한국기계가공학회지, 제18권, 제7호, pp.83～89(2019.07) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 18, No. 7, pp.83~89(2019.07) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2019.18.7.083

Ceramic Direct Rapid Tooling with FDM 3D Printing Technology

Geun-Sik Shin*, Hyun-Kyu Kweon**,#, Yong-Goo Kang*, Won-Taek Oh**
*Department of Mechanical Design Eng., Kumoh National Institute of Technology,
**Department of Mechanical System Eng., Kumoh National Institute of Technology

FDM 3D Printing 기술을 응용한 직접식 세라믹 쾌속툴링

신근식*, 권현규**,#, 강용구*, 오원택**
*금오공과대학교 대학원 기계설계공학과, **금오공과대학교 기계시스템공학과,
(Received 28 May 2019; received in revised form 11 June 2019; accepted 27 June 2019)

ABSTRACT

In the conventional casting and forging method, there is a disadvantage that a mold is an essential addition, and a production cost is increased when a small quantity is produced. In order to overcome this disadvantage, a metal 3D printing production method capable of directly forming a shape without a mold frame is mainly used. In particular, overseas research has been conducted on various materials, one of which is a metal printer. Similarly, domestic companies are also concentrating on the metal printer market. However, In this case of the conventional metal 3D printing method, it is difficult to meet the needs of the industry because of the high cost of materials, equipment and maintenance for product strength and production. To compensate for these weaknesses, printers have been developed that can be manufactured using sand mold, but they are not accessible to the printer company and are expensive to machine. Therefore, it is necessary to supply three-dimensional casting printers capable of metal molding by producing molds instead of conventional metal 3D printing methods. In this study, we intend to reduce the unit price by replacing the printing method used in the sand casting printer with the FDM method. In addition, Ag paste is used to design the output conditions and enable ceramic printing.

Keywords : 3D Printer(3차원 프린터), Fused Deposition Modeling(FDM), Ag Paste(Ag 페이스트), Direct Rapid Tooling(직접식 쾌속툴링), Liquid Type Extruder(액상형 엑추레이터)

1. Introduction

Many companies are costly in production of small quantities and prototypes, and production costs are increasing more than necessary. In order to overcome these drawbacks, we have met the customer needs with the 3D Metal Printing Technology[1] capable of manufacturing shapes, but the price and quality are not good. In addition, existing metal 3D printers are difficult to adopt easily in SMEs when the initial

Corresponding Author : hyunkyu125@gmail.com
Tel: 054-478-7347, Fax: 054-478-7319

investment cost is taken into consideration because the output strength, material, and maintenance cost are high. Therefore, there is a need for a 3D casting printer technology that can indirectly produce metal molds by producing casting molds, rather than directly molding products through existing Metal 3D printers. In fact, EOS[2] and Voxeljet[3] have devised a 3D printing technique capable of casting molds using lasers or adhesives. In addition to Europe, Koiwai in Japan and domestic corporations in Sentrol have used 3D cast printers. However, since the reliability and strength of the molding machine described above are the same as those of a general mold, they are expensive in terms of cost, so products that can be manufactured without lowering the unit cost and maintenance cost and being small and medium-sized enterprises are required.

This study is to form die casting products by combining FDM(Fused Deposition Modeling) method instead of SLS(Selective Laser Sintering)[4] or 3DP(3 Dimensional Printing) which is the basic method of die casting 3D printer, and to find the optimal value through the experiment.

2. Direct Rapid Tooling

2.1 Conventional indirect rapid tooling

The casting method that is used nowadays has been made by modeling the shape after making the wood directly by Indirect rapid tooling. As 3D printing technology becomes popular, it is possible to fabricate mold pattern by 3D printing molding instead of manual work. Fig. 1 is a schematic diagram of indirect rapid tooling. In this case, because of the process for pattern making, there is one more process than Direct Rapid Tooling, and even if printing is connected due to lowering of unit price and productivity, there is a slight decrease in efficiency.

Therefore, we are going to reduce the number of processes by making molds or molds themselves instead of making the shape of the wooden shape by using the 3D printer and modifying it with the direct type rapid tooling instead of the indirect type.

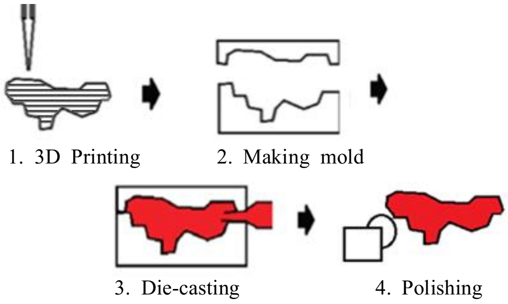


Fig. 1 Indirect rapid tooling using Normal 3D printer

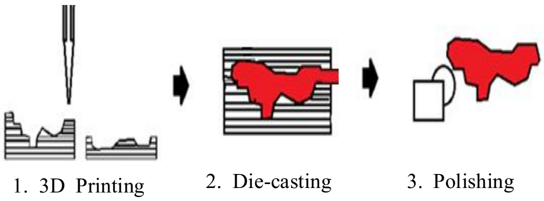


Fig. 2 Direct rapid tooling using FDM type printer

Fig. 2 describes the process of making a mold using an FDM printer.

2.2 Fused Deposition Modeling 3D printer

The existing 3D printer is FDM or FFF(Fused Deposition Modeling or Fused Filament Fabrication), which is a lamination method in which plastic is melted at high temperature and piled up one layer at a time.

Accessibility is good, the printer itself and the materials used are cheap, so it can be easily obtained by the general public. Also, the usage method is not complicated and 3D printer market is getting bigger. As the interest increases, it is a suitable form to use for education purposes only for sales to general elementary school students and adults. Fig. 3 is a Direct Mendel type 3D printer that is the basis of FDM type[5].

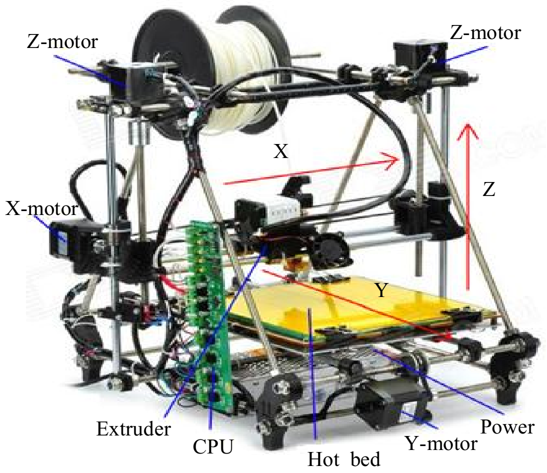


Fig. 3 3D printer model (Mendel i2)

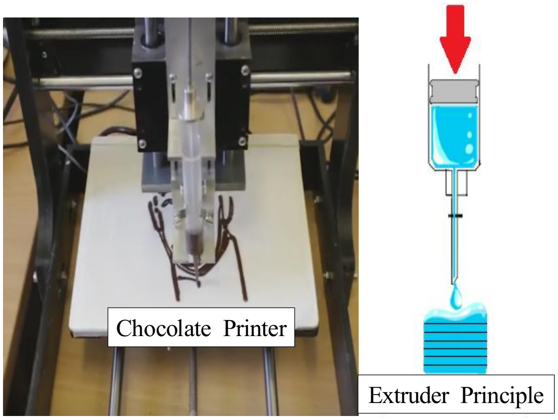


Fig. 4 Liquid type extruder

2.3 Mechanism of the extruder

In the case of general FDM type printer, extruder which supplies material is extrusion type which can be used only for plastic type thermoplastic materials by pushing down the threaded plastic of filament type in the extrusion type. However, since the product used in this study is a ceramic material, it is manufactured by the extrusion molding method that is using the liquid material compressed by the piston in the Fig. 4.

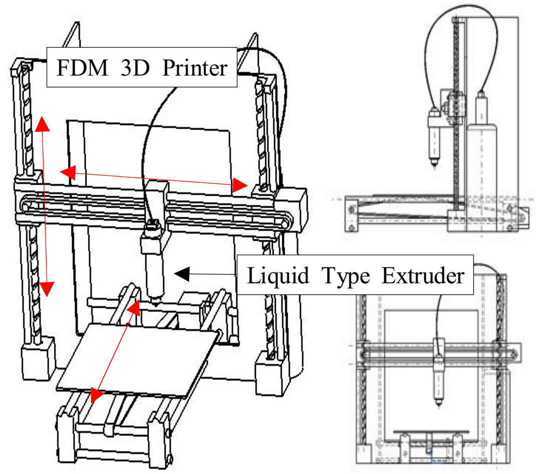


Fig. 5 Drawing of body and liquid type extruder

This method is similar to conventional chocolate printers likes 'A Study on Development of Three-Dimensional Chocolate Printer' of Kim's[6] and 'study on the convergence between ceramic product design and 3D printing technology -Ceramic product prototype development using the 3D printer' of Choi's[7].

3. Experiment Results

3.1 Setup of experiment equipment

As shown in Fig. 5, the liquid extruder described above is manufactured by using the actual FDM type printer to output the liquid material rather than the filament to form the liquid material.

For the extruder production of material injection, the method for ceramic material mold is made by press-fit type which is similar to extruder of existing chocolate printer. Since the output speed and shape forming are determined by the friction and viscosity of the inner wall of the pressurized cylinder, the liquid type material is manufactured so that the cylinder can be manufactured as a cartridge type and replaceable.

3.2 Material selection for experiment

The optimum output for product formation is derived through test results through iterative experiment considering the experimental variables that may affect the output. At this time, to optimize the layer by layer lamination shape, the optimal data of 2D state is extracted by using Ag paste, and then product formability through casting of aluminum is evaluated by using liquid type clay to be used in the 3D state.

Ag paste is 60 ~ 70% of silver, and ELCOAT P-100 is used in composition ratio of acrylic resin 5 ~ 15% and ethyl lactate 20 ~ 30%. In this case, the viscosity is 23dP (230cP at 25 °C), the toothpaste is 32dP (1dP = 0.1dPa.s), and the chocolate source is similar to 28dP. Table 1 shows the properties of the Ag paste to be printed in 2D form.

And the results of the experiment using toothpaste are shown in Fig. 6.

3.3 Material output setting

The flow entrapped in the cylinder must have the same flow rate by the law of mass conservation. It is defined by the same volume by the inlet & outlet of the syringe and can be expressed as shown in Fig. 7. And the following equation is satisfied.

$$A_1 l_1 = A_2 l_2 \qquad (1)$$

Where, A_1 is Syringe Area, A_2 is Syringe Aperture, ℓ_1 is Syringe Inner Length and ℓ_2 is Extrusion Material Length. It is summarized as the following:

$$l_1 = \frac{(\pi \times r_2^2) \times l_2}{(\pi \times r_1^2)} \quad (A_1 = \pi \times r_1^2, A_2 = \pi \times r_2^2) \qquad (2)$$

Where, r_1 an,d r_2 are the syringe inner radius and caliber radius for Inlet (1) and Outlet (2). In this way, the amount of material according to the output size can be calculated in advance, and the material can be consumed according to the capacity of the syringe. In addition, the output is not completed due to lack of materials, and the extruder can prevent the breakage of the mechanism due to idling of the motor.

Table 1 Typical properties of P-100

Division	Figure
Temperature range	-30 ℃ ~ 200 ℃
Importance(25℃)	2.3 ~ 2.5
Viscosity(25℃)	230
Drying time	25 ℃ × 12H, 150 ℃ × 0.5H

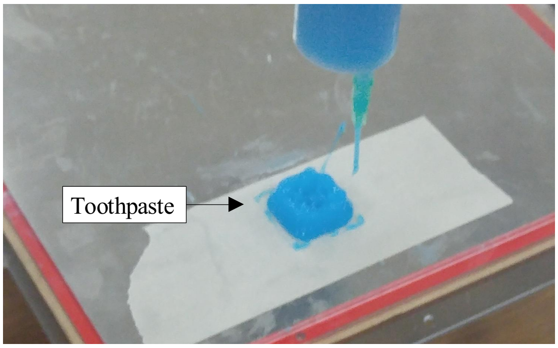


Fig. 6 Toothpaste test (Viscosity : 32dP)

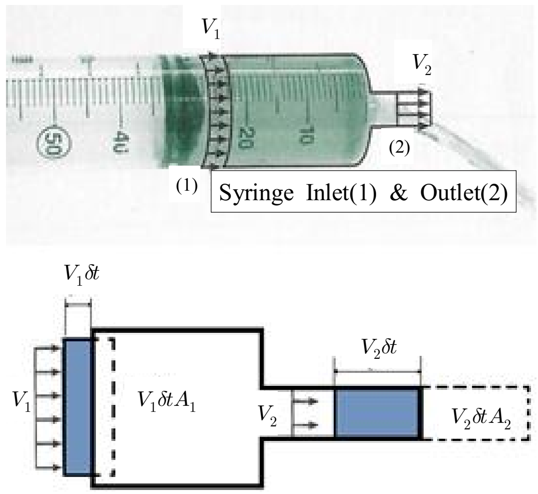


Fig. 7 Steady flow in or out

4. Results and Discussion

4.1 Ag paste & ceramic extruder

For the two kinds of experiment, a press-fit type extruder made in the shape of a cartridge and it is tried to experiment according to the material change. In order to obtain optimal data for each layer, we used Ag paste to confirm that it is similar to the input data for each line. Based on the 2D data, the viscosity of Ag paste and the liquid phase clay (3D shape), the formability of each variable was evaluated.

4.2 2D molding of Ag paste

Before forming the ceramic mold, parameters and factors are determined to obtain the lamination data for each line. One of the most important factors in printing is flow and layer height. By these two factors, the accuracy of 2D printing by one line at output was checked. In order to find the optimum value by two factors when measuring the line width of 2 mm in the same modeling, the width of the printed 2D molding is measured with an optical microscope.

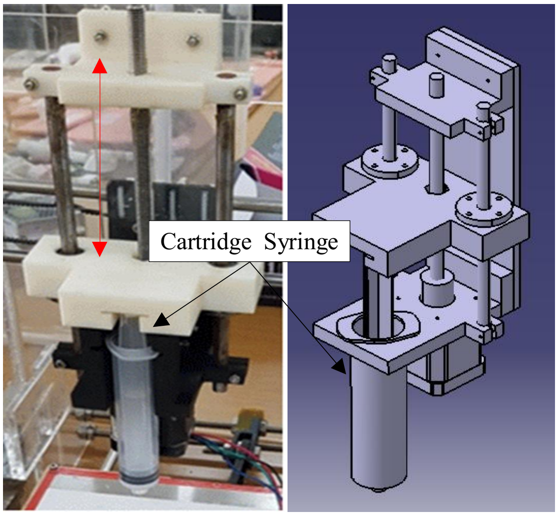


Fig. 8 Cartridge type extruder

Fig. 8 is a model of an extruder with a 20 ml cartridge using a 0.5 mm nozzle. After the wiring test as shown in Fig. 9, 10 with a ink similar to the viscosity of the Ag paste, the data to be the experimental standard is determined by the similar viscosity according to the concentration. Then, through the optical microscope, the factor value close to the actual input value width of 2mm (2000 μm) is found through the Fig. 11, 12 and Table 2.

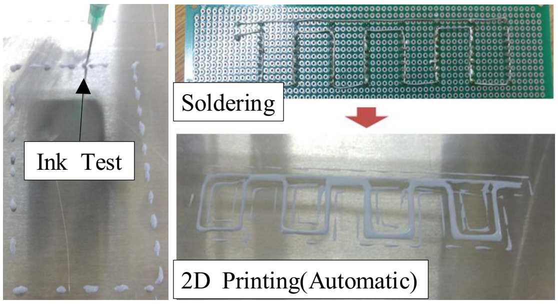


Fig. 9 Water sensitive test method (wiring)

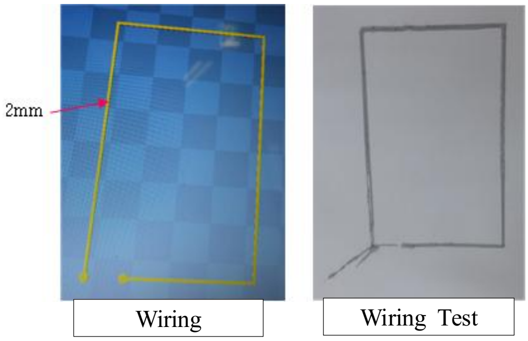


Fig. 10 Estimated and actual printed 2D model

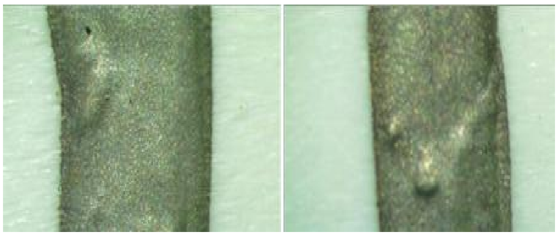


Fig. 11 Ag paste measurement (×20)

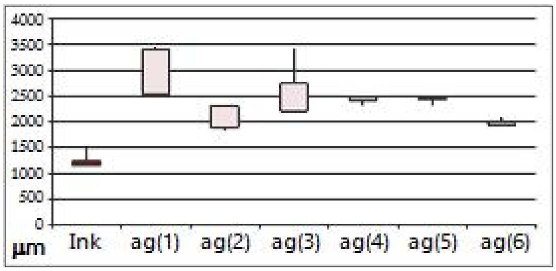


Fig. 12 The deviation of the electrode width and the average value

Table 2 Error and optimum value by factor

Material	Layer Height (mm)	Flow (%)	Measures (mm)	Error (%)
Ink	0.4	24	1279	56.37
Ag(1)	0.6	24	2981	32.91
Ag(2)	0.6	23	2026	1.28
Ag(3)	0.4	22	2704	26.04
Ag(4)	0.4	21	2398	16.60
Ag(5)	0.4	20	2413	17.12
Ag(6)	0.4	20	2003	0.15

4.3 3D molding of ceramic materials

It is found that the accuracy is increased by the optimum value of the parameters according to the experimental variables through the 2D molding. Based on this, we make 3D molding based on the same flow and layer height. In particular, considering the particle size, we try to laminate through 2 mm diameter nozzle instead of 0.5 mm diameter. In this way, the flow and layer height are increased similarly to make 3D data through 20% flow and layer height between 1 ~ 2 mm. Ceramic mold can be done by these conditions as shown in the Fig. 13. At this time, PLA is made with the FDM printer, and the clay and grease made with the liquid type extruder.

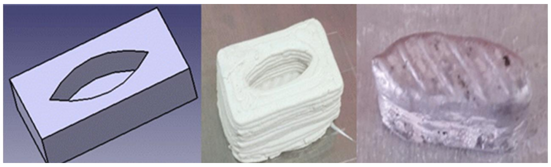
After then, the optimum value of the printout can be shown as shown in Table 3 and molded as in Fig. 14 for A6061 casting. As shown in Fig. 15, the length of the output was measured of 'a' (vertical length), 'b' (horizontal length), and 't' (thickness) using a vernier calipers. As a result, we can be obtained as shown in Table 4.

Printing Sample			
Material	PLA	Clay	Grease

Fig. 13 Test box 20×20mm (PLA, Clay, Grease)

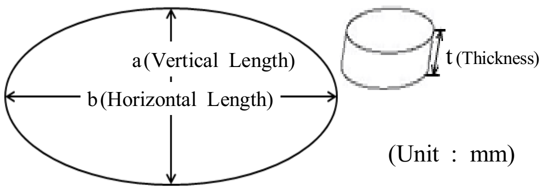
Table 3 Result of prototype (Nozzle Size : 2mm)

Output		Layer height	Flow
	Test 1 (ϕ40mm)	1.5mm	25%
	Test 2 (ϕ40mm)	1.5mm	23%
	Test 3 (ϕ40mm)	1.5mm	22%



1. 3D Modeling 2. Printing 3. Casting

Fig. 14 Casting molds (Model, Mold, Product)



(Unit : mm)

Fig. 15 Measurement of casting molds

Table 4 Comparison of casting results

Object	a (mm)	b (mm)	Thickness(mm)
Modeling	25	12	9
Measures	24.1	10.2	11.1

5. Conclusion

In this paper, a liquid type extruder was designed for direct rapid tooling fabrication such as die casting 3D printer using a liquid type material, which is not a solid form filament. After forming in 2D state using Ag paste, press-fit type output for ceramic printing was performed based on the Printing optimum value, and metal molding was completed with aluminum casting.

1. As the output according to the viscosity increased, the mold ability was affected by the properties of each material. This can be confirmed by ink and Ag paste with similar viscosity.
2. As a result of comparing the flow parameters and the layer heights, which are experimental parameters when the diameter is 0.5 mm through the actual Ag paste, it is confirmed that the error is accurate to 0.15% at flow 20% and layer heights 0.4 mm.
3. When the experiment was performed based on the data values in the Ag paste to obtain the 3D shape, the mold ability was verified through various materials. Particularly, it was possible to roughly select the factor value for the production of the ceramic mold.
4. When molten aluminum of A6061 is injected using a ceramic mold, which is formed in three dimensions, it is formed in a shape similar to 3D modeling. But it shows unstable data about 10% in approximate dimension. This seems to be due to the thermal expansion of the molten aluminum and the thermal deformation of the ceramic due to the high temperature, and in the case of the thickness, the molten liquid phase overflows and the measurement error may have occurred.

References

1. Duda, T., Raghavan Venkat, L., “3D Metal Printing Technology,” IFAC-PapersOnLine, Vol. 49, No. 29, pp. 103-110, 2016.
2. Kang, M. C., Ye, D. H., Go, G. H., “International Development Trend and Technical Issues of Metal Additive Manufacturing,” Journal of Welding and Joining, Vol. 34, No. 4, pp. 9-16, 2016.
3. Nyembwe, K., Mashila, M., van Tonder, P. J. M. , de Beer, D. J., Gonya, E., “Physical properties of sand parts produced using a voxeljet VX1000 three-dimensional printer,” South African Journal of Industrial Engineering, Vol. 27, No. 3, pp. 136-142, 2016.
4. Hwa, L. C., Rajoo, S., Noor, A. M., Ahmad, N., Uday, M. B., “Recent advances in 3D printing of porous ceramics: A review,” Current Opinion in Solid State and Materials Science, Vol. 21, No. 6, pp. 323-347, 2017.
5. Kang, Y. G., Lee, T. W., Shin, G. S., “The Influence of Experiment Variables on 3D Printing using ABS Resin,” Journal of the Korean Society of Manufacturing Process Engineers, Vol. 16, No. 2, pp. 94-101, 2017.
6. Kim, K. E., Park, K., Lee, C. B., “A Study on Development of Three-Dimensional Chocolate Printer,” Journal of the Korean Society for Precision Engineering, Vol. 34, No. 4, pp. 293-298, 2017.
7. Choi, J. H., Kim, U. S., Kim, J. H., No, H. G., Cho, W. S., “Study on the convergence between ceramic product design and 3D printing technology - Ceramic product prototype development using the 3D printer,” Journal of Digital Design, Vol. 13, No. 4, pp. 777-783, 2013.