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3D Printing Lightweight Structures in Architectural Scale

Tomohiro Yasui [*], Yasutomo Matsuoka [a], Taisuke Ohshima [b], Koki Akiyoshi [c], Hiroya Tanaka [d]

[*] Hiroya Tanaka Laboratory, Graduate School of Media and Governance, Keio University,
5322 Endo, Fujisawa, Kanagawa 252-0882, Japan,
chihiro8@sfc.keio.ac.jp

[a] Researcher, [b c] Doctor course student, [d] Associate Professor

[a] Takenaka R＆D Institute, [b c] The University of Tokyo, [d] Keio University, Japan

Abstract

In this research, we aim to build a method to realize the Lightweight Structure with a guaranteed strength by using a large 3D Printer. First, we selected a geometry called Gyroid to filling pattern of the inside structure from theoretical mechanics perspective. Furthermore, by comparing the intensity with those of general infill patterns on 3D Printing, we showed the structure mechanical characteristics Gyroid has. Moreover, by the comparative experiments with other shapes having a periodic internal filling, we have done validation experiments, including the specific constraints perspective of Fused Filament Fabrication (FFF) type 3D Printer. Finally, through these experimental results, we propose a method for realizing the ideal lightweight structures by 3D Printer technology based on the superiority in an inneral filling shape of structure Gyroid has.

Keywords: Architectural Scale 3D Printer, Light Structure, Morphology, Digital Fabrication, Module, Material

1. Introduction

In this research, we conducted a fundamental research on applying the use of 3D Printer, a digital fabrication machine, in the field of architecture. First, with standard 3D Printers, an enormous time is required to create a scalable object. Therefore, materials we can use by 3D Printing are also constrained in resin. It is very difficult for 3D Printing to become a process of constructing buildings. Therefore, we created an Architectural Scale 3D Printer, “ArchiFAB” shown as Figure.1, which is a machine to create objects that have the scale of an architecture in a short time with enough strength.

Still, the Printed materials are constrained sensitive material structurally as resin. The other existing building 3D Printers are possible to clear this constraint by replacing the existing manufacturing process[1][2]. However, since the solution is just replacing the existing manufacturing process, it is difficult to say that the solution utilizes the shaping of 3D Printer.

One of the excellent features of the 3D Printer is that it can freely form the shape data. The range of applications not only shapes the outside but also shapes the inside. Therefore, with an equal amount of material, we can realize a more robust, lightweight structure by combining effectively the innernal filling structure and the characteristics of the material used for the modeling.

2. Method

2.1. Architectural Scale 3D Printer "ArchiFAB"

ArchiFAB can be shaped using a standard material of 3D printers Polylactide (PLA) as with existing FFF type 3D Printer. The FFF type 3D Printer is a standard way of shaping a 3D model by stacking a melted resin. In order to output the products in architectural scale, the development of new performance such as machinery sending off a large quantity of material, outputting resin with an optimum diameter, and accuracy of output form is required. In order to realize those performances, new machinery being able to output directly from raw material of filaments called pellets, and a head outputting the resin with an optimum diameter were developed. By fulfilling these requirements, the ArchiFAB realized the large-sized shaping like Figure.2 in a short time guaranteeing precision.

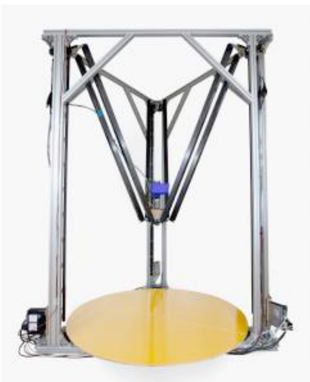


Figure 1: ArchiFAB

Figure 2: 3D Printing Chair

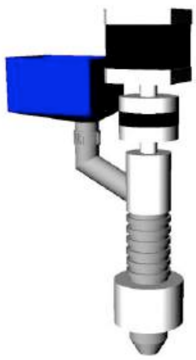


Figure 3: Pellet system

Table 1: ArchiFAB's basic information

Item	Description
Classification	Delta model
Output form	Fused Filament Fabrication (FFF)
Appearance size	228[cm] height × 175[cm] width × 150[cm] depth
Output size	1300[mm] diameter × 510[mm] height
Injection nozzle diameter	3.0[mm]
Material	Polylactide (Pellet)

2.2. Internal filling patterns commonly used in 3D Printers

Internal filling patterns commonly used in 3D Printers are already determined and selected from the following patterns called Linear, Grid and Honeycomb, shown in Figure.4. These specifications are prioritized in order to realize a 3D modeling. Therefore, these are not considered whether it is mechanically superior or not[3]. Existing building 3D printers described above clear the constraints by using a method such as changing material. This means, for applying to the architecture with maintaining the modeling power of the 3D Printer, we need to compensate the structure mechanical characteristics in other ways.

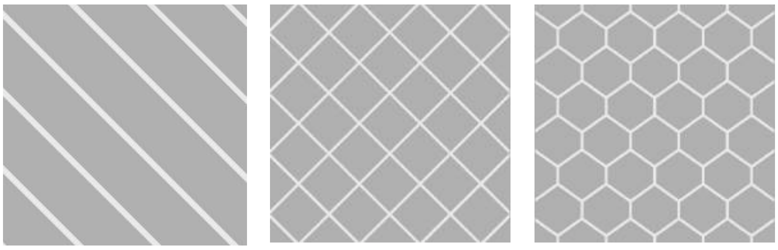


Figure 4: General internal filling patterns on 3D Printing
(Left: Linear, Center: Grid, Right: Honeycomb)

2.3. Periodic internal filling pattern

In 3D Printer, we can realize a more lightweight structure than a solid object by modifying the inside structure of the object[4]. The shape with the advantage of efficient internal filling and a structural, mechanical are called Octet truss, Truncated octahedron, and Gyroid[5].

The Gyroid structure shown as Figure.5 is also called “Minimum curved surface”. This means we can shape with a minimum of material by using grid structure than any fill patterns if we shape the object with same volume. Also the Gyroid structure is closely related to the K_4 crystal, which is the most rigid structure crystals existing in nature[6]. Therefore, we think Gyroid structure is a suitable internal filling pattern in order to realize the lightest structure. Furthermore, the Gyroid structure has a complex curved surface inside. Therefore, it is one of the shapes which can be molded easily by development of 3D Printing technology.

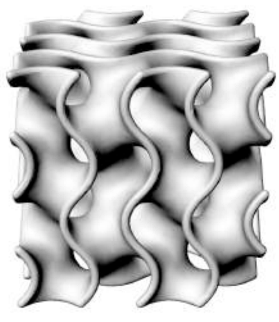


Figure 5: Gyroid Structure Model

Figure 6: Gyroid Structure Module

3. Experiments

We conducted experiments against structures with internal filling patterns printed by a large-scale 3D Printer in order to realize the Light Structure. The material used for these structures are all polyactide (PLA), a material that is commonly used for 3D Printing. Not only is PLA inexpensive and easy to model objects, they are also inadhesive and durable. These material characteristics makes PLA suitable for creating large objects with 3D Printing.

3.1. Basic Experiment

First, we performed compressive durability tests with small experiment models printed by desktop 3D Printers. We used MF-1000 by Mutoh Engineering Inc. as the exteriment model printing machine.

3.1.1. Overview

In the experiment, we measured the deformation that resulted after putting a compression of up to 2500[N] to the experiment models. Also, in order to investigate the unique physical characteristics that 3D printed objects have, we compressed the model from both vertical and horizontal direction to the layering direction.
We will show the outline of the experiment material in the Table.2 below. Each experiment model has the same density, and they all use 3.0mm phai filaments from SainSmart.

Table 2: Test body information

Internal filling pattern	Grid	Honeycomb	Gyroid
The appearance			
Material	3.0 mm phai filament (SainSmart)		
Volume size	125[cm^3] (5[cm] height × 5[cm] width × 5[cm] depth)		
Weight	29[g]		
Density	0.232[g/cm^3]		
Molding time	3 hours	3 hours 6 minutes	2 hours 41 minutes

3.1.2. Result

We will attach the results of 3.1.1 experiment below shown as Table.3 and Figure.7. From this data, we discovered that internal filling patterns that are generally used for 3D printing ensures enough strength in the vertical direction of the layer direction, but will become 0.55 times that strength when "Grid" pattern is used, and 0.8 when "Honeycomb" pattern is used. On the other hand, Gyroid structure, a periodic internal filling pattern, displayed durability in almost any direction, independent from the layering direction.

Table 3: The maximum load value

Internal filling pattern	Grid	Honeycomb	Gyroid
Vertical	2196[N]	2623[N] (overload)	2770[N] (overload)
Horizon	1374[N]	2005[N]	2533[N] (overload)

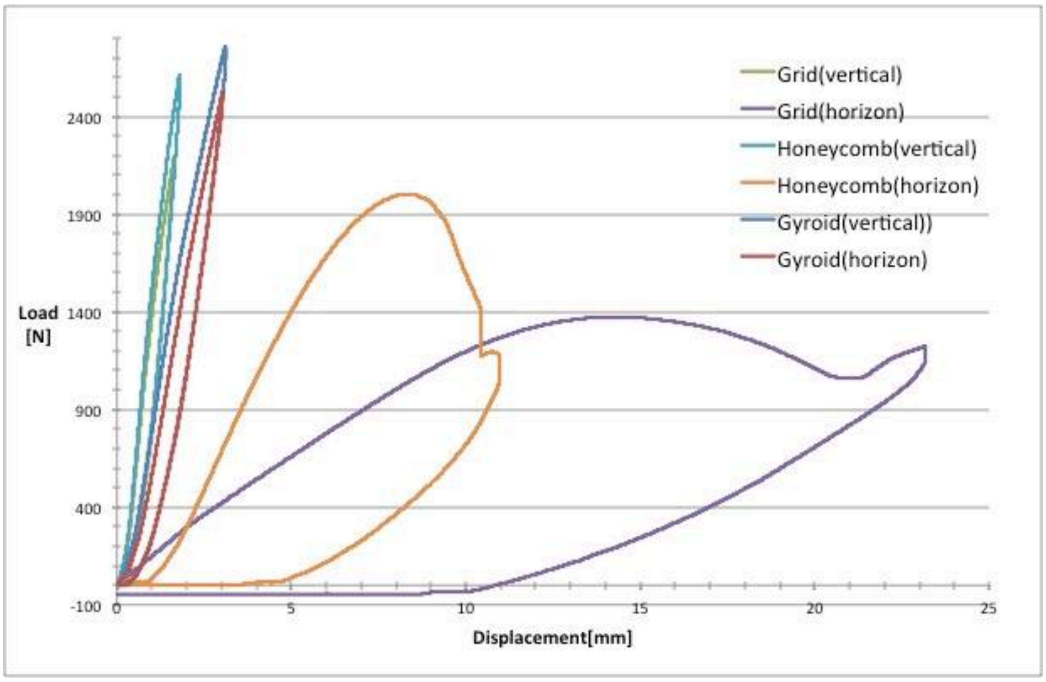


Figure 7: Structural mechanical properties of each Internal filling pattern

3.2. Experiment in Large scale

From the experiment conducted in section 3.1, Gyroid structure, which has periodic internal filling pattern, has shown its physical characteristic are independent from printing direction, unlike other patterns that are used for 3D Printing. However, Gyroid structure is not the only structure with periodic internal filling pattern; Octet truss, Truncated octahedron also share the same geometric character. Therefore, these structures are estimated to have the same character when printed.

In order to verify this, we will conduct compressive durability tests to test models with periodic internal filling pattern, printed with "ArchiFAB" from section 2.1.

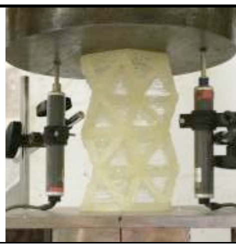
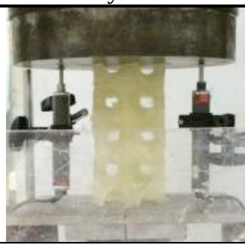
Figure 8: Experimental installation

3.2.1. Overview

We measured the deformation of the experiment models, just the same as the experiment done in section 3.1. Since the models we used were larger than the ones used in section 3.1, we used an experiment instrument that is capable of 25[ton] of pressure.

The details of the experiment models are described in Table.4. Each experiment models share the same density. The PLA resin pellets of UNITIKA is used as the model material.

Table 4: Test body's information

Periodic internal filling pattern	Octet truss	Gyroid
The appearance		
Material	PLA Pellet (UNITIKA)	
Volume size	1052[cm^3]	
Weight	291[g]	
Density	0.277[g/cm^3]	
Molding time	2 hours 8 minutes	1 hours 43 minutes

3.2.2. Result

We will attach the results of 3.2.1 experiment below shown as Table.5 and Figure.9. The experiment result showed that structures with Gyroid pattern had 1.48 times the durability against compression than those with Octet truss patterns with same density. Therefore, we can say that Gyroid pattern structure has advantage in physical characteristic copmared to other periodic internal filling pattern structures with same density.

Table 5: The maximum load value

Periodic internal filling pattern	Octet truss	Gyroid
	13.66[ton]	20.22[ton]

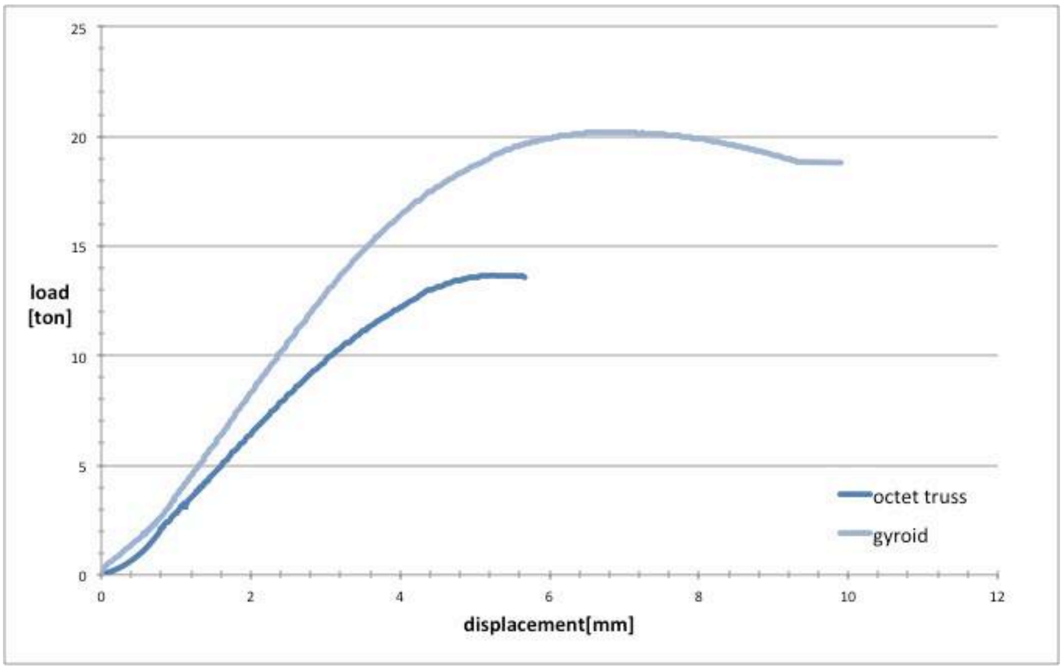


Figure 9: Structural mechanical properties of each Periodic internal pattern

4. Conclusions

4.1. Development Large scale 3D Printer "ArchiFAB"

We developed architectural scale 3D Printer, "ArchiFAB", in collaboration with enterprise. The machine enabled us to create objects at architectural scale. Also, we improved the injection mechanism after changing the injection material from filaments to pellets. Through this improvement, we were able to observe a significant reduction of material cost and raise of processing speed.
Today, the variety of materials that are sold as pellets is limited, but they are expected to increase in the future. PLA is suitable for 3D Printing, yet they are also age quickly. In addition, by using different material, we may be able to realize a lighter and more durable structure. Also, materials such as PET resins, well known for being a mass-waste in cities, may be used as a valid material for 3D Printing.

4.2. The superiority of Gyroid inner structure for realizing the Lightest Structure

The experiments from section 3.1 proved that Gyroid structure did not have any anisotropy. When applying a structure to real-life architecture, durability against forces such as compressive force, tensile force, and shearing force needs to be considered. Therefore, the anistropy-less structure of Gyroid is very effective.
Through the comparison of periodic pattern structures from the experiment done in section 3.2, we

showed the validity of Gyroid structure. This is also due to the difference of suitability for FFF type 3D Printing between different structures. Models that have discrete shapes on each printing surface, such as Octet truss, are more difficult to print, compared to Gyroid patterns, which has a shape that allows printers to print continuously.
For these reasons, the most applicable internal filling structure for making objects with FFF type 3D printers is the Gyroid structure.

Acknowledgement

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