Fabrication and Operation of Ceramic 3D Printer by FDM Method

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Abstract –*The application of 3D printing technology in manufacturing is becoming more and more popular, that to production has increasing potential in many fields including ceramic production. This paper describes the process of designing and manufacturing an experimental 3D printer with kaolin ceramic materials by the FDM method, describing the process of preparing printing materials from ceramic solution and then printing the product and checking for errors of dimension by the 3D Scan method. This study aims to propose solutions to design ceramic printers with compact machine structures that can meet production in the field of creating fine art ceramic products. The research results show that the machine structure is very stable during operation and the printed patterns are created very evenly in the printing layers, the measurement results from the 3D scanner show that the deviation is acceptable. This result can be applied in ceramic factories to create diverse fine art products.*

Key Words: *3D printing, 3D Scan, FDM, Kaolin ceramic*

1. INTRODUCTION

3D printing, also known as additive manufacturing, has developed rapidly and has demonstrated great potential for manufacturing in many industrial areas [1, 2]. Today, 3D printing technology is changing the way and object of production of products as well as the time and place of production, additive manufacturing has been seen as a landmark event of the industrial revolution. new [3]. Specifically, 3D printing technology is changed and different materials are used, in addition to PLA or ABS plastic materials for production, the materials are also applied. Ceramic objects are applied in many fields, especially those used to store essentials, decorations, and construction [4, 5]. In FDM 3D printing technology, plastic or metal materials, after being bonded layer by layer, will have the property of shrinking when the temperature is reduced. The application of 3D printing technology with ceramic materials is similar, however, with ceramic materials, no heating head and heat table are used [6].

In recent years, many studies have evaluated FDM printing technology with different types of ceramic materials [7-9]. Author Mohamed Zied Chaari and colleagues conducted an experiment to convert 3D printers (FDM) from plastic materials to 3D printers with WASP ceramic materials [10]. The test results have checked the operating mechanism of the printhead and the material properties suitable for each printing method. In the research project of shaping ceramic products using 3D printing technology, the authors Zhang and Ling compared media forming technology and ceramic technology using 3D printing technology. The authors found 3D printing to be more efficient and accurate, especially for the mass production of complex designs [11]. The team of authors Eliza Romanczuk-Ruszuk and his colleagues studied the 3D printing process with ceramic materials. The purpose of the study is to evaluate the underlying theories presenting the main groups of ceramic materials produced by additive 3D printing (FDM) technology [12].

This paper describes the process of designing and manufacturing an experimental 3D printer with kaolin ceramic materials by the FDM method, the machine can produce ceramic parts in unique and diverse shapes, increasing productivity and quality in the ceramic industry. The testing process is presented from the stage of designing the printed product model with Computer Aid Design (CAD) to setting parameter settings, printing mode on Ultimaker Cura software, and then fabricating products on fine art ceramic printers. Kaolin ceramics has been tested on 3D printers to shape simple and complex products. Experimental results show that this study has met the requirements of creating diverse and rich products with very even and beautiful prints. This paper can contribute on bring 3D printing technology into production in the field of unique product shaping for ceramic production facilities.

2. MACHINE DESIGN

2.1 Machine cofiguration

The fine art ceramic 3D printer built in this study is intended for application in shaping fine art products from ceramic materials with the size of the printing space in the range (150×150×150) mm. The machine design includes the mechanical drive part and the electrical system. In the mechanical part, the detail assemblies need to be structurally calculated to ensure the stability and transmission in the limited stroke. The machine frame connects the machine parts and the shaft to ensure precise and flexible movement to form the most complete system [13, 14]. Based on the principle of shaping ceramic products by traditional manual methods, combining existing 3D printer structures. From there, the authors have designed a 3D printer with axes and components configured to suit the ceramic printing material. In particular, the ceramic feeding and regulating system is designed and manufactured based on the characteristics of this ceramic material, which will help the printed product to be more beautiful and quality. The machine parameters are shown in Table 1. The fine art ceramic printer is used with Arduino Mega 2560 RAMPS 1.4 controller circuit and Proterface software to operate the machine. This control circuit is modified and installed firmware according to the printer program for Cartesian coordinate system to match the designed machine configuration.

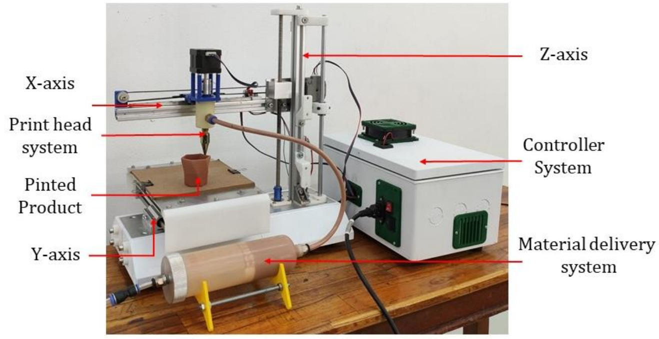


Figure 1: *Structure of Ceramic 3D Printer after fabrication*

Table 1: *Parameter of chosen components*

Components	Parameters
Step motors (X, Y, Z, E0)	Nema17/0.9°; 42×42×38 mm
Stepmotor Driver	Driver A4988; 0 ÷ 2A
Linear motion X-axis	Timing belts GT2; Pully 20 tooth
Linear motion Y-axis	Timing belts GT2; Pully 36 tooth
Linear motion Z-axis	Ball screw T8; pitch 2 mm/rev
Controller	Arduino Mega 2560, RAMPS 1.4

2.2 Ceramic material printhead

The authors have designed and built a print head for ceramic materials that ensures stable working during printing. The feeding chamber is used with a glue pump tube with a capacity of 300ml of printing material, using pneumatic force to push the compression piston to push the material through the material regulator as shown in Figure 2. Adjust the amount of material to be adjusted. pushed out so that the pneumatic valve helps to adjust the pressure at the level of edema. This process is tested several times to select the most suitable pressure level to supply enough media to the ceramic regulator. Pneumatic pressure depends on many factors such as the flexibility of the material being prepared, the adjustment parameters on the regulator, and ensuring that the ceramic quantity is printed evenly during the forming process for the product. The print head is driven by a NEMA 17 stepper motor. The screw is driven through a coupling to compress and use the ceramic material. Ceramic material will be led into the feed head, the compression screw regulates by rotation and compression pushes the material down to the nozzle. The amount of material secreted depends on the print mode and printhead. The nozzle will determine the size of the material extrusion line [15, 16]. The screw installed on the 600 step/mm driver produces enough extrusion force to force the ceramic out. This factor is related to the accuracy of the screw rotation speed and the amount of ceramic extruded by adjusting the amount to form a uniform printing layer and the product prints beautifully and evenly in the printed layers.

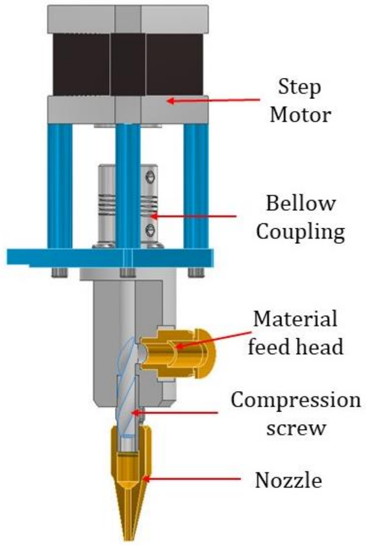


Figure 2*: Structure of the material print head system*

Parameters of the design compression screw are as following screw pitch 5 mm; diameter Ø6 (mm); total length of the screw 72 mm; screw head Ø5 as shown in Figure 3. The feed head has a diameter of Ø6.5 (mm) and the nozzle has a diameter of Ø2.5 (mm). The screw installed on the 600 step/mm driver produces enough extrusion force to force the ceramic out. This factor is related to the accuracy of the screw rotation speed and the amount of ceramic extruded by adjusting the amount to form a uniform printing layer and the product prints beautifully and evenly in the printed layers.

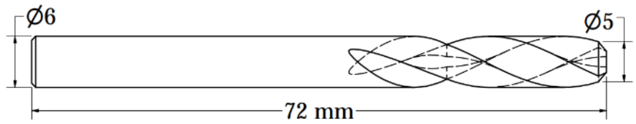


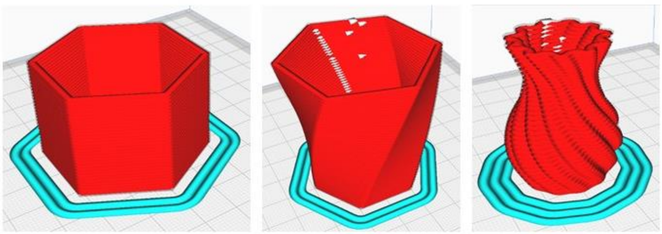
Figure 3: *Dimensions of the compression screw*

2.3 Ceramic material

Kaolin ceramic is a material widely used by countries with developed industries such as the US, UK, France, Japan, etc. to study old ceramics [17-19]. The chemical composition of pure ceramic with the formula $Al_2O_3.2SiO_2.2H_2O$ includes the composition Al_2O_3 = 39.48%, SiO_2 = 46.60%, H_2O = 13.92% [20]. Before printing, the ceramic needs to be treated to remove hardened ceramic particles by filtering through a mesh screen and dispensing with water at a level suitable for printing. The printed samples are mixed with water according to the ratio: 700 grams of ceramic mixed with 95 ml of water. In order to choose suitable dispensing ratio for ceramic printers, the authors have tested it many times before and found that this ratio is just soft enough, not broken, and suitable regulating the quantity of ceramic when printed.

2.4 Printing parameter setting

Setting parameters is an important step in the FDM printing process. Set print parameters to synchronize the materials used, print speed, and print quality factors. Setting parameters is similar to printing plastic materials, but with FDM printing method with ceramic materials, it will focus on correcting key parameters that may affect print quality. First, the sample model was designed on Inventor Professional 2022 software and exported in STL format. Next, use Ultimaker Cura software to declare the parameters and print modes to be compatible with 3D ceramic applications. Finally export the file converting CAD files to G-Code as parameters (print layer height, print wall thickness, density, print speed, travel speed, ...). The modified printing parameters of Ultimaker Cura software are as follows.



Model 1 Model 2 Model 3

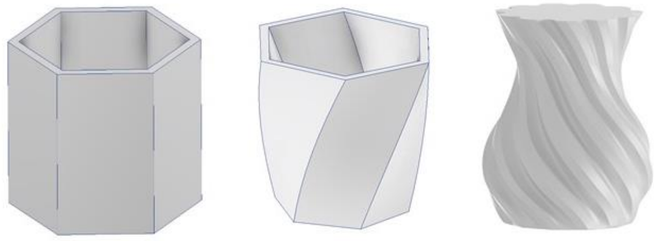
Figure 4: *Set parameters and classifiers for model*

Table 1: *Setting print parameter*

Parameter	Unit	Value
Layer height	mm	1.0
Initial layer height	mm	1.0
Wall thicknees	mm	3.0
Print speed	mm/s	10.0
Infill density	%	0
Top/Bottom line width	mm	2
Feed pressure	kgf/cm2	3

3. RESULTS AND DISCUSSION

To conduct a printer experiment with ceramic materials, the authors designed three product samples that clearly showed the simplicity of the model from simple to complex. Sample 1 is designed according to a hexagonal block with an overall size of (45×48) mm^2. Sample 2 is designed in a twisted hexagonal shape with an overall size of (45×48) mm^2. Model 3 is designed in the form of a vase with 11 sides and twisted edges from the bottom to the mouth of the vase with an overall size of (45×45) mm^2. After setting the printing parameters for the three samples, the printing time of sample 1 was 9 minutes, the total volume of ceramic used for the sample was 15 grams; the printing time of sample 2 is 14 minutes, the mass of ceramic used in the sample is 25 grams; The printing time of sample 3 is 10 minutes, the mass of ceramic used in the sample is 14 grams.



Model 1 Model 2 Model 3

Figure 5: *Prototype design model*

3D Scan technology will be applied to test the printed sample to review the size and quality of the printed sample. The measuring sample is glued with 1.5mm reference points directly on the surface and placed on a dedicated turntable for 3D Scan. The sample scanning process will be carefully handled by applying white powder so that the machine can scan all sides. When the scan is complete, the sample will be treated for surface quality and dimensioned on Gom Inspect software. Surfaces are processed in areas that are defective due to unrecognizable machine scanning or in hidden corners, the processed mesh resolution is 0.01 mm. The test results are presented in Tables 3 and Table 4.

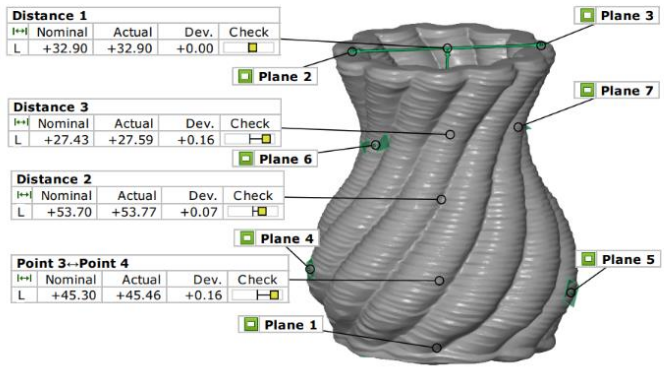


Figure 6: *The model is measured by 3D Scan technology*

Table 2: *Results of measurement to model height (mm)*

Model	Parameter Design	Measurement Results	Deflections
1	45	43.60	1.40
2	45	43.90	1.10
3	55	53.77	2.77

Table 3: *Results of measurement to model width (mm)*

Model	Parameter Design	Measurement Results	Deflections
1	48	48.40	0.4
2	48	48.50	0.5
3	45	45.30	0.3

After the forming process for the 3 samples, the printed sample will be measured and compared with the design model size and the printed sample size. The results of the printed samples are as follows: the printed samples do not change in shape compared to the designed model. In particular, print pattern 1 has a simple shape, so the straight-motion printhead profile has little influence on the change of running pattern and less vibration during printing, the printing layers are quite even and stable from the second printing layer. to the final printing layer, the height deviation is -1.4 mm and the width dimension deviation is +0.4 mm compared to the overall design model size. For sample 2, the profile moves in a straight line, but there is a greater change in the print line, so the vibration is negligible and does not affect the print quality much, the other printing layers are even but unstable, and the error size with deviation in height is -1.1 mm and the size deviation in width is +0.5 mm compared to the overall size of the design model. For model 3, the motion profile is constantly changing, so there is a vibration but it does not affect the print quality, the printing layers are stable and even, the size difference in height is -2.77 mm, and the degree of Size deviation in width +0.3 mm compared to the overall size of the design model. The results show that the samples meet the requirements in terms of shape and surface, but the height size is somewhat reduced and the width size increased, but the deviation is small, within the allowable range print product quality.

Model 1 Model 2 Model 3

Figure 7: *The model test results on printing*

In addition, to better evaluate the print quality, the authors also tested 3 different samples with complex profiles. The printed samples are of good quality, the printing layer is very uniform and stable. Create a very diverse and rich shape. The above results show that the manufacturing and application of 3D printing technology in production, especially in the field of fine art ceramics, is very positive. This research result can contribute to fine ceramic production facilities having more product development opportunities in the future.

Figure 8: *Printed model products with complex patterns*

4. CONCLUSIONS

The article presented in detail the process of researching, designing, manufacturing 3D printers, and testing printing on kaolin ceramic materials. The machine structure including the transmission part, feeder part, and regulating part is described and explained. The process of setting printing and material handling parameters, and conducting test printing are presented and discussed. Research results show that the products created by 3D printers with ceramic materials are diverse and rich, creating a unique feature for ceramic. Thereby, the application of 3D printing technology by FDM method in ceramic art production is very appropriate. The results of this research will be the first steps for the development of the application of high technology in production, especially in the ceramic industry..

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