International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-6 Issue-6, August 2017

Study on Design and Manufacture of 3D Printer based on Fused Deposition Modeling Technique

Ngoc-Hien Tran, Van-Cuong Nguyen, Van-Nghia Nguyen

Abstract: Additive manufacturing (AM) known as 3D printing has been applied for applications in different fields such as aerospace, automotive, biomedical, and energy industries. Currently, with the rapid growth of this technology, there are a large number of 3D printing methods in the market. Each method has its own advantages, applications, and limitations. Materials used for printing also are classified into groups such as polymers, metals, ceramics, and cermets. Along with research on new materials, new printing technologies, 3D printers are more widely applied. For education field in universities, rapid prototyping from 3D printing enables to build 3D models for graphic design and rapid prototyping courses. On the basis of inheriting the available research for training in universities, the authors propose the design and manufacture of 3D printers using FDM printing method. This paper presents the results of design and fabricating 3D printer. The printing test results have demonstrated the functionalities of the designed machine.

Index Terms: 3D printer, FDM, additive manufacturing, rapid prototyping, ABS, PLA.

I. INTRODUCTION

In the field of modern manufacturing, computer aided design (CAD) systems, computer aided process planning (CAPP), computer aided manufacturing (CAM) programming, and computer numerical control (CNC) are widely applied. Figure 1 shows a closed loop from design to manufacture. In the traditional strategy, from 3D CAD model design to CAM programming to have G-code, then machining on the CNC machines to create products. Different from this traditional method, that is reverse engineering and rapid prototyping. Reverse engineering (RE) [1,2] is a closed loop between product design and product creation. RE includes analytical steps to obtain information about the product that is available such as information on functionalities, geometry, materials. Then proceed to restore the CAD model for detail or develop into a new 3D model. Finally, the 3D printer or CNC machine is used to make the product. 3D printing is a rapid prototyping (RP) technology [3,4] in which the product is made up of printing layers. There are many different printing methods available today. Some popular printing methods are selective laser melting (SLM), fused deposition modeling (FDM), direct metal laser sintering (DMLS).

Manuscript published on 30 August 2017.
* Correspondence Author (s)
Ngoc-Hien Tran, Faculty of Mechanical Engineering, University of Transport and Communications, Hanoi, Vietnam, E-mail: ulsanuni@gmail.com
Van-Cuong Nguyen, Faculty of Mechanical Engineering, University of Transport and Communications, Hanoi, Vietnam, E-mail: nguyencuong@utc.edu.vn
Van-Nghia Nguyen, Faculty of Electrical and Electronic Engineering, University of Transport and Communications, Hanoi, Vietnam, E-mail: nguyennghia.nh@gmail.com

Most materials can be used to create 3D printing products. The material can be in liquid, powder or solid form [5]. This technology is currently developing and refining, which can create plastic to metal products. In those applications, for education in universities [6], 3D models for training are focused on. Figure 2 shows some 3D models as the gearbox created by 3D printers for mechanical training.

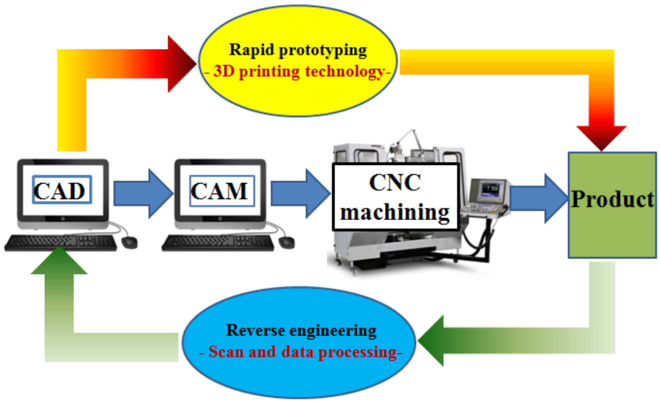

Fig. 1 A closed loop from design to manufacture with RE and RP

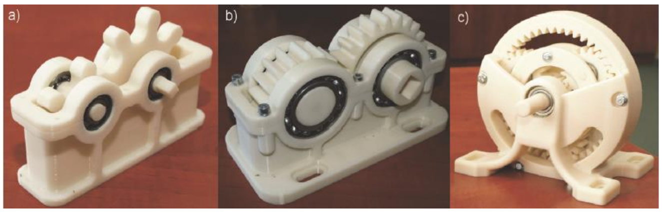

Fig. 2 Gearbox with parts fabricated by 3D printing [4]

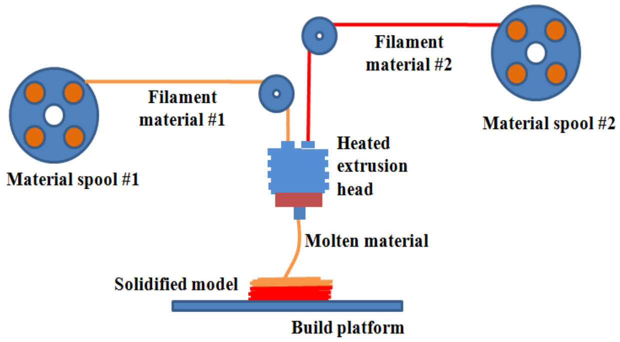

Fig. 3 Mechanism of fused deposition modelling

This paper presents the method of designing and manufacturing the 3D printer according to FDM printing technology (3D-FDM). The test results of the 3D printing process with ABS, PLA materials achieve the geometric accuracy of the printed product.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

Figure 3 shows the principle of FDM printing with two different color printing materials. Using the method of extrusion of thermoplastic materials based on the principle of melting plastic fibers is deposited through a thermal nozzle on a surface. The nozzle movement is controlled according to the 3D data supplied to the printer. Each layer after settling will solidify and bond to the previously printed layer [4,5,7].

II. LITERATURE REVIEW

3D printing is an advanced prototyping technology. Commercial printers are produced not only by companies such as 3D systems, Stratasys, Z Corporation [8-10] but also by universities such as Cardiff University in the UK. In the auxiliary manufacturing laboratory - Cardiff University, researches on printers for plastic and metal products have been studied since the 1990s [11,12].

Currently, with the rapid growth of AM technology, there are a large number of 3D printing methods in the market. Selection of an appropriate method for a printed object is a difficult decision in consideration of the interactions between the quality, properties, cost, build envelope, build time and so on. In the literature, the knowledge based systems have been proposed to have fast response to users which 3D printing method is suitable for a specific application.

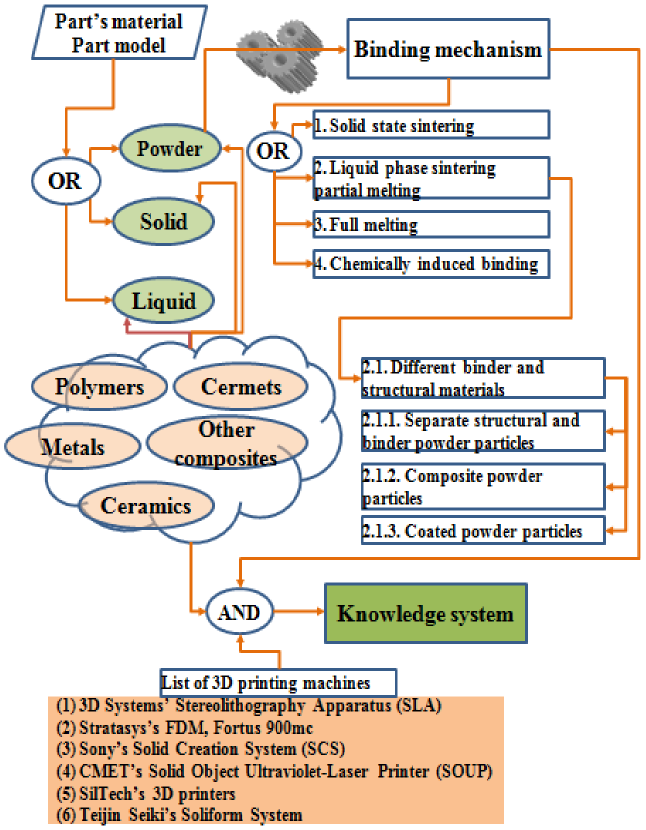

Fig. 4 Classification of 3D printing methods

To carry out this research, materials, printing method, and printing machine ability are analyzed and classified for developing the knowledge system as shown in Figure 4 [13]. Materials used for printing are classified into groups such as polymers, metals, ceramics, and cermets. In each group, materials are classified into types such as powder, solid, and liquid. For applications with plastic materials such as ABS, PLA in filament form, FDM is a suitable 3D printing method. Resent researches focus on evaluation of the quality of the FDM and applications of FDM for medical field [14]. For developing and refining the FDM technique, many vendors not only supply different AM systems to the market but also support the open source for users to develop the control system for specific applications [15]. In consideration of the printed part's quality with FDM technique, evaluation of open source as well as material properties have been carried out [16,17]. One of important applications of the FDM technique is for education field with graphic design and rapid prototyping courses [6].

The paper aims to present the results of the design and manufacture of the 3D printer with FDM technique. This research enables user to deeply understand about the FDM technique which supports well for education in universities as well as for researches on methods to improve the printed part's quality.

III. SYSTEMATIC PROCEDURE FOR DESIGN AND MANUFACTURE OF THE 3D-FDM PRINTER

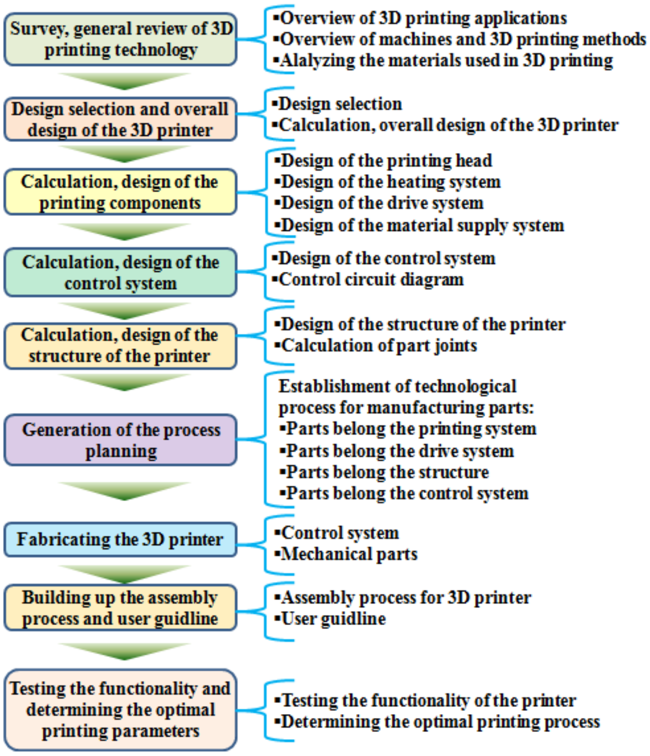

Fig. 5 Steps for design and manufacture the 3D-FDM printer

The process of designing and manufacturing 3D-FDM printers is shown in Figure 5. From the survey and overview of 3D printing technology, the authors selected the design and overall design of the 3D printer based on analysis of existing designs such as Flash Forge, Ultimaker, DeltaRostock, and Rerap Prusa. Components of the 3D-FDM printer such as printing parts, control system, frame structures are calculated and designed. On that basis, the machining process planning, manufacturing parts, and assembling parts and components into the whole machine are carried out.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-6 Issue-6, August 2017

Experiments on the 3D-FDM printer are carried out to evaluate the functionality of the 3D-FDM machine.

IV. DRIVER SYSTEM OF THE 3D-FDM PRINTER

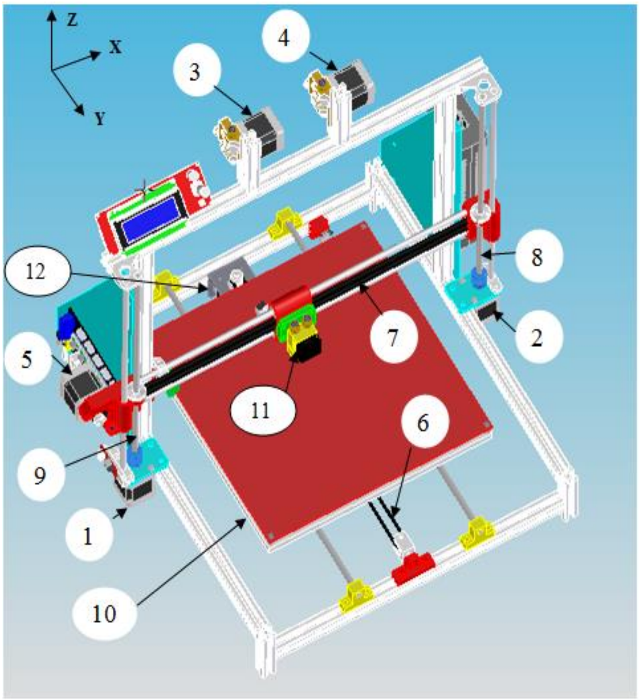

Fig. 6 Driver system for printing process

Figure 6 illustrates the 3D-FDM machine's driver system. The motors (described by 1 and 2) drive the printing head (described by 11) to translate up and down along the Z axis through screws and shafts (described by 8 and 9). The printing head is driven to translate along the X axis by the motor (described by 5) through the belt conveyor (described by 7). The build platform (described by 10) translates along the Y axis using the motor (described by 12) through the belt conveyor (described by 6). The motors (described by 1, 2, 3, 4, 5 and 12) are NEMA 17 42H42HM-0504A-18 motors. The motors (described by 3, 4) are used to drive the roll of plastic material for the printing head.

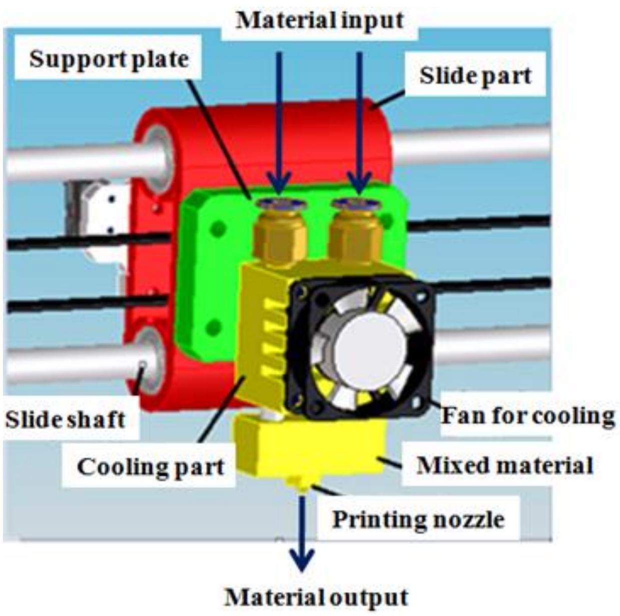

Fig. 7 Printing head of the 3D-FDM printer

The machine is designed to have a printing head moving translation along the X, Z axis. The build platform with the heat transfer table moves along the Y axis. To calculate the next parts of the 3D-FDM printer, the input parameters for design process include ABS, PLA materials, maximum printing size 310x310x250 mm, printing thickness between 0.1 mm and 0.5 mm.

Figure 7 shows the printing components including the printing head, heating material, and the cooling unit to ensure the printing head temperature. The printing unit is mounted on the rack and slide on the guide shaft to perform X-axis motion for printing. Figure 8 shows the material supply system including the motor for driving the filament material, rollers, and material supply components. The NEMA 17 42H42HM-0504A-18 is used to drive the material roll.

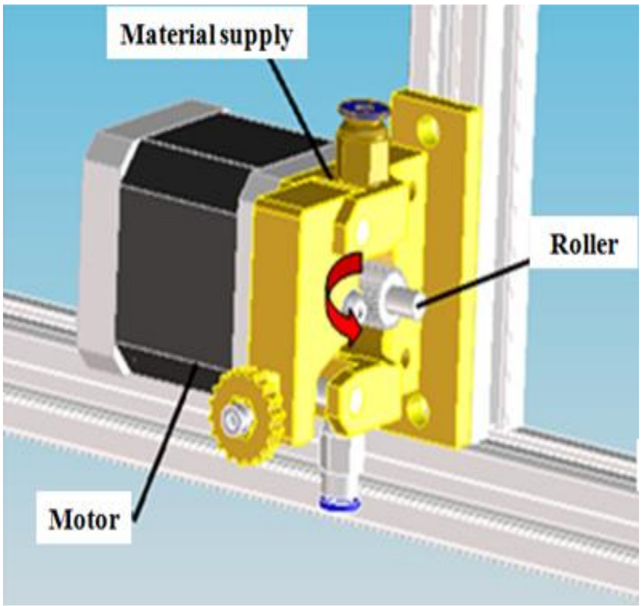

Fig. 8 Material supply system for the 3D-FDM printer

V. CONTROL SYSTEM OF THE 3D-FDM PRINTER

Figure 9 shows the 3D-FDM printer's control system. The control program from computer is transferred to the MKS Gen V1.4 microcontroller via the USB port. The motors driving the X, Y, Z axes, the position sensors, and the temperature display are connected to the MKS Gen V1.4 microcontroller as shown in Figure 10.

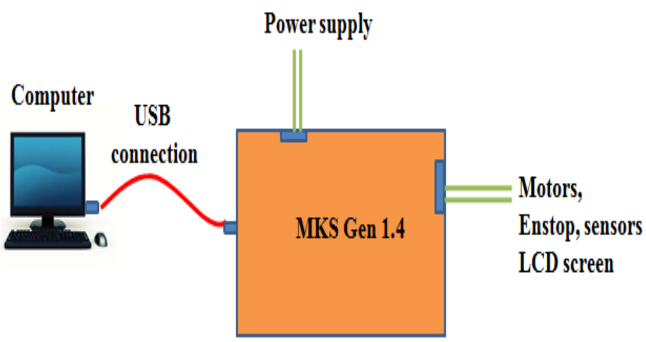

Fig. 9 Control system of the 3D-FDM printer

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

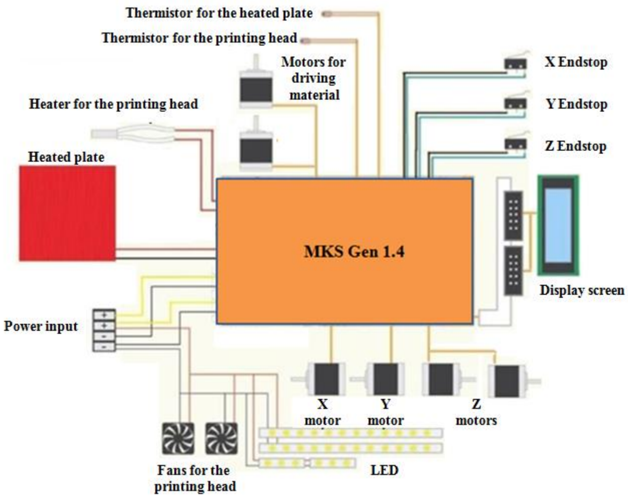

Fig. 10 Connection of MKS Gen 1.4 to control devices

VI. MODEL OF THE MANUFACTURED 3D-FDM PRINTER

Figure 11 shows the structure of a 3D printer designed and manufactured. The Marlin software was chosen as the 3D printing driver software. Marlin is an Arduino-based program for 3D printing controllers using the Atmel's AVR microcontrollers. For each design of the 3D printers, it is necessary to set the following information: information of the control circuit; printer name; number of plastic extrusion; source type; temperature sensor; set up the extruder temperature stabilization; minimum allowable temperature; maximum allowable temperature; power supply for heat table; set up to prevent temperature problems for the printer; set the print area size; and set up the LCD controller.

Repetier-Host V1.6.2 software is used to create G-code for 3D printer. The parameters on the Repetier-Host software must be properly installed with the 3D printer to be used.

The specifications of the 3D-FDM printer are as follows:

- 3D printer with FDM printing technology;
- Printing materials: ABS, PLA plastics;
- Maximum product size: 310x310x250mm;
- Printing thickness: 0.1 ÷ 0.5 mm.

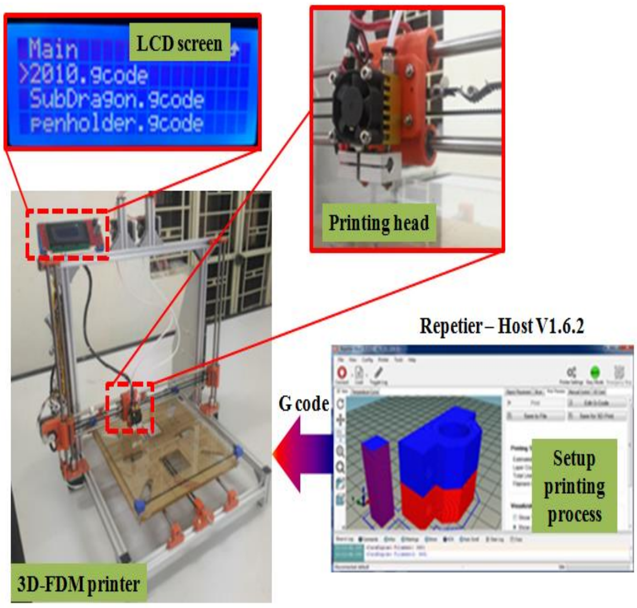

Fig. 11 Model of the manufactured 3D-FDM printer

VII. TESTING THE FUNCTIONALITY OF THE 3D-FDM PRINTER

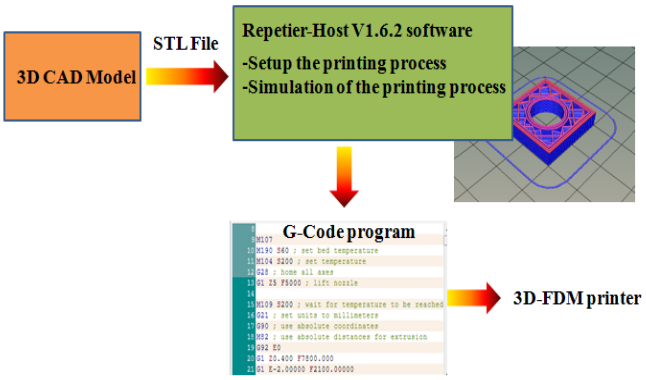

Fig. 12 Steps for printing process on the 3D-FDM printer

To evaluate the machine's functionality, the printing process test was carried out with ABS material. The step-by-step process of an experimental print is shown in Figure 12 [18]. Table 1 shows the printing parameters for 5 different printing tests. The size of the printed part is 50x50x30mm. The printing results are shown in Figure 13. The 3D-FDM printer ensures the geometry precision, smooth printing surface, not warped.

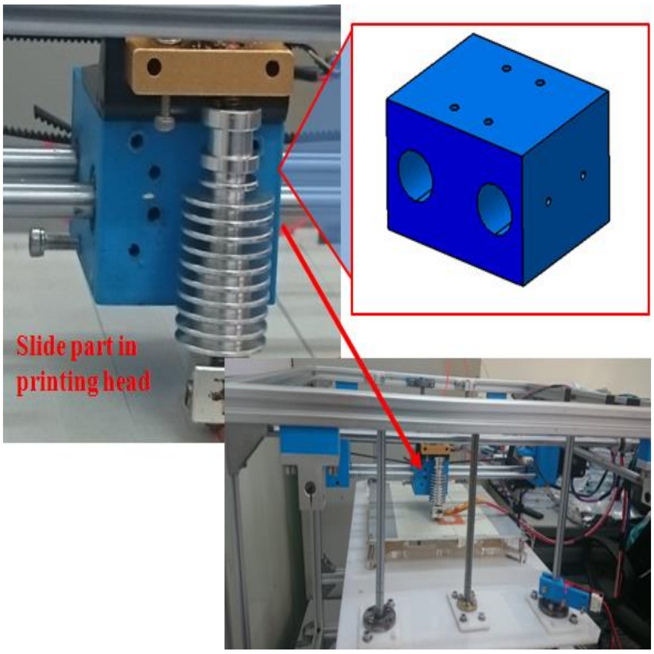

Fig. 14 Parts of the printing head printed by the 3D-FDM printer

The 3D-FDM printer works well on the basis of the above experimental results. The printed products ensure the requirements of geometric precision as well as surface smoothness. With that result, some parts were printed by the 3D-FDM printer. Figure 14 shows the printing head parts printed by the 3D-FDM printer with ABS material replacing the metal parts. Figure 15 shows the gear parts of the ABS material printed by the 3D-FDM printer.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

Table 1: Printing Parameters for Five Samples

Printing parameters	Sample #1	Sample #2	Sample #3	Sample #4	Sample #5
First Layer height (mm)	0.4	0.2	0.2	0.2	0.2
Layer height (mm)	0.3	0.3	0.3	0.15	0.2
Perimeters	3	3	6	3	4
Solid layer (Top)	3	3	10	8	10
Solid layer (Bottom)	3	3	10	8	10
Fill density (%)	20	40	5	10	10
Fill pattern	Zigzag	Zigzag	Zigzag	Zigzag	Zigzag
Top/Bottom fill pattern	Zigzag	Zigzag	Zigzag	Zigzag	Zigzag
External Perimeter (mm/s)	60	60	60	60	30
Small Perimeter (mm/s)	15	15	15	15	15
Infill (mm/s)	80	80	80	80	40
Solid infill (mm/s)	20	20	20	20	20
Top solid infill (mm/s)	15	15	15	15	15
Support material (mm/s)	60	60	60	60	60
Bridges (mm/s)	60	40	40	40	20
Gap fill (mm/s)	20	20	20	20	20
Travel (mm/s)	130	130	130	130	130
Filament diameter (mm)	1.75	1.75	1.75	1.75	1.75
Extrusion multiplier	1	1	1	1	1
Extruder/Bed First (^{0}C)	200/60	200/60	200/60	200/60	200/60
Extruder/Bed Other (^{0}C)	195/60	195/60	195/60	195/60	195/60

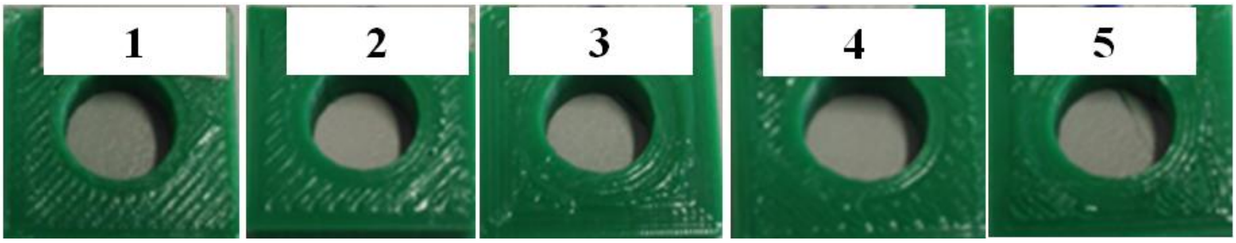

Fig. 13 Samples of the Expremental Printing

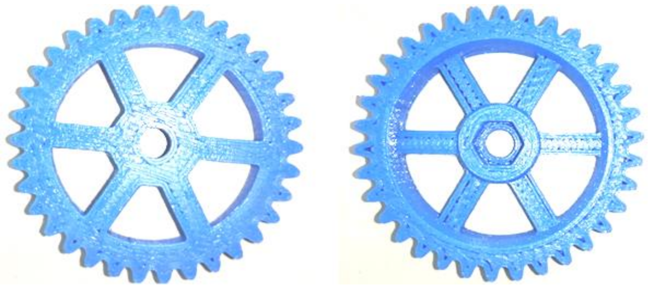

Fig. 15 Gears printed by the 3D-FDM printer

VIII. CONCLUSIONS

The 3D-FDM printer has been designed and manufactured. The experimental printing process with ABS material for precision printing in geometric dimensions ensures that the machine meets the technical specifications required. Some ABS plastic parts assembled on the 3D-FDM printer have been printed to replace some metal parts. This paper presents the results of the design and manufacture of the 3D printer using the FDM printing method which achieves the required technical features. The optimum printing parameters to ensure product quality for different plastics will be carried out as the further research.

ACKNOWLEDGMENT

This work was funded by Vietnam Ministry of Education and Training. [Grant number: B2016-GHA-06].

REFERENCES

1. Vinesh Raja and Kiran J. Fernandes, Reverse Engineering, Springer, 2008.
2. G. Baronio, S. Harran, and A. Signoroni, "A critical analysis of a hand orthotics reverse engineering and 3D printing process," Applied Bionics and Biomechanics, vol. 2016, pp. 1-7, 2016.
3. Ali Kamrani and Emad Abouel Nar, Rapid prototyping: Theory and Practice, Springer, 2006.
4. Grzegorz Budzik, "The use of the rapid prototyping method for the manufacture and examination of gear wheels," in Advanced Applications of Rapid Prototyping Technology in Modern Engineering, InTech publisher, 2011.
5. Gideon N. Levy, Ralf Schindel, and J.P. Kruth, "Rapid manufacturing and rapid tooling with layer manufacturing (LM) technologies: State of the art and future perspectives," CIRP Annals - Manufacturing Technology, vol. 52, no.2, pp.589-609, 2003.
6. C.P. de Sampaio, R.M. de O. Spinosa, J. Vicentin, D.Y. Tsukahara, J.C. da Silva, S.L.S. Borghi, and F. Rostirolla, "3D printing in graphic design education: Educational experiences using fused deposition modeling (FDM) in a Brazilian university," In High Value Manufacturing – Bártolo et al. (eds.), pp.25-30, 2014.
7. R.M. Raymond, T.B. Joseph and M.D. Aaron, "Hybrid deposition manufacturing: design strategies for multimaterial mechanisms via three- dimensional printing and material deposition," Journal of Mechanisms and Robotics, vol. 7, pp. 1-10, 2015.
8. http://web.stratasys.com, July, 2017.
9. http://www.3dsystems.com, July, 2017.
10. http://www.zcorp.com, July, 2017.
11. http://www.materialstoday.com, July, 2017.
12. http://www.cardiff.ac.uk, July, 2017.
13. H.S. Park and N.H. Tran, "A decision support system for selecting additive manufacturing technologies," Proceedings of the 2017 International Conference on Information System and Data Mining, pp. 151-155.
14. H. Chen, X. Yang, L. Chen, Y. Wang, and Y. Sun, "Application of FDM three-dimensional printing technology in the digital manufacture of custom edentulous mandible trays," Scientific Reports, pp. 1-6, 2016.
15. http://www.reprap.org, July, 2017.
16. 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.
17. S.H. Kochesfahani, "Improving PLA-based material for FDM 3D-printers using minerals (principles and method development)," In *SPE ANTEC, Indianapolis*, pp. 1598–1614, May 2016.
18. H.S. Park and N.H. Tran, "Computer aided process planning for 3D printing," *Journal of the Korean Society of Manufacturing Technology Engineers*, vol. 24, no. 2, pp.148-154, 2015.

Ngoc-Hien Tran received the B.Sc. degree from University of Transport and Communications and M.Sc. degree in Mechanical Engineering from Hanoi University of Technology, in 2001 and 2007, respectively, in Vietnam. He received his Ph.D. degree in Mechanical Engineering from Ulsan University in Korea in 2011. Currently, he is an associate professor at the Faculty of Mechanical Engineering, University of Transport and Communications, Hanoi, Vietnam. His research interests include CAD/CAM/CAE, Intelligent Manufacturing System, and Additive Manufacturing. His researches are published in some ISI Journals, and Conference Proceedings.

Van-Cuong Nguyen received the B.Sc. degree from University of Transport and Communications in 2007 in Vietnam. He received his Ph.D. degree from Tula State University in Russia in 2013. Currently, he is a lecturer at the Faculty of Mechanical Engineering, University of Transport and Communications, Hanoi, Vietnam. His research interests include CAD/CAM/CAE and manufacturing technology.

Van-Nghia Nguyen received B.S. degree from University of Transport and Communications, Hanoi, Vietnam (UTC) in 1995, M.S. degree in 2002, and received Ph.D. degree in Vietnam Institute of Electronics, Informatics and Automation in 2006. He is currently a lecturer of faculty of Electrical and Electronic Engineering, UTC. His research interests include power electronic, measurement technique and technical diagnosis.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)