifies at room temperature. An adhesive (glue) is provided at the heated bed for the successful first layer, the heated bed moves in a vertical axis provide extruder 3-dimensional freedom to move, extruder moves up a certain layer thickness to deposit the next layer. This step reruns until the part is built. Many researchers have worked for the optimization of various process parameters to improve the printing Quality of FDM 3D parts and uses hybrid algorithms to verify and validate the results.[45-52].

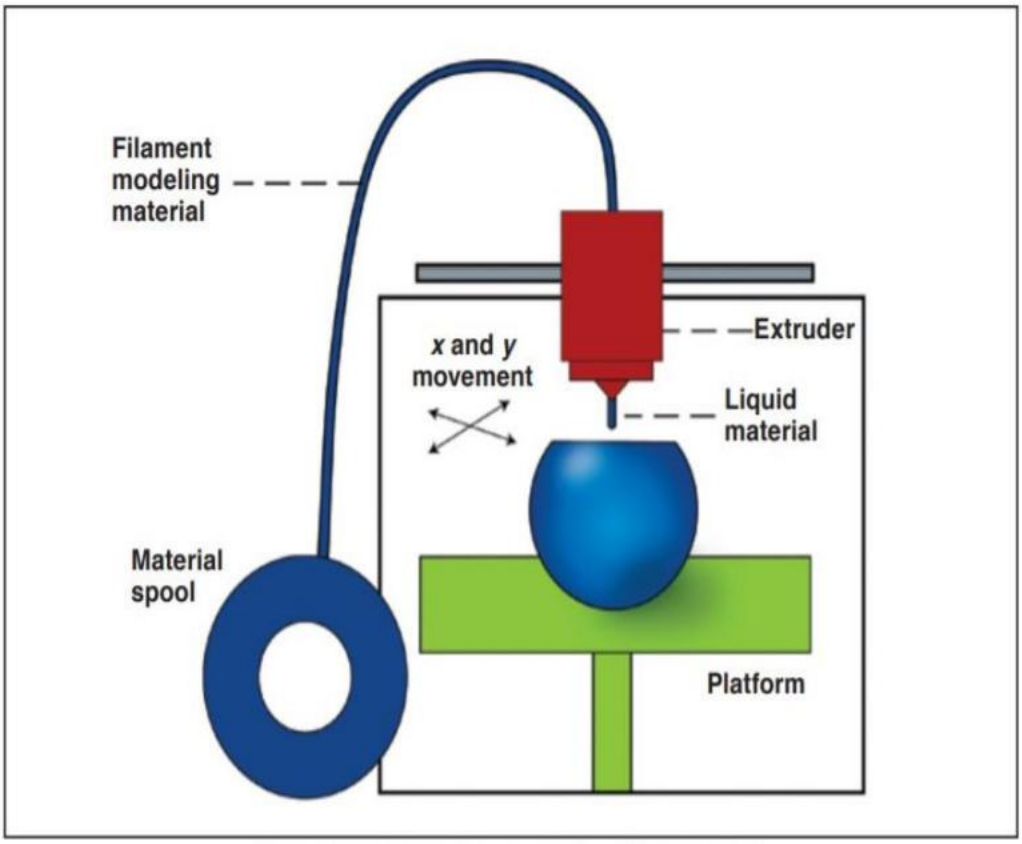

Fig 4 Fused deposition modeling printer.

Most Important Parameters Affecting the FDM 3D Printing Fabrication

• Layer height – is taken in mm, which affects the resolution of the print. If the layer height is taken higher than the printing will be fast but resolution of the print will be lower. whereas if it is taken lower than the printing will be slow but the resolution of the print will be high.

• Infill density – density of infill of the print, infill can vary from 0% to 100%.

• Infill pattern – there are so many patterns of the infill of the print affected by infill density. Patterns like Lines and Zig-Zag change the directions on alternate layers and reduce the filament cost. The Grid, Triangle, Tri-hexagon, cubic are printed fully in each layer.

• Ironing – used to smoothen the top layer, the nozzle will move one more time onto the top layer without extruding the filament. Which melt the plastic and gives a smoother surface.

• Temperature – the temperature of the nozzle varies from 210°C to 250°C and bedplate temperature varies from 70°C to 110°C. Depends on the material like here ABS extrusion temperature was 230°C and PETG extrusion temperature was 240°C.

• Velocity – is the speed at which nozzle moves and extrude the filament layer by layer. The speed of the nozzle can vary from 60 to 100mm/s, higher the speed faster will be the print.

• Retraction – retract the material when the nozzle goes from one point to another of a fabricating part. which helps in minimizing the problem of stringing and gives us a finished part.

• Raster angle – during printing the FDM 3D Printing makes an angle between the path of the nozzle and the x-axis that angle is defined as a raster angle which is differed by 90° between two adjacent angles, it influences the concoct accuracy and the mechanical performance of the fabricated test piece.

Applications

Since ancient times, 3D printers have been used to create complex physical objects from 3D computer models for a variety of purposes, including the production of goods and the study of the past through the arts, medicine, surveying, and preservation of the past. Some are shown in the fig 5.

• Food – nowadays, 3d printing is used in the food sector like making a statue of someone with chocolate or making a cake which looks like a car, etc. one just has to choose a design and fill up a raw material to print.

• Automobile – 3d printing is the future of the automobile sector. In this sector, make a design in the cad and fabricate it in the FDM 3D printing. Even the complex shapes and designs can be fabricated through FDM 3D printing. Spare parts that are outdated can be fabricated through Fused deposition modeling3D printing.

• Bio-printing – FDM can be used to make human parts like bones, ligaments. its uses are so vast that even a human heart is fabricated through FDM 3D printing.

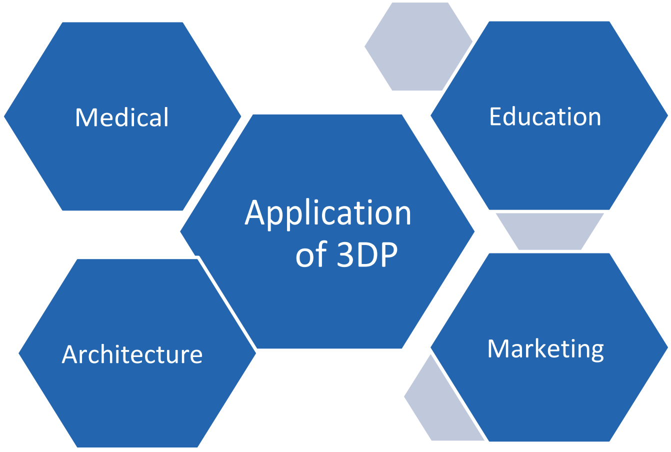

Fig 5 application of the 3d printing

Advantages

There are so many advantages of the 3d printing in so many applications some of them are shown in fig 6

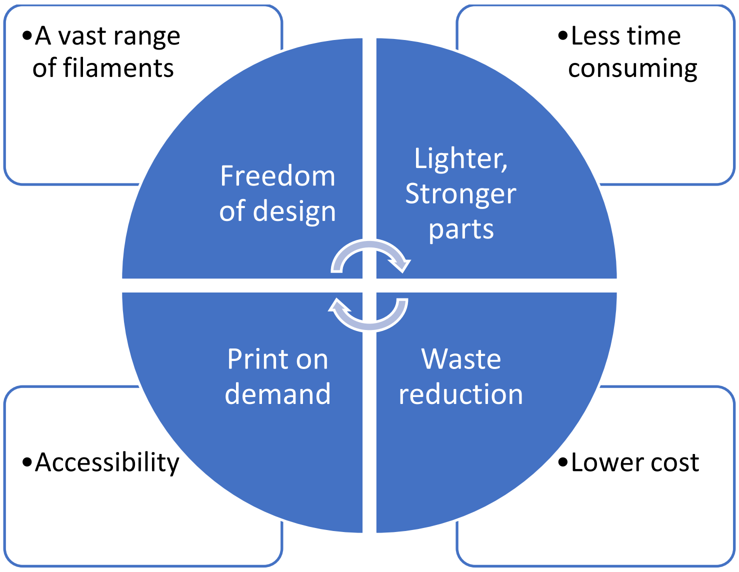

Fig 6 advantages of the additive manufacturing printing

Problems and their remedies

• Leveling – if leveling is not done properly then either the nozzle comes too close to the bed or too away from the bed in both the cases extruded filament will not stick to the bed and print will be bad. solution – nozzle should be at the 0.01mm gap.

• Blocked nozzle – usually nozzle blocked when the filament is changed or left unused for a couple of hours because every filament has its own melting point and the filament is clogged in the nozzle when it solidifies. solution – before extruding the filament through the nozzle or replacing the filament with different filament, the nozzle should be cleaned with a 0.4mm size needle.

• Nozzle out of order – while setting the parameters for a print the temperature of the nozzle shows either a -19°C temp or a gives a warning that nozzle is out of order. solution – this happens because sometimes the thermistor is not working properly so changing the thermistor will solve the issue.

• Stringing – while printing the nozzle moves over a nonprinting area it leaves a string from that point to another point. This problem occurs in some materials like PETG. solution – enabling the retraction speed and adjust the values accordingly will overcome this issue.

• Popping sound coming from the nozzle – when filament extruded through the nozzle sometimes it gives popping sound because the filament gets moistured from the surrounding and when it extruded it makes air bubbles which gives popping sound. solution – cover the filament in the airtight box and put some descents to absorb the moisture which left in the box.
• Wraping – wraping occurs because the temperature of the bed is too low that the print will not stick to the bed. solution – we can use the adhesions and raise the bed temperature.

CONCLUSION

In this review, a number of other topics are discussed along with the use of 3D printing in production. As it enters the production sector, 3D printing technology offers numerous advantages to individuals, organisations, and the government. As a result, further research is required to decide how to best encourage the applicability of the technology. The infrastructure for fabrication area may be built by enterprises and the government with this new technology. The objective of this page is to provide a general overview of the different 3D printing processes, production materials, and applications. Future studies will be possible on the various kinds of fast prototyping tools and the best materials to utilise.

REFERENCES

[1] Gibson, I., Rosen, D. W., & Stucker, B. (2014). Additive manufacturing technologies (Vol. 17). New York: Springer.
[2] Levy, G. N., Schindel, R., &Kruth, J. P. (2003). Rapid manufacturing and rapid tooling with layer manufacturing (LM) technologies, state of the art and future perspectives. CIRP annals, 52(2), 589-609.
[3] Kruth, J. P. (1991). Material incress manufacturing by rapid prototyping techniques. CIRP annals, 40(2), 603-614.
[4] Singh, R., Kumar, R., & Ranjan, N. (2019). Sustainability of recycled ABS and PA6 by banana fiber reinforcement: thermal, mechanical and morphological properties. Journal of The Institution of Engineers (India): Series C, 100(2), 351-360.
[5] Singh, R., Kumar, R., Feo, L., &Fraternali, F. (2016). Friction welding of dissimilar plastic/polymer materials with metal powder reinforcement for engineering applications. Composites Part B: Engineering, 101, 77-86.
[6] Fabbrocino, F., Farina, I., Amendola, A., Feo, L., &Fraternali, F. (2016, June). Optimal design and additive manufacturing of novel reinforcing elements for composite materials. In Proceedings of the 7th European congress on computational methods in applied sciences and engineering, Crete, Greece (pp. 5-10).
[7] Kumar, R., Singh, R., Ahuja, I. P. S., Amendola, A., & Penna, R. (2018). Friction welding for the manufacturing of PA6 and ABS structures reinforced with Fe particles. Composites Part B: Engineering, 132, 244-257.
[8] Kumar, R., Singh, R., Ahuja, I. P. S., Penna, R., &Feo, L. (2018). Weldability of thermoplastic materials for friction stir welding-A state of art review and future applications. Composites Part B: Engineering, 137, 1-15.
[9] Kumar, R., Singh, R., Hui, D., Feo, L., &Fraternali, F. (2018). Graphene as biomedical sensing element: State of art review and potential engineering applications. Composites Part B: Engineering, 134, 193-206.
[10] Pandey, P. M., Reddy, N. V., &Dhande, S. G. (2003). Improvement of surfacefinish by staircase machining in fused deposition modeling. Journal of materialsprocessing technology, 132(1-3), 323-331.
[11] Ahn, S. H., Montero, M., Odell, D., Roundy, S., & Wright, P. K. (2002).Anisotropic material properties of fused deposition modeling ABS. Rapid prototypingjournal, 8(4), 248-257.
[12] Es-Said, O. S., Foyos, J., Noorani, R., Mendelson, M., Marloth, R., &Pregger,B. A. (2000). Effect of layer orientation on mechanical properties of rapid prototypedsamples. Materials and Manufacturing Processes, 15(1), 107-122.
[13] Lee, C. S., Kim, S. G., Kim, H. J., &Ahn, S. H. (2007). Measurement ofanisotropic compressive strength of rapid prototyping parts. Journal of materialsprocessing technology, 187, 627-630.
[14] Wang, T. M., Xi, J. T., &Jin, Y. (2007). A model research for prototype warp deformation in the FDM process. The International Journal of AdvancedManufacturing Technology, 33(11-12), 1087-1096.
[15] Sun, Q., Rizvi, G. M., Bellehumeur, C. T., & Gu, P. (2008). Effect of processingconditions on the bonding quality of FDM polymer filaments. Rapid PrototypingJournal, 14(2), 72-80.
[16] Zhang, Y., & Chou, K. (2008). A parametric study of part distortions in fuseddeposition modelling using three-dimensional finite element analysis. Proceedings ofthe Institution of Mechanical Engineers, Part B: Journal of EngineeringManufacture, 222(8), 959-968.
[17] Anitha, R., Arunachalam, S., & Radhakrishnan, P. (2001). Critical parametersinfluencing the quality of prototypes in fused deposition modelling. Journal ofMaterials Processing Technology, 118(1-3), 385-388.
[18] Agrawal, S., &Dhande, S. G. (2007). Analysis of mechanical error in a fuseddeposition process using a stochastic approach.
[19] Pandey, P. M., Thrimurthulu, K., & Reddy*, N. V. (2004). Optimal partdeposition orientation in FDM by using a multicriteria genetic algorithm. InternationalJournal of Production Research, 42(19), 4069-4089.

[20] Durgashyam, K., Reddy, M. I., Balakrishna, A., & Satyanarayana, K. (2019).Experimental investigation on mechanical properties of PETG material processed byfused deposition modeling method. Materials Today: Proceedings.
[21] Singh, R., Garg, H., & Singh, S. (2018). Process Capability Comparison of FusedDeposition Modelling for ABS and Fe-Nylon (6) Feedstock Filaments. MaterialsToday: Proceedings, 5(2), 4258-4268.
[22] Vishwas, M., & Basavaraj, C. K. (2017). Studies on Optimizing ProcessParameters of Fused Deposition Modelling Technology for ABS. Materials Today:Proceedings, 4(10), 10994-11003.
[23] Lay, M., Thajudin, N. L. N., Hamid, Z. A. A., Rusli, A., Abdullah, M. K., &Shuib, R. K. (2019). Comparison of physical and mechanical properties of PLA, ABSand nylon 6 fabricated using fused deposition modeling and injectionmolding. Composites Part B: Engineering, 107341.
[24] Miguel, M., Leite, M., Ribeiro, A. M. R., Deus, A. M., Reis, L., &Vaz, M. F.(2019). Failure of polymer coated nylon parts produced by additivemanufacturing. Engineering Failure Analysis, 101, 485-492.
[25] Dawoud, M., Taha, I., &Ebeid, S. J. (2016). Mechanical behaviour of ABS: Anexperimental study using FDM and injection moulding techniques. Journal ofManufacturing Processes, 21, 39-45.
[26] Sood, A. K., Ohdar, R. K., & Mahapatra, S. S. (2010). Parametric appraisal ofmechanical property of fused deposition modelling processed parts. Materials &Design, 31(1), 287-295.
[27] Sood, A. K., Ohdar, R. K., & Mahapatra, S. S. (2012). Experimentalinvestigation and empirical modelling of FDM process for compressive strengthimprovement. Journal of Advanced Research, 3(1), 81-90.
[28] Im, Y. G., Cho, B. H., Seo, S. H., Son, J. H., Chung, S. I., &Jeong, H. D. (2007).Functional prototype development of multi-layer board (MLB) using rapid prototypingtechnology. Journal of materials processing technology, 187, 619-622.
[29] Chen, Y. F., Wang, Y. H., & Tsai, J. C. (2019). Enhancement of surfacereflectivity of fused deposition modeling parts by post-processing. OpticsCommunications, 430, 479-485.
[30] Boschetto, A., Bottini, L., &Veniali, F. (2016). Finishing of Fused DepositionModeling parts by CNC machining. Robotics and Computer-IntegratedManufacturing, 41, 92-101.
[31] Galantucci, L. M., Lavecchia, F., &Percoco, G. (2009). Experimental studyaiming to enhance the surface finish of fused deposition modeled parts. CIRPannals, 58(1), 189-192.
[32] Ippolito, R., Iuliano, L., &Gatto, A. (1995). Benchmarking of rapid prototypingtechniques in terms of dimensional accuracy and surface finish. CIRP annals, 44(1),157-160.
[33] Chang, D. Y., & Huang, B. H. (2011). Studies on profile error and extrudingaperture for the RP parts using the fused deposition modeling process. TheInternational Journal of Advanced Manufacturing Technology, 53(9-12), 1027-1037.
[34] Song, R., &Telenko, C. (2019). Causes of Desktop FDM Fabrication Failures inan Open Studio Environment. Procedia CIRP, 80, 494-499.
[35] Beniak, J., Holdy, M., Križan, P., &Matúš, M. (2019). Research on parametersoptimization for the Additive Manufacturing process. Transportation ResearchProcedia, 40, 144-149.
[36] Mansouri, M. R., Montazerian, H., Schmauder, S., &Kadkhodapour, J. (2018).3D-printed multimaterial composites tailored for compliancy and strainrecovery. Composite Structures, 184, 11-17.
[37] Le, H. P. (1998). Progress and trends in ink-jet printing technology. Journal ofImaging Science and Technology, 42(1), 49-62.
[38] Renap, K., &Kruth, J. P. (1995). Recoating issues in stereolithography. RapidPrototyping Journal, 1(3), 4-16.
[39] Anderson, J. (2007). Advantages and disadvantages of laser stereolithography.Ezin Articles.
[40] Beaman, J. J., Barlow, J. W., Bourell, D. L., Crawford, R. H., Marcus, H. L., &McAlea, K. P. (1997). Solid freeform fabrication: a new direction inmanufacturing. Kluwer Academic Publishers, Norwell, MA, 2061, 25-49.
[41] Deckard, C., & Beaman, J. J. (1988, December). Process and control issues inselective laser sintering. In Sensors and Controls for Manufacturing-1988.
[42] Kamrani, A. K., & Nasr, E. A. (2010). Engineering design and rapidprototyping. Springer Science & Business Media.
[43] Crump, S. S. (1991). Fast, precise, safe prototypes with FDM. ASME, PED, 50, 53-60.
[44] Kruth, J. P., Leu, M. C., & Nakagawa, T. (1998). Progress in additive manufacturing and rapid prototyping. Cirp Annals, 47(2), 525-540.
[45] Yadav, D., Chhabra, D., Garg, R. K., Ahlawat, A., &Phogat, A. (2020). Optimization of FDM 3D printing process parameters for multi-material using artificial neural network. Materials Today: Proceedings, 21, 1583-1591.
[46] Ahlawat, A., Sahdev, R. K., Gupta, R. K., & Chhabra, D. (2021). 3D FDM Printable Polymer Composites and Polymer Nanocomposites: State of the Art. Journal of Nano-and Electronic Physics, 13(2).
[47] Yadav, D., Chhabra, D., Gupta, R. K., Phogat, A., & Ahlawat, A. (2020). Modeling and analysis of significant process parameters of FDM 3D printer using ANFIS. Materials Today: Proceedings, 21, 1592-1604.
[48] Akash, A., Ravinder, K. S., Gupta, R. K., & Deepak, C. (2021). 3D FDM Printable Polymer Composites and Polymer Nanocomposites: State of the Art.
[49] Yadav, D., Garg, R. K., Ahlawat, A., & Chhabra, D. (2020). 3D printable biomaterials for orthopedic implants: Solution for sustainable and circular economy. Resources Policy, 68, 101767.

[50] Deswal, S., Narang, R., & Chhabra, D. (2019). Modeling and parametric optimization of FDM 3D printing process using hybrid techniques for enhancing dimensional preciseness. International Journal on Interactive Design and Manufacturing (IJIDeM), 13(3), 1197-1214.

[51] Phogat, A., Chhabra, D., Sindhu, V., & Ahlawat, A. (2022). Analysis of wear assessment of FDM printed specimens with PLA, multi-material and ABS via hybrid algorithms. Materials Today: Proceedings.

[52] Deshwal, S., Kumar, A., & Chhabra, D. (2020). Exercising hybrid statistical tools GA-RSM, GA-ANN and GA-ANFIS to optimize FDM process parameters for tensile strength improvement. CIRP Journal of Manufacturing Science and Technology, 31, 189-199.