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A Review on Application of Machine Learning in Fused Deposition Modeling

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Abstract. Fused deposition modeling **(FDM)** is a example of additive manufacturing (AM) which uses joining of materials in a layer by layer based methodology to manufacture a component, FDM can build complicated part geometries and intricacies in least time when compared to traditional manufacturing methods. It doesn't require any fixed process plan, special looting and involve very little human intervention. FDM parts offer superb heat and chemical resisting behavior and shows excellent strength-to-weight ratios. Despite of all these advantages, FDM parts are facing inconsistency in part properties, reliability and accuracy. To meet the consislent quality standard and process reliability real time monitoring of FDM process is requisite. Research trend shows that machine learning (ML) aided models are proficient computational technology which enable AM processes to achieve the high quality standard, product consistency and optimized process response. In this direction, integration of machine learning (ML) and FDM process is relatively less explored. Though the researches are limited in number, a review based study on the application of ML in FDM process is lacking which can help the researchers to decide their areas of research. Authors got motivated to bridge this gap by presenting a state of art showing the applicability of ML methods in FDM process.

Keywords: Fused Deposition Modeling,Machine Learning

INTRODUCTION

Lightweight structures possessing high strength, stiffness, and energy absorption are the prevailing requirement in the current customer-centric product development environment. Due to the unique capability of controlling of mechanical properties, number of structures have gained attention in recent times in various fields(Joshi et al., 2010, Ingrole et al., 2017, Yu et al., 2018). Metamaterials, the most popular lightweight structures, are man-made complex structures which have counterintuitive properties due to their geometrical configuration. Metamaterials are characterized by three elastic constants i.e. Young's modulus, shear modulus, bulk modulus and a dimensionless parameter, Poisson's ratio(Yu et al., 2018). These structures have unique mechanical properties such as negative Poisson's ratio (NPR), high shear modulus, negative compressibility, and negative stiffness, which differentiate these from conventional structures. Among metamaterials, auxetic or NPR structures have distinctive mechanical properties like high indentation resistance, impact resistance, bending stiffness, fracture toughness, vibration damping, hardness, and excellent shock absorption capacity as compared to the conventional positive Poisson's ratio structures(Elipe and Lantada, 2012, Zhang and Yang, 2016). Auxetic structures are widely used in applications such as automotive (car bumper and instrumental panel), aerospace (fuselage and seat structure), protective equipment (helmet and pads) and biomedical (implant and stent) due to their high strength, stiffness and specific energy absorption (SEA).

Fused deposition modelling (FDM), also known as fused filament fabrication (FFF) is a known additive manufacturing (AM) technique capable of fabricating complex products with reduced cycle time. In addition, it does not require any specific tooling and a definite process plan. The process also allows minimum human intervention. It is widely used in different engineering and medical applications. Instead of the widespread application of FDM products, the FDM process lacks consistency in part properties, process reliability, and part accuracy. In recent years, advancements in computing technology have enabled machine learning (ML) techniques to satisfy the FDM reliability and part accuracy. However, the importance of ML in the FDM process is still not established. Therefore, an experimental investigation will be performed on complex parts manufactured by FDM in the proposed work. Regression and ML models are developed to predict the responses, namely surface roughness, dimensional accuracy, and fabrication time(Joshi et al., 2010, Ingrole et al., 2017, Yu et al., 2018, Elipe and Lantada, 2012, Zhang and Yang, 2016).

LITERATURE

The proposed methodology of literature review on FDM is shown in Figure 1. Because of the heat generated by ME extruder, the hot layer is bonded by fusion to the previously deposited layer. Bellehumeur et al. (1996). Investigated the effect of factors on the porosity and compressive strength of the porous structures. A model was established for the forecast of the effect of air gap on porosity of the structure. Too et al. (2002). Studied the impact of process parameters on compressive strength and stiffness of tissue engineering scaffold fabricated by ME. They found that air gap and raster width are most significant parameters. Ang et al. (2006). Studied gradient auxetic structures as cores in aero-engine fan blade. Their natural frequencies and mode shapes for first three fundamental modes are investigated. The optimized configuration resulted in decrease in mass of fan blade, reduction in dynamic modal displacement and decrease in first three natural frequencies. Lira et al. (2011). Investigated in-plane mechanical behavior of graded honeycomb structure. They observed more deformation at the loading end with the increase of the impact velocity. Shen et al. (2013). Observed that stiffness of specimens having sandwich deposition configuration (with raster angle ± 45º) is higher than the specimen with default configuration (i.e. with zero raster angle). Magalhaes et al. (2014). Performed a parametric analysis of the effect of Poisson's ratio (cell angle) and relative density (wall thickness) on mechanical properties of auxetic structures. They concluded that the ultimate strength of structure is scale dependent when Poisson's ratio and relative density is kept constant. Zhang et al. (2016). Conducted an experimental study to investigate the effect of geometric parameters on mechanical properties. They developed various models by genetic programming (GP), automated neural network (ANN), fuzzy logic, and response surface methodology (RSM) and compared their performances with experimental findings. They found that ANN models perform best, followed by GP and RSM. Panda et al. (2018) Proposed novel design for energy dissipating structures using gradient auxetic configuration. Optimization is also performed to minimize mass of crash box with constraints of crash resistant force and energy absorption Hou et al. (2018). Studied cylindrical structures with triangular and hexagonal configurations for impact loading. They observed that normalized plastic energy absorption is affected by relative density. Ratio of cell wall to skin thickness is found to be a vital factor for determining SEA and deformation mode. Keeping positive density gradient along crushing direction enhances energy absorption at early stage. Chen et al. (2018a). Proposed a workflow for design and manufacturing that simultaneously integrates material design, structural design and product fabrication of functionally graded materials (FGMs). The proposed approach is also validated on FGM tensile structures with different material gradient. Ituarte et al. (2019). Found that infill density is most significant process parameter for compressive strength of tissue engineering scaffold. Dave et al. (2019). Compared the compressive performance of regular, auxetic and hybrid honeycomb structures. The constant relative density structures were compared for their mechanical properties. Hybrid structure developed by the combined design of regular and auxetic honeycomb structures exhibited the best performance. Raeisi et al. (2019). Derived the relationship of mechanical properties along different loading directions of Aux-Hex structure. In X-direction, energy absorption capacity was increased by 38% with uniform and stable deformation of unit cells. Xu et al. (2019). Concluded that influence of extruder temperature is more on cooling rate of material than other process parameters such as support temperature, speed, and layer height Vanaei et al. (2020). Performed a comparative study of re-entrant chiral (RCA) and regular re-entrant structure experimentally and numerically under compression loading. Multi-jet fusion (MJF) technique with a polyamide 12 (PA12) was used for fabrication of specimens. They found that RCA structure outperforms regular auxetic structure for strength and specific energy absorption (SEA). Alomarah et al. (2020). Validated a mathematical approach to parameterize lattices into Bezier surfaces, and also fabricated non-planer lattices via curved-layer fused deposition. Geometrical parameters of lattice were varied and specimens were tested under cyclic loading. They observed that lattices with higher auxeticity result in less energy dissipation. McCaw and Cuan-Urquizo (2020). Studied star-chiral auxetic structure numerically and experimentally. The hierarchical deformation mechanism was observed by varying geometrical parameters of unit cell of structure. They found that Poisson's ratio is dependent on the ratio of thickness and ligaments. Attard et al. (2020). Established theoretical nonlinear models of 2-dimensional (2D) and 3-dimensional (3D) Double-V micro-structure to anticipate normalized Young's modulus and Poisson's ratio as a function of strain. A significant effect of geometrical parameters was observed on the mechanical properties. Gao et al. (2020). Investigated the crushing performance of novel auxetic hierarchical crash box. They compared its performance with traditional crash box and found that novel crash box has higher energy absorption ability. Further, they performed multi-objective optimization techniques including archive-based micro genetic algorithm (AMGA) and found that AMGA outperformed. Tan et al. (2021)

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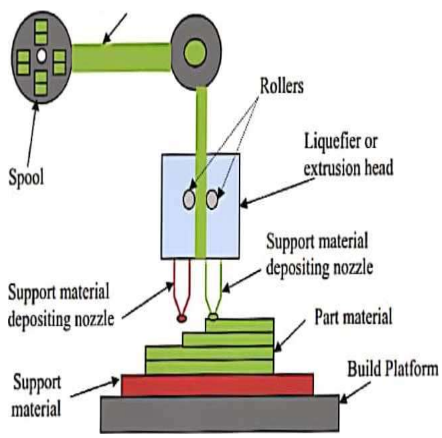

Fig 1.FDM machine

After the review of the literature so far, following important outcomes are obtained-

1. This literature is the interdisciplinary, which includes knowledge of AM and ML techniques.

2. Fabrication of complex parts is efficient and economical using AM and also characteristics of produced parts can be improved using ML techniques.

RESEARCH GAP

Worldwide researchers have made efforts to improve surface characteristics and mechanical properties of parts / structures produced by ME technique. Following conclusions are drawn from the literature review –

Many researchers have investigated ME process to improve surface finish and dimensional accuracy; and minimize time of fabrication of simple geometrical parts. But further efforts should be made to investigate ME process for geometrical parts having complex features such as pyramidal and conical. Although efforts have been made to study mechanical properties of standard ASTM components, but limited literature is available regarding study of influence of geometric and gradient parameters of auxetic structures on mechanical properties i.e. strength, stiffness, and SEA under compressive, shear and flexural loading. Limited literature is available on investigating the influence of ME process parameters on mechanical properties of standard ASTM components, but research efforts are required to study effect of process parameters on ME fabricated auxetic structures under compressive, shear and flexural loading.

Therefore, there is enough scope of experimental study of ME fabricated auxetic structures to improve surface characteristics and mechanical properties.

MACHINE LEARNING AND THEIR MODELS

Machine learning is a technique of artificial intelligence (AI) where initial training of the machine is done by human and thereafter, machines will automatically learn from their past experience. The human interface is very less which is only used for initially training of machine. Learning of the machine from its past experience provide fast, accurate and an effective ways to study and analyze the data. Machine learning models requires large number of data to train them but the process can be begin with moderate dataset and doesn't have to wait for large dataset. This section of the paper will present in brief the basic of ML and their related models. Figure 3 presents that ML can be categorized into: (1) Supervised learning (2) Unsupervised learning and (3) Reinforcement learning.Though there is one more ML algorithm known as semi-supervised algorithm (combination of supervised and unsupervised algorithm) but that is relatively less used. Further, categorization of supervised and unsupervised learning is shown in Fig. 2. Brief description related to learning algorithms are discussed as under.

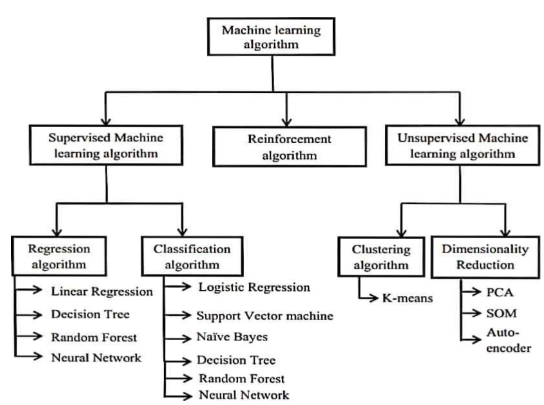

Fig 2 Machine Learning and Their Models

DISCUSSIONS AND FUTURE SCOPE

Fused deposition modeling also known as fused filament fabrication (FFF) is a known AM technique capable of fabricating complex products with reduced cycle time. It doesn't require any specific tooling and definite process plan. The process also allows minimized human intervention. It is widely used in different engineering and medical applications. Instead of widespread application of FDM products, FDM process lack in providing consistency in part properties, process reliability and pan accuracy. Advancement in computing technology enable the use of machine learning techniques to satisfy the FDM reliability and part accuracy but a review study showing the importance of ML in FDM process is still not established.

REFERENCES

[1] Alomarah, A., Masood, S. H., Sbarski, I., Faisal, B., Gao, Z. & Ruan, D. 2020. Compressive properties of 3D printed auxetic structures: experimental and numerical studies. *Virtual and Physical Prototyping,* 15, 1-21.

[2] Ang, K. C., Leong, K. F., Chua, C. K. & Chandrasekaran, M. 2006. Investigation of the mechanical properties and porosity relationships in fused deposition modelling-fabricated porous structures. *Rapid Prototyping Journal*.

[3] Attard, D., Farrugia, P., Gatt, R. & Grima, J. 2020. Starchirals–a novel class of auxetic hierarchal structures. *International Journal of Mechanical Sciences,* 179, 105631.

[4] Bellehumeur, C., Bisaria, M. & Vlachopoulos, J. 1996. An experimental study and model assessment of polymer sintering. *Polymer Engineering & Science,* 36, 2198-2207.

[5] Boldrin, L., Hummel, S., Scarpa, F., Di Maio, D., Lira, C., Ruzzene, M., Remillat, C. D., Lim, T.-C., Rajasekaran, R. & Patsias, S. 2016. Dynamic behaviour of auxetic gradient composite hexagonal honeycombs. *Composite Structures,* 149, 114-124.

[6] Chen, L., Zhang, J., Du, B., Zhou, H., Liu, H., Guo, Y., Li, W. & Fang, D. 2018a. Dynamic crushing behavior and energy absorption of graded lattice cylindrical structure under axial impact load. *Thin-Walled Structures,* 127, 333-343.

[7] Chen, Y., Li, T., Jia, Z., Scarpa, F., Yao, C.-W. & Wang, L. 2018b. 3D printed hierarchical honeycombs with shape integrity under large compressive deformations. *Materials & Design,* 137, 226-234.

[8] Dave, H. K., Rajpurohit, S. R., Patadiya, N. H., Dave, S. J., Sharma, K. S., Thambad, S. S., Srinivasn, V. P. & Sheth, K. V. 2019. Compressive strength of PLA based scaffolds: effect of layer height, infill density and print speed. *Int. J. Mod. Manuf. Technol.,* 11, 21-27.

[9] Elipe, J. C. Á. & Lantada, A. D. 2012. Comparative study of auxetic geometries by means of computer-aided design and engineering. *Smart Materials and Structures,* 21, 105004.

[10] Gao, D., Sun, Q., Hu, B. & Zhang, S. 2020. A framework for agricultural pest and disease monitoring based on internet-of-things and unmanned aerial vehicles. *Sensors,* 20, 1487.

[11] Hou, W., Yang, X., Zhang, W. & Xia, Y. 2018. Design of energy-dissipating structure with functionally graded auxetic cellular material. *International Journal of Crashworthiness,* 23, 366-376.

[12] Ingrole, A., Hao, A. & Liang, R. 2017. Design and modeling of auxetic and hybrid honeycomb structures for in-plane property enhancement. *Materials & Design,* 117, 72-83.

[13] Ituarte, I. F., Boddeti, N., Hassani, V., Dunn, M. L. & Rosen, D. W. 2019. Design and additive manufacture of functionally graded structures based on digital materials. *Additive Manufacturing,* 30, 100839.

[14] Joshi, S., Ju, J., Berglind, L., Rusly, R., Summers, J. D. & Desjardins, J. D. Experimental Damage Characterization of Hexagonal Honeycombs Subjected to In-Plane Shear Loading. International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, 2010. 35-41.

[15] Li, X., Lu, Z., Yang, Z. & Yang, C. 2018. Anisotropic in-plane mechanical behavior of square honeycombs under off-axis loading. *Materials & Design,* 158, 88-97.

[16] Lira, C., Scarpa, F. & Rajasekaran, R. 2011. A gradient cellular core for aeroengine fan blades based on auxetic configurations. *Journal of Intelligent Material Systems and Structures,* 22, 907-917.

[17] Magalhães, L., Volpato, N. & Luersen, M. 2014. Evaluation of stiffness and strength in fused deposition sandwich specimens. *Journal of the Brazilian Society of Mechanical Sciences and Engineering,* 36, 449-459.

[18] Mccaw, J. C. & Cuan-Urquizo, E. 2020. Mechanical characterization of 3D printed, non-planar lattice structures under quasi-static cyclic loading. *Rapid Prototyping Journal*.

[19] Panda, B., Leite, M., Biswal, B. B., Niu, X. & Garg, A. 2018. Experimental and numerical modelling of mechanical properties of 3D printed honeycomb structures. *Measurement,* 116, 495-506.

[20] Raeisi, S., Tapkir, P., Ansari, F. & Tovar, A. 2019. Design of a hybrid honeycomb unit cell with enhanced in-plane mechanical properties.

[21] Shen, C., Lu, G. & Yu, T. 2013. Dynamic behavior of graded honeycombs–a finite element study. *Composite Structures,* 98**,** 282-293.

[22] Tan, H., He, Z., Li, E., Cheng, A., Chen, T., Tan, X., Li, Q. & Xu, B. 2021. Crashworthiness design and multi-objective optimization of a novel auxetic hierarchical honeycomb crash box. *Structural and Multidisciplinary Optimization,* 64**,** 2009-2024.

[23] Too, M., Leong, K., Chua, C., Du, Z., Yang, S., Cheah, C. & Ho, S. L. 2002. Investigation of 3D non-random porous structures by fused deposition modelling. *The International Journal of Advanced Manufacturing Technology,* 19**,** 217-223.

[24] Vanaei, H., Shirinbayan, M., Deligant, M., Raissi, K., Fitoussi, J., Khelladi, S. & Tcharkhtchi, A. 2020. Influence of process parameters on thermal and mechanical properties of polylactic acid fabricated by fused filament fabrication. *Polymer Engineering & Science,* 60**,** 1822-1831.

[25] Xu, J., Wu, Y., Wang, L., Li, J., Yang, Y., Tian, Y., Gong, Z., Zhang, P., Nutt, S. & Yin, S. 2018. Compressive properties of hollow lattice truss reinforced honeycombs (Honeytubes) by additive manufacturing: Patterning and tube alignment effects. *Materials & Design,* 156**,** 446-457.

[26] Xu, M., Xu, Z., Zhang, Z., Lei, H., Bai, Y. & Fang, D. 2019. Mechanical properties and energy absorption capability of AuxHex structure under in-plane compression: Theoretical and experimental studies. *International Journal of Mechanical Sciences,* 159**,** 43-57.

[27] Yang, C., Vora, H. D. & Chang, Y. 2018. Behavior of auxetic structures under compression and impact forces. *Smart Materials and Structures,* 27**,** 025012.

[28] Yu, X., Zhou, J., Liang, H., Jiang, Z. & Wu, L. 2018. Mechanical metamaterials associated with stiffness, rigidity and compressibility: A brief review. *Progress in Materials Science,* 94**,** 114-173.

[29] Zhang, Q., Chen, J., Zhao, Z., Tan, H., Lin, X. & Huang, W. 2016. Microstructure and anisotropic tensile behavior of laser additive manufactured TC21 titanium alloy. *Materials Science and Engineering: A,* 673**,** 204-212.

[30] Zhang, X. & Yang, D. 2016. Mechanical properties of auxetic cellular material consisting of re-entrant hexagonal honeycombs. *Materials,* 9**,** 900.