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Study of 3D Printer for Educational Use

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Abstract

Recently, 3D printer has attracted attention as innovative production machine. Original patent of 3D printing was admitted in 1980 in Japan. Several kind of printing method were developed after the patent was disclosed. Their methods are designated as Additive manufacturing (AM) by ASTM International in 2009. Extrusion deposition method as one of AM is handled easily and price is acceptable for educational usage. Da Vinci 1.0 (XYZ printing Inc.) 3D printer was used in this study. The printing method is gradually expanding in educational user but not yet sufficiently confirmed the performance like accuracy affected by the printing condition. This study was conducted to clarify the influence to accuracy by extruded layer resolution setting (fine or coarse layer) and printing direction. Printing behavior was also observed. From the experimental study, the achieved accuracy limit in some of operating conditions, experienced notice when using the 3D printer and allowable utilizing engineering field was obtained.

***Keywords**:* 3D printer, plastic printing, extrusion deposition method, additive manufacturing.

1. Introduction

The 3D printing method has initially shown in the patent of Kodama [1] in 1980. After that, several 3D printing methods are devised and patented. Since their main patens were disclosed, various application fields from engineering to medicine have been more widely considered. Nowadays, their progress is highly paid attention in expanding application provability. The price of 3D printer is very wide of high and low for the required need. The high price machine above several hundred thousand dollars is for professional and expert. It has high accuracy and is available for many kind of materials. Recently, 3D printer lower than several thousand dollars is appeared for personal or family use. Product experiences using low price machines are extremely increasing by easy usage even if relatively low accuracy. In educational field, 3D printing is regarded as a good training tool for students to have interest in manufacturing. Also it is necessary to grasp the accuracy of 3D printer in engineering. In this study, low price 3D printer (da Vinchi 1.0, by XYZ printing Inc.) so called material extrusion type [2-3] was used.

This study was conducted to clarify the influence to accuracy by extruded layer resolution setting (fine or coarse layer) and printing direction. Printing behavior was also observed. From the experimental study, the achieved accuracy limit in several operating conditions, experienced notice when using the 3D printer and allowable utilizing engineering field are obtained.

2. Outline of 3D Printing Method

"3D printing" is defined as the fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology [4]. Also the process is shown from web translation [5] as a process for making a physical object from a three dimensional digital model, typically by laying down many successive thin layer of a material. The method was designated as additive manufacturing (AM) by ASTM International in 2009. These methods are categorized such a number of processes as binder jetting, directed energy deposition and material extrusion etc. based on printing machines and materials that are used. Each method, by a machine, is restricted to use a couple of materials.

Low price 3D printer is almost the type of the material extrusion method and uses the plastic of ABS (Acrylonitrile Butadiene Styrene) or PLA (Polylactic Acid) as the material. The conceptual process view of this type is shown in Fig. 1. Ejecting molten plastic is supplied from extruder. Extruded plastic is forming the profile on the layer1 according to a designed profile. Then bed is slightly lowered in accordance with the layer resolution setting. The successive thin plastic layer is continuously formed until the configuration is completed. This process is controlled by the software mainly programed by the type of Standard Triangle Language (STL) file format.

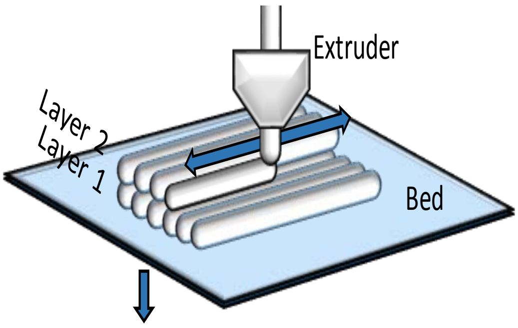

Fig. 1 Conceptual process view of the material extrusion method

3. Employed 3D Printer

System configuration for this study is shown in Fig 2. All components except computer are assembled in the 3D printer. Specification of the Employed 3D printer is Table. 1. Filament of the plastic material (ABS was used in this study) is supplied to the extruder and fused by the heater installed inside which is set in the setting temperature of 220℃ (for ABS). Bed is heated up to 90℃ (for ABS) in the warm up before printing. The bed moves downward in depending on the three kinds of layer resolution setting that is the normal, good and excellent. It seems that the layer resolution setting will influence strongly to the accuracy and printing time of the product. Printing process is automatically controlled by the software of the 3D printer until printing is completed. Operator works are input the shape and dimensions on the software in a computer, and send it to the 3D printer when printing will start.

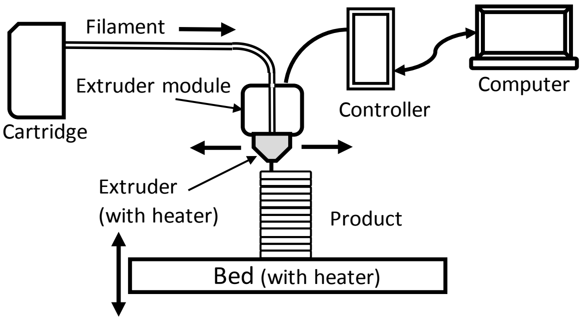

Fig. 2 System configuration of 3D printing

Table. 1 Specification of 3D printer

Model	da Vinch 1.0
Printing technology	Fused filament fabrication (FFF)
Printing head	Single
Maximum build volume	200mm × 200mm × 200mm
Layer resolution setting	Excellent (standard) 0.2mm
	Good (Fast) 0.3mm
	Normal (Ultra fast) 0.4mm
Filament diameter	1.75mm
Nozzle diameter	0.4mm
File type	.stl format, (XYZ software)
Manufacurer	XYZ printing Ltd

4. Test Procedure

Firstly, the main characteristics of the used 3D printer, such as the temperature of extruder and bed, the temperature of extruding material, the diameter and the volume flow rate of filament supplied to extruder were confirmed. Wall temperature of the extruder was measured by laser pyrometer (model: THI-101C, TASCO JAPAN Co., Ltd.), surface temperature of the bed was by ∅1.6 K-type sheath thermocouple and the temperature of extruding material was by K-type element thermocouple with 0.2 mm diameter. Relative measurement points are shown in Fig. 3.

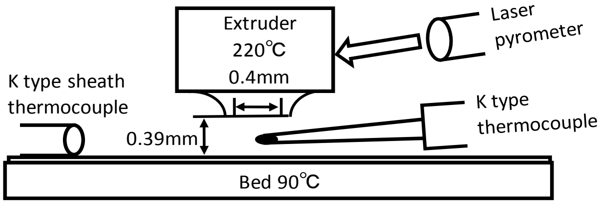

Fig. 3 Temperature measurement position

Each size of the product was measured by the measuring microscope (Model MF, MITUTOYO Co., Ltd.) which was calibrated by reference glass scale of 100 mm length. Room temperature was maintained on 20 ℃.

Test was mainly conducted to clarify the accuracy of the 3D printer when varying the layer resolution setting using sample product as shown in Fig 4. Software of the sample is offered by XYZ printing Co., Ltd., on the website [6].

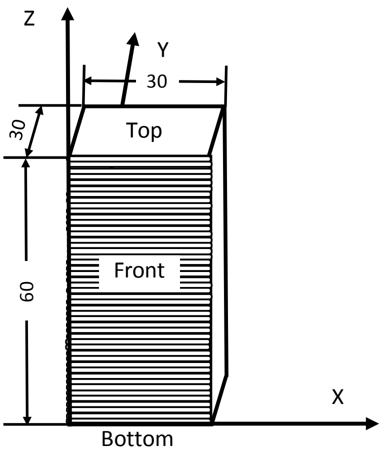

Fig. 4 Dimension of sample product

5. Result and Discussion

5.1 Temperature measurement of each positions

Plastic filament is fused through extruder and flows out from the nozzle of the extruder outlet. After flowing out, plastic material is formed the design profile. In the printing process, the material is quickly cooled and shrunk, and then the volume is reduced a little. It seems to affect the accuracy of the product dimension. Therefore, the temperature of each part was measured.

Temperatures around extruder after warm up are shown in Fig. 5. Printing will start from this temperature condition. Each temperature during printing is difficult to measure because that extruder moves so quickly to follow. Therefore, shrink process is estimated roughly using these values. Temperature of extruding material is approximately 175℃. Bed is heated by heater installed inside bed. Glass plate is set on the bed for easily clean up after removing the product. Temperature of the bed is measured on the glass set on the bed as shown in Fig. 3. It was measured during 20 min after starting the printing. The trend of them is shown in Fig. 6. The difference of the temperature of the bed is within about 10 ℃. It seems that bed temperature is controlled well under 100 ℃ by heater. If the temperature is raised to the melting temperature of ABS over 100 ℃, the bottom of the product is softened and dimension of the product will be affected. The temperature of the extruder surface is supposed to fluctuate largely because of its quick moving. Table 2 shows the average value between 20 min. The temperature of the extruder surface is decreasing gradually because of cooling by surrounded air.

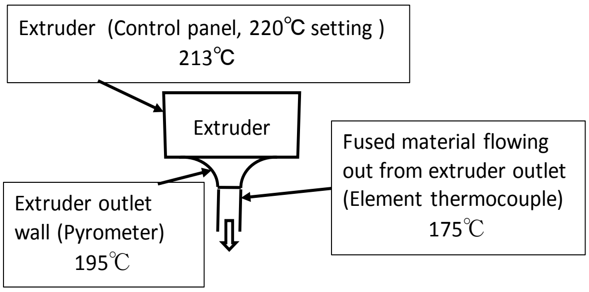

Fig. 5 Temperature around extruder

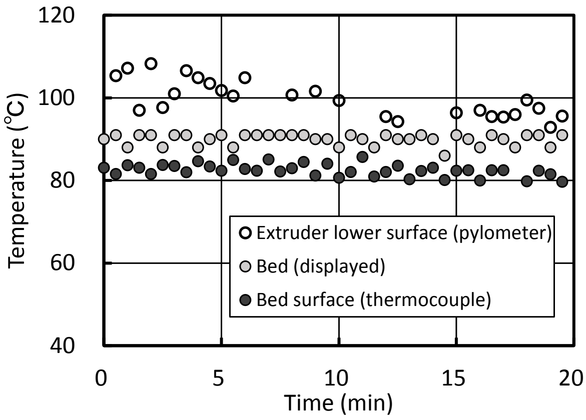

Fig. 6 Temperature of parts

Table. 2 Average temperature of each part

	Extruder surface (pyrometer)	Bed (displayed)	Bed surface (thermocouple)
Average (℃)	100	90	82
Max(℃)	108	91	86
min(℃)	93	86	80

5.2 Printing way and behavior of the extruder

Before printing, glue is painted once or twice on the bed to remove the product easily after printing. Home position of the extruder is set on the right rear side viewing from the front. Printing is started from the home position of the extruder. Firstly, some of the plane layers which have the design profile are quickly formed at the bottom. Following the bottom layers, the bed step down to make the next layer. The extruder prints two or three loops along the outer shape of the product, then prints a hexagonal shape within the outer shape of the product as shown in Fig. 7. The product is not fully filled inside by the plastic material. Similarly, before the final layer of the top position, several layers are formed as a horizontal plane. The volume flow rate of the filament was 1.7 mm^3/s in the excellent condition.

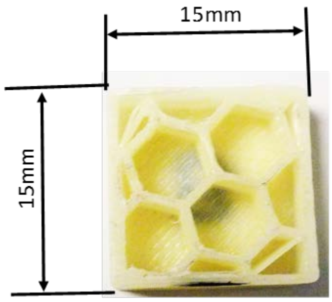

Fig. 7 Cross sectional view from the top side

5.3 Accuracy of the printed product

In order to examine how the layer resolution setting affects to accuracy of the printing, the three setting conditions were selected from the specification of the printer as shown in Table. 1. Used profile of the printing is three-dimensional rectangular shape as shown in Fig. 4. Figure 8 indicates the example of the enlarged layers. When changed layer resolution setting from excellent to normal, measured layer width from the bottom to a length of 10 mm to the top direction (Lz) are shown in Figs. 9 – 11. Summarized data are shown in Table. 3.

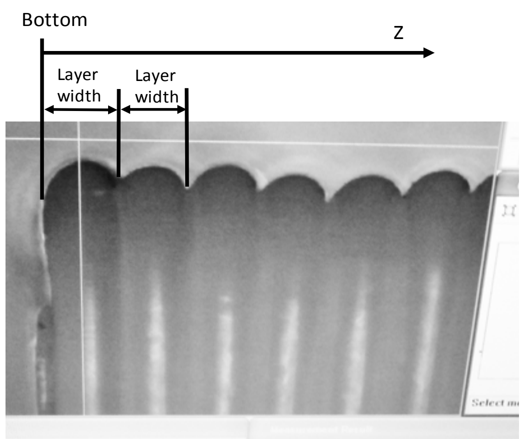

Fig. 8 Enlarged layers photo

Each figure shows that the maximum width appears around Lz of 2 mm which is the length from the bottom. It meets that the printing behavior shifts from a plane shape to a hexagonal shape. Bottom layer width is the smallest in these data, because the self-weight presses the bottom which is heated by the bed during printing. Average width is near the layer resolution setting values as shown in Table. 2. Setting width is realized well in each condition. Standard deviation becomes smaller in the order of normal, good and excellent. It was recognized that the highest accuracy in the layer width was obtained by the excellent condition. And also it is suggested that the relationship between the self-weight and the bed temperature at the bottom layer is important to be improve the dispersion. However the relationship of the temperature and the layer softened is not cleared yet.

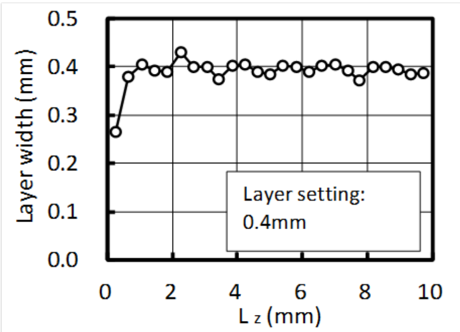

Fig. 9 Layer width in the normal condition

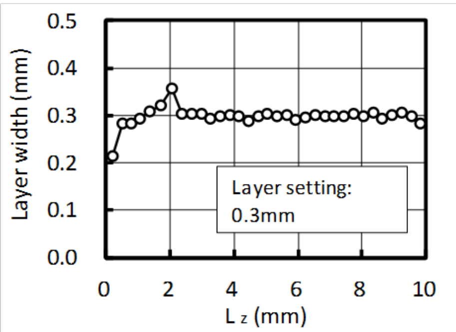

Fig.10 Layer width in the good condition

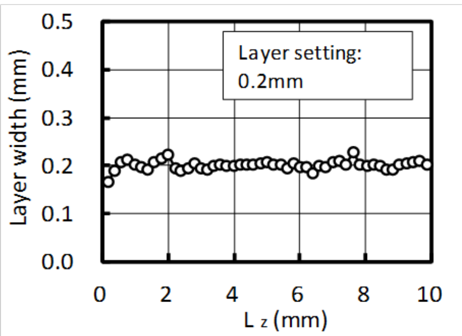

Fig. 11 Layer width in the excellent condition

Designed product is the vertical cube which has the dimension as shown in Fig. 4. It has X-axis length of 30 mm, Y-axis length of 30 mm and Z-axis length of 60 mm. Each axis has 4 sides. The difference obtained by subtracting the design value from the measured value is shown for each axe in Figs.12 - 14.

Table. 3 Summary on the layer width

	Normal (0.4mm)	Good (0.3mm)	Exellent (0.2mm)
Average (mm)	0.39	0.30	0.20
Max. (mm)	0.43	0.36	0.23
Miv. (mm)	0.26	0.21	0.17
Std.Dev (mm)	0.029	0.019	0.009

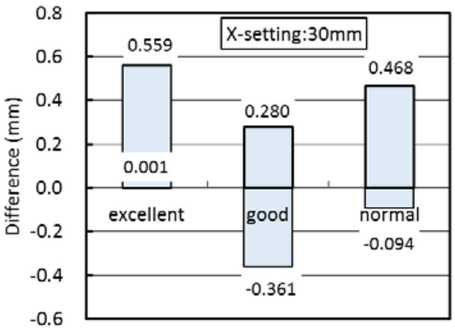

Fig. 12 Difference (X-axis)

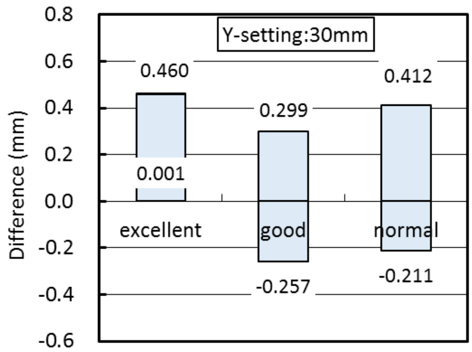

Fig. 13 Difference (Y-axis)

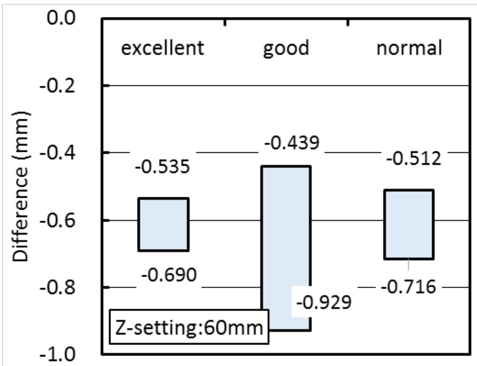

Fig. 14 Difference (Z-axis)

From Fig.12 - 13, negative value was obtained for the good and normal conditions. On the other hand, the positive value was obtained only in the excellent condition. Considering the product in manufacturing, negative value is undesirable because of cause to the defective product. The maximum difference was 0.6 mm in the excellence condition. Positive difference is able to modify into the design value by machining. From Fig. 14, negative value was obtained in all of conditions in Z-axis direction. Maximum difference in the excellence condition was about 0.7 mm. It cannot assert that these negative values are caused by the shrinkage property of the plastic material. Because in the X and Y direction, reduced dimension caused by shrinkage is not appearing clearly. Therefor additional measurement is necessary. Considering apply the 3D printer to injection mold, shrinkage property is the important factor when designing.

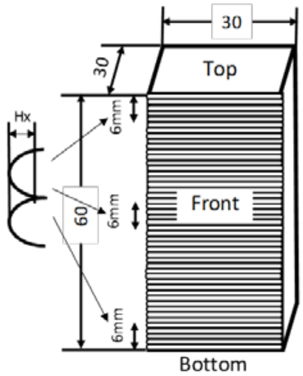

Fig. 15 Measuring position in dispersion measurement

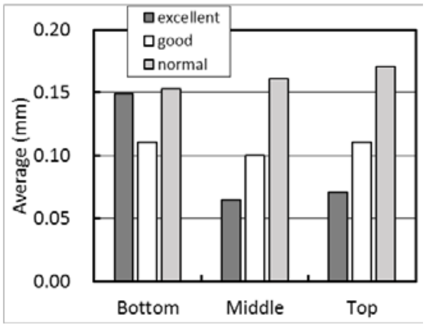

Fig. 16 Average of Hx

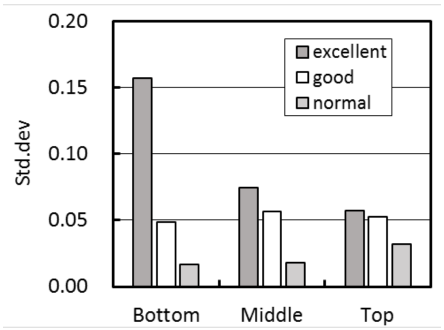

Fig. 17 Standard deviation of Hx

Product has the side shape as shown in Fig. 8. These typical shapes in the 3D printing cause to lower the accuracy of dimension of the product. To survey the dispersion of Hx length shaped on the layer edges as shown in Fig. 15, Hx was measured within the length of 6 mm to the Z direction at the bottom, the middle and the top position. From Fig. 16, the average values of Hx at the bottom, the middle and the top position are almost similar in the good condition. And also it is seen in the normal condition. They are a little bit large values. On the other hand, at the middle and the top position in the excellent condition, the average values are about 0.07 mm. But, in the bottom position, the value is twice. It is supposed that the bottom layers in the excellent condition are largely affected by heating from the bed and pressing with the self-weight. Also dispersion of Hx in the bottom position is larger than the middle and the top position. It corresponds to the influence of the layer width in the bottom position as previously described.

5.4 Utilization in educational field

As one of the application in the educational field, 3D printer is considered to be utilized in the plastic injection molding. Its advantage is able to design of the flexible and effective cooling water path. By means of the quickly and uniformly cooling the plastic inside mold, more precise quality is obtained. In the industrial field, this technology has been developed already using high accuracy 3D printer with metal materials [7]. Machining the mold after 3D printing is adopted in the industrial technology. Using the low price 3D printer, students are able to have the opportunity to learn a Computer Aided Design (CAD) software for the 3D printer and to practice the printing. Fused plastic is gradually shrunk when it's cooled in the process to product. Then it is very important to understand the shrinkage property of the plastic to get precise dimension of product. It will be conducted in further study.

Other approach in educational usage is to contribute to the 'MONOZUKURI' [8] training practice. It aims for students to practice a kind of the creative robot mechanism combined with plastic components.

6. Conclusion

From the result of measuring the characteristics of a personal and low price 3D printer, the followings are concluded.

(1) Fundamental printing process is similar in the industrial and the personal 3D printer. Using low price 3D printer, knowledge of the software and hardware of 3D printing can be acquired.

(2) Various temperature conditions of each part were measured and grasped the temperature of required ABS material.

(3) In X and Y direction which means a horizontal plane, the design dimension is achieved roughly even if there are some dispersion. It is found out that some additional machining after printing is required to get design dimension.
(4) In Z direction which means the vertical, the maximum reduced difference of 0.7 mm from design dimension was recognized. Relation between shrinkage of the plastic material and the temperature of the material is remained for further study.
(5) It was confirmed that the 3D printer is available to learn the plastic injection mold technology and useful as a preliminary practice for the industrial 3D printer. It will be expected that the 3D printer contributes for nurturing the creative thinking in the manufacturing.

7. Reference

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