A Review on 3D Printing using Fused Deposition Modeling

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Abstract- In additive manufacturing, fused deposition modeling is the most extensively utilized technology. It is the technique of building a three-dimensional object by depositing material in successive layers of a controlled environment. The limited choice of materials and the reality that FDM components are more often used as a presentation or conceptual parts rather than functioning parts are the main disadvantages of using fused deposition modeling (FDM) in industrial applications. Scientists have recently explored many approaches for broadening the range of materials that may be used in the FDM process, resulting in an increase in the employment of FDM in a variety of manufacturing industries. This is a comprehensive review of the literature on the subject of FDM with the goal of recommending future research directions aimed at boosting industry recognition of FDM printed components. The significance of reviewing the current research on this topic, is not just to distinguish practical and useful aspects, key process parameters, and constrictions, but also to determine the extent to wherein the results of these studies are useful and can be implemented in the future research and real-world applications.

Keywords– 3D Printing, FDM.

1. INTRODUCTION

For a long time, subtractive manufacturing mainly milling or cutting has been used for transforming material to the desired object. Many drawbacks and complications during this traditional manufacturing technique forced scientists to innovate new manufacturing processes [1]. One of the new techniques developed was additive manufacturing. Rapidly generated and additive manufacturing technique, controlled by computer is known as Rapid Prototyping (RP). In RP, the desired shape of the object is obtained by adding layer by layer of working material. This technique reduces material wastes and business risk. Also, there is no need for any cutting tool, tool changing, and tool maintenance [2]. 3D printing is a procedure that employs the rapid prototyping (RP) manufacturing technique, which is the most often used word for RP. Three-dimensional items, body parts, models, and components made of diverse materials such as plastics are manufactured via 3D printing.3D Printing works on the principle of the digital model created by computer software from an original 3D object (model) [3].

Initially, 3D Printing and its equipment were very expensive that's why it was used for only rare and big projects like lick stater. Day by day, the development in machine equipment, process, and free software made the 3D Printing machine cost-effective for every object production [4]. As the technology developed, today there is not only one type of 3D Printing technology available. All those types of technology have their limitations, features, methodology, rate, and accuracy. Among all of them, the Fused Deposition Modelling (FDM) process was found to be more user-friendly, most usable, and low in cost. In the FDM process, only filament was used to perform the printing, unlike other techniques where resin-based material must be used [5].

2. BACKGROUND

For the last three decades, 3D printing has developed in various forms. But from the last 5 years, the manufacturing transformation was found very cost-effective and user-friendly compared to the traditional technique, which is noticed as the breakthrough point in the development of the procedure. Also, nowadays the development of new technology, operating software, and flexible materials make a wide range of manufacturing objects using 3D printing machines [6]. So can an individual create or manufacture new objects with their suitable measurements. Around the 1980s inkjet printing was the most used rapid manufacturing. Later the actual 3D printing technology i.e., Stereo Lithography was used for manufacturing in 1984 by Charles Hulls [7]. Later in the 1990s, stereolithographic apparatus was developed by Hull to enhance SLA technology. Initially, the Hull device was very simple which works on heating optically using a laser and found that manufacturing could be done much faster than traditional methods. Stereolithography (SLA) relies on a type of acrylic-based substance called photopolymer. When you discharge a UV laser beam into a pool of liquid photopolymer, the light-exposed part transforms into a solid piece of plastic that can be molded into the shape of your 3D- design model

[8]. In 1992, DTM, a start-up, released the world's first selective laser sintering (SLS) machine which uses a laser to sinter powder rather than liquid. In the same year, 3D Systems (Charles Hull's company) produced the world's first stereolithographic apparatus (SLA) machine, which enabled the layer-by-layer fabrication of complex items in a fraction of the time [9]. Later, a 3D printer was utilized to create an organic body, which was created for the first time in 1999 A.D. To adapt that part in the body, the part was covered by the patient’s cells. This concept was developed by the Wake Forest Institute for Regenerative Medicine. In 2002, for the 1st time, the same scientists developed an effective artificial kidney printed by a 3D printing machine [10].

3. FUSED DEPOSITION MODELING (FDM)

Material extrusion is a class of additive manufacturing processes that includes FDM. Because of the peculiar filament usage, it's also termed as Fused Filament Fabrication (FFF) [11]. This technique made use of thermoplastics such as ABS (Acrylonitrile butadiene styrene), wax, and nylon. The first step of the process is to reheat the thermoplastic until it becomes intertwined. After it, the CAD record was implemented on the material through the printer to create the 3D object layer by layer [12].

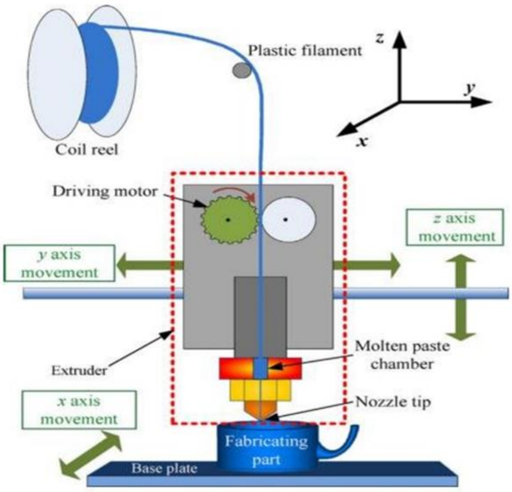

Figure 1: Basic Structure of FDM Technology

Figure 2: The thermoplastic used as filament in the printing

A cylinder guides the platform below the gap of the thickness of the printed layer after each layer is printed. The basic constituent of FDM technology consists of various parts, as shown in Figure 1. The common filament used for the printing is a thermoplastic, shown in Figure 2.

4. APPLICATIONS OF 3D PRINTING

To execute the rapid prototyping technology and purpose i.e., to make physical samples easily (less complicated), 3D printing was invented and developed. It helps the controller to identify and analyze flaws rapidly. It boosts the product development process of the company. These are some applications of 3D printers:

- Medicine: one of the most promising areas of use of 3D printers is the medical sector. Many medical problems like critical body part transplantation, medical research, and regenerative medicine. In 2012, doctors and engineers at Hasselt used a 3D printer successfully to make a prosthetic jaw transplant instrument for a patient [13].
- Automotive and Aerospace sector: Even after the 1st world war, the 3D printer was developed and invited to manufacture arms, parts of missile guns, and other war instruments. Later furthermore development of 3D printers helps to produce body parts for automobiles. The same complicated body part made by a 3D printer weighs 70% less than traditionally generated parts. That helps companies to manufacture aircraft with less weight [14]. It also reduces carbon production and the cost of the companies. Even with fewer raw constituents and manufactured parts, it possesses more strength and toughness.
- Rapid manufacturing: development of rapid prototyping increases the variety of product design, proper utilization of raw materials, and

increased the accuracy of finished body parts and components [15].

- Mass customization: Many businesses have developed services that allow customers to replicate their desired outcomes by using simple web-based customization tools. Customers may now copy the casings of their mobile phones. Nokia has made the 3D blueprints of their phones available so that users may replicate their phone covers [16].

5. EXISTING RESEARCH ON FDM PRINTING

J. Lee [17] experimented with FDM rapid-prototyped acrylonitrile butadiene styrene (ABS) materials to see how fatigue affected them. For the experiments, dog bone shaped FDM was created and tested at various tensile stress levels in various orientations. In a tensile tester, the extension periodically stress was 25.4 mm/min and relaxed at 12.7 mm/min for sample testing. The printed ABS plus-P430 (production-grade thermoplastic) material has a greater tensile strength but lower strain energy than the printed ABS-P400 (general purpose) material. Because parallel fatigue degradation was found in all primary axes, there was no impact on the fatigue degradation mechanism.

N. Hill [18] investigated the failure criteria and material properties of FDM polycarbonate in raster orientation. All the material's mechanical properties were calculated as a function of raster angle. The material's failure mechanism map was analyzed using the methodology, which included analyzing properties that were a function of orientation. Tension, hardness, and density were used in the analysis, which was done at raster angles of 0^0 to 90^0 with 15^0 intervals. The material's properties were discovered to be highly orientation dependent. Furthermore, the substance has the highest hardness in the 0^0 and 90^0 cases. The material exhibits lower elongation, tensile, and yield strength when the failure mechanism is related to welds than when the failure mechanism is attributed to beads.

B.M. Tymrak [19] examined fatigue behavior utilizing polylactic acid (PLA) parts (FDM) Using fused deposition modeling. The part orientations were utilized as input factors to evaluate the effect on the material's tensile stress. Tensile stress was measured using the Zwick Z010 universal testing equipment at periodic 80, 70, 60, and 50 percent. In static loading, it was discovered that parts built in the X orientation have higher tensile stress. The 45° build orientation part, on the other hand, shows higher tensile stress under cyclic loading.

S. O. Akande [20] investigated and optimized process parameters during FDM with surface finish and dimensional accuracy responses in an experimental setting. The parts were made on an FDM machine with varying fill densities, layer thicknesses, and deposition speeds. The experiments used two levels of each factor. To obtain the optimum points and machine settings, the Taguchi method was combined with a factorial design of experiment (DOE). The dimension measurement of the fabricated part was done with a Mitutoyo digital caliper. For comparison and actual dimension accuracy measurement, the measured data was inserted into the CAD design. The Ra value was calculated using the Taylor-Hobson surface texture for measuring surface roughness. Pareto chart analysis was used to compare the results. Some specimens were made for confirmation experiments after the data analysis yielded optimal solutions. The best point for surface finish was found to be different from the best point for dimensional accuracy. It was suggested that using FDM techniques, parts could be manufactured based on the experimental data.

A. P. Gordon [21] investigated FDM with polylactic acid in an experiment and optimized the process to reduce the number of experiments. The stiffness, strength, generalized loading, and ductility process parameters were optimized using a two-level Taguchi test matrix. E399/D5045 and ASTM E8/D638 were the work pieces used in the experiments. Tensile and fracture strength were the output responses studied in this study. The best overall combination is the machining setting observed in the results and its optimization.

M. Raju [22] aimed to discover the best machining settings or process parameters for the best mechanical and surface quality during the FDM process. The experiment sequence was organized using a Taguchi L18 orthogonal array. The study's optimization and analysis were carried out using the PSO-BFO (particle swarm and bacterial foraging optimization) algorithm. Support material, layer thickness, orientation, and model interior were the experiment parameters. Flexural modulus, hardness, tensile strength and surface roughness were the output responses studied in the experiments. The individual influence of experimental parameters on each response was investigated using S/N ratio plots. The optimum point of the FDM process was found to be at support material type sparse, the part orientation of 60o, the layer thickness of 0.007mm, and high-density model interior.

Srivastava et al. [23] used ABS material for multi-objective optimization of the FDM process. The experiments were carried out and the results were calculated using RSM. raster width, layer height, , air gap, angle, orientation, and contour width were all three-level process parameters. Time and support material were used to create the output response. For a better understanding, fuzzy logic analysis was used in the study. For those 6 process parameters and 2 output responses, a total of 86 experiments (runs) were carried out using the RSM design. The optimum point was found to be 0.48mm of contour width,0.254 mm of slice height, 0.4 mm of the air gap, 0.48 mm of raster width and 0° of raster angle and orientation.

J. A. Preuss et al. [24] attempted to fix additive manufacturing resolution to develop and access complex 3D structure microfluidic devices. These devices can separate and analyze functional units (protein, DNA, cells, and their parts). A smart 3D design of microfluidic free-flow electrophoresis is designed and developed in this paper. Printed wells, microfluidic devices, a robust, repeatable method, and an electrode chamber are all part of the research (use of polycarbonate membranes for segregation). Separation was achieved using a mixture of amino acids and fluorescence dyes in a practical application and trial test.

L. Wang [25] studied the best structure for a branch joint (especially a three-branch joint) to support a heavy vertical load. The study employed a simple and complex topology optimization technique. The branch joint was created using the additive manufacturing concept, or 3D printing. The printed joint was compared to joints created using traditional methods. Stress was uniformly distributed on the 3D-printed branch joint, according to the findings. Furthermore, the method's improved static behavior indicated that it could be used for tree-like structures in future projects. 3D printing with topology optimization has been discovered to be successful and viable for manufacturing three-branch joints.

P. Kumar [26] investigated the design of biological tissues using a synthesis technique in topology optimization. To design a large deformation complaint mechanism, the optimization was based on density. To make the tissue, the desired strains were optimized. The 3D printing material was poly diacrylate, which was simplified and analyzed using ABAQUS.

X. Peng [27] concentrated on the chemical (rather than mechanical) properties of 3D printed materials and their catalytic functions. Some of these 3D printed materials were used to make high-value-added chemicals from C1 molecules as chemical catalysts and reactors. Ni-SCR, Fe-SCR and Co-SCR self-catalytic reactors have been used in the study. The research focused on 3D printing as a cost-effective and simple method of producing catalysts and reactors.

J. Chun [28] investigated 3D printing technology for fashion design and production. The simulation technique is used to explore the impact of parameters on wearable product design aspects. Two different parametric motifs were investigated using TPU and ABS as printing materials. Smaller products or accessories can be printed due to the small bed size limitation of 3D printers. Despite this, the study's focus was on producing full-size fashion items. The study also failed to mention the difficulties with printed cloths while wearing and washing them.

Author (Year)	**Specimen Material**	**Process Parameters**	**Responses**
J. Lee et al. (2013)	ABS, ABS plus	Orientation angle	Tensile strength, strain energy
N. Hill et al. (2014)	Polycarbonate	Raster angle	Tensile strength, hardness
B.M. Tymrak et al. (2015)	ABS, PLA	Build orientation, layer thickness	Tensile strength
S. O. Akande (2015)	ABS	Layer thickness, infill density, speed	Surface roughness, dimensional accuracy
A. P. Gordon et al. (2016)	PLA	Temperature, speed, infill direction, relative	Tensile strength, fracture testing
M. Raju et al. (2018)	ABS	Support material, Layer thickness, model interior build orientation	Surface roughness, flexural modulus hardness, tensile strength,
Srivastava et al. (2018)	ABS	Slice height, contour width, air gap, orientation, raster width, and angle	Build time, support material volume
J. A. Preuss et al. (2020)	A mixture of fluorescence dyes & amnio acids	A mixture of concentrated different samples	Separated elements of the mixtures

L. Wang et al. (2020)	Cast-steel joints	Material Density	Flexibility, strain, static behaviour
P. Kumar et al. (2020)	Poly diacrylate	Tensor, displacement field	Strains on the tissue
X. Peng et al. (2020)	Fe, Ni, Co SCR	Reaction temperature, pressure	Geometrical analysis, CH selectivity, Fuel selectivity
J. Chun et al. (2021)	TPU, ABS	Length, thickness, and depth of object	Complex design features

6. RESULTS AND DISCUSSIONS

It is clear from the literature analysis about the creation of materials that are novel and suited to FDM technology has increased significantly over the previous decade, and that this trend will continue. It is being investigated if it is possible to produce new materials for FDM while also optimizing process parameters, which is an important factor in the production of high-quality components with improved material, mechanical, and thermal characteristics in the research investigations. Currently, there are many distinct kinds of FDM systems available, each with its own set of parameters for the flowability of the material used for the best possible outcome. To overcome the above constraint, many scientists, first investigated the rheological characteristics when inventing new materials. The MFI of the new material was then adjusted to match the machine's requirements in order to increase process capability. The impacts of technique parameters, as well as the inter-relationship between two or more factors, should be carefully investigated to increase our understanding of the material and mechanical characteristics of FDM-fabricated components.

A variety of optimization methodologies have been utilized to evaluate and optimize the processing parameters of the FDM for the creation of different materials. According to the findings of the above-mentioned study effort, the Taguchi approach and ANOVA are frequently employed by researchers as optimization strategies. The advantages of conducting research of an FDM part through using the Taguchi technique for fabrication using a newly designed material include the ability to study the interaction effects between different parameters during the fabrication process and the generalization of the experiment plan by limiting the number of process variables that need to be inspected.

7. FUTURE SCOPE

Approximately 80% of the study is devoted to enhancing the mechanical qualities of the FDM component, which is composed of conventional FDM materials such as PLA and nylon, by the optimization of process parameters. Recent years have seen a significant increase in the creation of innovative materials for FDM technology, owing to increased competition and technological advancements. These new materials will broaden the range of applications for FDM technology and also improve the properties of materials that are existing. While there are standards for a range of materials used in traditional manufacturing, there are currently no generally published standards for materials employed in 3D printing. No comprehensive research was done on the link between mechanical characteristics, material and process parameters for the many types of materials employed in the FDM technology. Work on the FDM machine is also needed to support high-melting-point materials, like increasing the machine's melting temperature range. A low-cost, widely available material, ABS is the subject of the great majority of research into improving mechanical properties due to its wide commercial availability and low cost. Few research, on the other hand, has concentrated on improving the thermal FDM-produced components created from other materials by optimizing process parameters, which is a more challenging problem to overcome.

8. CONCLUSION

The conclusion of this research is that FDM has a variety of utilizations and is a rapidly developing manufacturing process. The breadth of using objects manufactured with FDM for various uses will be broadened by developing new materials consistent with this FDM technology, which will help businesses stay competitive in their marketplaces. There have been several studies conducted on optimizing process parameters for various materials, such as layer thickness, raster angle, extrusion temperature and raster width, that have been examined. ANOVA analysis, Taguchi optimization, and RSM optimization are some of the approaches presented in this literature review that have shown to be effective in actual implementations. According to the findings of this review, it is necessary to create optimization methods that consider noise and surrounding factors that might have an impact on accuracy of part as well as surface roughness, as present technique do not take these factors into consideration. The review paper also noted areas of experimentation which needed to be conducted to improve the FDM printing process and expand the spectrum of materials that are available for use in FDM applications.

REFERENCES

[1] Nagendra Kumar Maurya, Vikas Rastogi, Pushpendra Singh. "An overview of mechanical properties and form error for rapid prototyping", CIRP Journal of Manufacturing Science and Technology, Vol. 29, Part A, May 2020, pp. 53-70, 2020.

[2] C.A. Griffithsa, J. Howarthb, G. de-Almeida Rowbothamb, A. Reesa, "Effect of build parameters on processing efficiency and material performance in fused deposition modelling", Procedia CIRP, vol. 49, pp - 28 – 32, 2016.

[3] Vijay. B. Nidagundi, R. Keshavamurthy, C. P. S. Prakash, "Studies on Parametric Optimization for Fused Deposition Modelling", Process, Materials Today: Proceedings, vol.- 2, pp. 1691 – 1699, 2015.

[4] Vishwas M, Basavaraj C. K., Vinyas M., "Experimental Investigation using Taguchi Method to Optimize Process Parameters of Fused Deposition Modeling for ABS and Nylon Materials", Materials Today: Proceedings, vol. 5, pp. 7106–7114, 2018.

[5] Samuel Clinton Daminabo, Saurav Goel, Sotirios A. Grammatikos, Hamed Yazdani Nezhad, Vijay Kumar Thakur, "FDM-based Additive Manufacturing (3D Printing): Techniques for Polymer Material Systems", Materials today chemistry, vol. 16, pp. 1-57, 2020.

[6] G. Nyiranzeyimana, J.M. Mutua, B.R. Mose, T.O. Mbuya. "Optimization of process parameters in fused deposition modelling of thermoplastics: A review", Material science and engineering Technology, vol. 52, pp. 682-694, 2021.

[7] M. Nalbant, H. Go kkaya, G. Sur "Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning", Materials and Design, vol. 28, pp. 1379–1385, 2007.

[8] Sakthivel Murugan R., Vinodh S. "Parametric optimization of fused deposition modelling process using Grey based Taguchi and TOPSIS methods for an automotive component", Rapid Prototyping Journal, Vol. 27 No. 1, pp. 155-175, 2020.

[9] Diana Popescu, Aurelian Zapciu, Catalin Amza, Florin Baciu, Rodica Marinescu. "FDM process parameters influence over the mechanical properties of polymer specimens: A review", Polymer Testing, Vol. 69, pp. 157-166, 2018.

[10] Faujiya Afrose, S. H. Masood, Pio Iovenitti, Mostafa Nikzad, Igor Sbarski. "Effects of part build orientations on fatigue behaviour of FDM-processed PLA material", Progress in Additive Manufacturing, vol. 1, pp. 21–28, 2016.

[11] Maraboina Raju, Munish Kumar Gupta, Neeraj Bhanot, Vishal S. Sharma. "A hybrid PSO–BFO evolutionary algorithm for optimization of fused deposition modeling process parameters", Journal of Intelligent Manufacturing, vol. 30, pp. 2743–2758, 2019.

[12] E. Vijayaragavan, Leya Miriam Kurian, H. Sulayman, T.V. Gopal. "Application of Rapid Prototyping in the Treatment of Clubfoot in Children", Procedia Engineering, vol. - 97, pp - 2298 – 2305. 2014.

[13] Farzad Rayegani, Godfrey C. Onwubolu, "Fused deposition modeling (FDM) process parameter prediction and optimization using group method for data handling (GMDH) and differential evolution (DE)" Springer-Verlag London, International Journal of Advanced Manufacturing Technology, vol. 73, pp. 509-519, 2014.

[14] Aladdin Alafaghani, Ala Qattawi, "Investigating the effect of fused deposition modeling processing parameters using Taguchi design of experiment method", Journal of Manufacturing Processes, vol. 36, pp. 164–174, 2018.

[15] Lu Wang, William M. Gramlich, Douglas J. Gardner, "Improving the impact strength of Poly (lactic acid) (PLA) in fused layer modelling (FLM)", Polymer, vol. 114, pp. 242-248, 2017.

[16] Aladdin Alafaghania, Ala Qattawia, Buraaq Alrawia, Arturo Guzmana, "Experimental Optimization of Fused Deposition Modelling Processing Parameters: A Design-for-Manufacturing Approach", Procedia Manufacturing vol. 10, pp. -791 – 803, 2017.

[17] Lee. J., and Huang, A., "Fatigue analysis of FDM materials. Rapid Prototyping Journal", Mechanical Engineering, University of Arkansas, Fayetteville, Arkansas, USA, vol. 19 (4), pp. 291–299, 2013.

[18] Nevin Hill and Mehrdad Haghi, "Deposition direction-dependent failure criteria for fused deposition modeling polycarbonate", Rapid Prototyping Journal, vol 20, pp. 221–227, 2014.

[19] Syed Hasan Masood, Omar Ahmed Mohamed, Jahar Lal Bhowmik, "Optimization of fused deposition modelling process parameters for dimensional accuracy using I-optimality criterion Measurement", Measurement, vol. 81, pp. 174–196, 2015.

[20] A. P. Gordon, J. Torres, M. Cole, "An approach for mechanical property optimization of fused deposition modeling with polylactic acid via design of experiments", Rapid Prototyping Journal, vol. 22(2), pp. 1-18, 2016.

[21] Maraboina Raju, Munish Kumar Gupta, Neeraj Bhanot, Vishal S. Sharma, "A hybrid PSO–BFO evolutionary algorithm for optimization of fused deposition modelling process parameters", Journal of Intelligent Manufacturing, 2018, https://doi.org/10.1007/s10845-018-1420-0.

[22] Manu Srivastava, Sandeep Rathee, Sachin Maheshwari, T.K. Kundra. "Multi-objective optimisation of fused deposition modelling process parameters using RSM and fuzzy logic for build time and support material", International Journal of Rapid Manufacturing, Vol. 7, pp. 25-42, 2018.

[23] John-Alexander Preuss, Gia Nam Nguyen, Virginia Berk, Janina Bahnemann, "Miniaturized free-flow electrophoresis: production, optimization, and application using 3D printing technology", Electrophoresis, Vol. 42, pp 305–314,2021.

[24] Longxuan Wang, Wenfeng Du, Pengfei He, and Mijia Yang, "Topology Optimization and 3D Printing of Three-Branch Joints in Treelike Structures", J. Struct. Eng., Vol. 146(1), pp. 1-14, 2020.

[25] P. Kumar, C. Schmidleithnery, N. B. Larseny, and O. Sigmund, "Topology Optimization and 3D-printing of Large Deformation Compliant Mechanisms for Straining Biological Tissues", Structural and Multidisciplinary Optimization, Vol. 2, pp. 1-23,2020.

[26] Qinhong Wei, Hangjie Li, Guoguo Liu, Yingluo, Yang Wang, Yen Ee Tan, Ding Wang, Xiaobo Peng, Guohui Yang & Noritatsu Tsubaki, "Metal 3D printing technology for functional integration of catalytic system", Nature Communications, Vol. 11, pp. 1-8,2020.

[27] Jiwoon Jeong, Hyein Park, Yoojeong Lee, Jihye Kang and Jaehoon Chun, "Developing parametric design fashion products using 3D printing technology", Creative Commons Attribution 4.0 International License, Vol. 8, pp. 1-25,2021.

[28] A. E. Tontowi, L. Ramdani, R. V. Erdizon, D. K. Baroroh, "Optimization of 3D-Printer Process Parameters for Improving Quality of Polylactic Acid Printed Part", International Journal of Engineering and Technology, Vol. 9 No. 2, pp. 1-13, 2017.