Analysis of angle comparison for the “Kawung” pattern module development based on additive manufacturing method using 3D filament from recycled plastic waste material

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**Abstract.** The process of additive manufacturing, particularly in 3D printing, is very closely related to CAD (Computer-Aided Design) files, 3D printers, and materials for creating object layers. Of course in the printing process, there are some limitations on the design and rules that must be considered. For example, material, design and printer settings to obtain maximum results. In this project an angle comparison analysis is performed on the Kawung module design to find out the most efficient and effective conditions in the printing process. From the strength test, the T3 Kawung module is found to be the most powerful with polypropylene material (recycled PP from Robries) with a yield strength of 20 MPa, a breakpoint of 13 N and maximum stress of 21.17 MPa.

1. **Introduction**

The use of 3D printing technology has now expanded to the fashion design industry. The world designers are currently developing patterns that will be used as 3D printed clothing. There have been many experiments on developing patterns using 3D printing technology. In the process, additive manufacturing, in this case 3D printing has a close relation to CAD (Computer-Aided Design) files, 3D printers and materials for creating object layers. Indonesia has many unique patterns that can be developed based on this technology [1,2]. The development of 3D printing on fashion in the world began with Irish Van Herpen in his collection called Crystallization. In the international competition conducted by Purmundus in 2017, Danit Peleg as a fashion designer who also uses 3D printing technology managed to become the first winner with a title of Birth of Venus [3]. In Indonesia, there are designers who have developed 3D fashion designs, such as Tex Saverio. He made an Exoskeleton Collection that contained 5 haute couture dress designs using a mixture of fabric and 3D printed materials [2].

On the other hand, Indonesia as a country rich in culture has various decorations. Decorative types in Indonesia are often applied to various works of art ranging from carvings, batik-pattern, and so forth [4,5]. Previous research on printed 3D fashion using PLA material and simulation tests have also been carried out on the 3D module [1,6]. Of course in the printing process, there are some limitations on the design and rules that must be considered, for example, material, design and printer settings to achieve maximum results. In this project an angle comparison analysis is performed on the Kawung module design to find out the most efficient and effective conditions in the printing process.
2. Methods

2.1 Production Method
This paper used both quantitative and qualitative approach methods. In addition to benchmarking the right conditions in the printing process, testing methods are carried out in 3 forms of modules to see the differences on each. The constraints considered during the test phase are printer settings and the use of the same material.

2.1.1 CAD (Computer-Aided Design)
CAD (Computer Aided Design) is a software to support the design process [7]. CAD software is used by designers to improve the quality of design, facilitate communication with documentation, and create a database for manufacturing. The output of the CAD is a file for printing, machining, and other manufacturing methods. Keep in mind that the output of CAD is also in the form of technical drawings. Therefore, CAD software is often used for 3D design.

2.1.2 CAM (Computer-Aided Manufacturing)
CAM is any computer software to control manufacturing machines. CAM is also intended as a computer assistant in file processing, management, transportation, and storage, which mainly to accelerate the production processes with precise dimensions and minimize material usage. The function of CAM is processing the files from CAD and further to control manufacturing machines. Often used Manufacturing methods are 3D printing, laser cutting, and CNC [8].

Print head based AM methods relies on the thermal extrusion and then fusing of a thermoplastic filament through a suitable extrusion nozzle. This method is often referred to as Fused Filament Fabrication (FFF), or Fused Deposition Modelling (FDM), and its low cost and simplicity has seen it emerge as the dominant AM method in the hobbyist market [9]. The application of the Fused Filament Fabrication (FFF) program can be defined as the simplest 3D printing technology, with some limitations on design and rules that must be considered. This technology often requires material support to support its FFF parts [8]. A cheap and often used printing technique is what is called Fused Deposition Modeling (FDM) [10], where the thermoplastic polymer is melted in an extruding nozzle, and the fluid material is deposited on the 3D printer bed, and then the printing begins with the first layer of the planned object [3]. After completing the first layer, the printing base is lowered then printing continues to stack the layers until the object is printed completely.

2.1.3 Support structures and part orientation
What often happens in Fused Filament Fabrication (FFF) print is overhangs (hanging). Overhangs occur when a portion of the printed layer of material has a larger printed area, or extruding outward from the previous / lower layer. Sloping walls or curved surfaces of the printed object are examples of overhangs. When an object is printed with a slope of 45 degrees or more than 45 degrees from a vertical baseline, the object needs supporting material to prevent from an distorted overhang. At a slope angle of less than 45 degrees from a vertical baseline, it does not require a supporting structure to reinforce it, as shown in Figure 1.

2.1.4 Bridging
Bridging, in the context of printing process, means 2 anchor points to support the printed object, in the same manner as a bridge. If there are no supports to fill the gap between the bridge, the material will sag, as shown in Figure 2. Adding distance of the bridge will affect print and/or build quality [11].

2.2 Shape Transformation Method
Geometric pattern varieties (pattern) contain elements of lines, angles, fields, and space. Lines may have straight, curved, spiral, or zig-zag pattern. There are also shapes such as circles, squares, rectangles,
triangles, and also kites. A beautiful geometric decoration (pattern) is made from the combination of lines and shapes. Geometric pattern are touted as the oldest pattern, because of their development since prehistoric times. Kawung pattern, the basic pattern of intersecting circles, depicts the palm fruit trees that have been known in Java since at least the 13th century, hence recognized as a very old design [5].

Overhang with less than 45 degree angle from a vertical baseline does not require support material.

**Figure 1. Overhangs on FFF printer**

The horizontal length of the bridge must not exceed 10 mm to prevent from a distortion due to the gravity pull.

Bridging experiment with various lengths. Distorted objects of exceeding 10 mm of bridge length.

**Figure 2. Bridging on an FFF printer**

### 3. Test Results and Discussions

#### 3.1 Shape Transformation: Kawung Pattern

Kawung pattern are derived from intersecting circular base shape that has been used for a very long time. Their geometric shapes are considered for making 3D pattern models.

#### 3.2 Configuration A

The use of Kawung pattern as a 3D model configuration is taken from the arrangement of the petals and follows a pattern based on the rotation of the pattern, as exhibited in Figure 3.
3.3 Configuration B
Kawung pattern with configuration A is taken as a reference form to be used in creating a 3D model. The modifications to form the Kawung of configuration B which is made more geometrically, is composed by reducing the existing indentations, as shown in Figure 4.

4. Module Design
In making the model, we took a particular interest in configuration B because it has many possibilities on the angular variable. The module design is based on configuration B with different angular variables to find out how the angles of the modules affect the printing process that has the same settings. The 3D modeling process is carried out to find a printable model. The model formation is obtained for Kawung into a single unit. The following pattern depicted in Figure 5 is the Kawung model with cross configurations that are combined into a single unit. The fourth model of the Kawung pattern is also developed through experiments carried out on the slope of the model, which is useful for finding models that are easy to print as well as a detailed appearance, even without a finishing process (e.g., paint).

The results of the experiment on configuration B will be tested in a stress simulation. The aim is to simulate the strength the modules listed in Table 1, and compare their strength ratios. The comparison is aimed at obtaining modules that have the required strength for the product.
Table 1. Design module

| Modul | Explanation |
|-------|-------------|
| ![T1 module](image1.png) | T1 module  
Angle: 15 degrees |
| ![T2 module](image2.png) | T2 module  
Angle: 45 degrees |
| ![T3 module](image3.png) | T3 module  
Angle: 60 degrees |

5. Printing Settings
The use of slicing in CAM software as a computer assistant in file processing, management, transportation, and storage, which main purpose is to accelerate the production processes with precise dimensions and minimize material usage. To produce suitable printing products, several printing settings are made as listed in Table 2.

Table 2. Printing settings

| No | Indicator                      | Settings          |
|----|--------------------------------|-------------------|
| 1  | Material                       | Polypropylene (PP) |
| 2  | Layer Height                   | 0.1 mm            |
| 3  | Infill                         | 20%               |
| 4  | Print Temperature              | 238°C             |
| 5  | Build Plate Temperature        | 65°C              |
| 6  | Travel Speed                   | 1,500 mm/min      |
| 7  | Build Plate Adhesion Type      | Skirt             |
| 8  | Support                        | No support        |

6. Printing Process
From the same printing settings and different module angles, the difference information is obtained during the printing process. Table 3 as in the following presents the printing results, including the time and weight of the printed module.

The printing process uses software with identical printing settings, aimed to find modules with effective time and weight based on differences in angles of the module. It was found that T1 module has the fastest production time, which is 14 minutes, with the lowest weight if compared to the others. For the longest production time is found to be the T2 module, with 21 minutes. Then T3 module is found to be the heaviest module, amounting to 0.34 gr. In term of the production time, T3 module eventually is the average of the other modules.
7. Comparison of Simulation Results
From the printing process, the simulation stage is then performed to measure the strength of the existing modules by using the same material. The following are the results of the simulation.

7.1 T1 Module
In the T1 module, a stress test is performed to determine the strength of each module. The testing phase uses several heavy samples to determine breaking points for each of these modules. The T1 module has a flat shape with a height of 4.525 mm and a slope angle of 15° chain segment. The T1 module is induced by 1.0 N, 2.0 N, and 3.0 N of forces. Results of stress test simulation for T1 module are exhibited in Figures 6 to 8.

7.2 T2 Module
In the T2 module, a stress test is performed on the second module. The testing phase uses several heavy samples to determine the break points for each module. The T2 module has a 45° chain tilt angle that aims to reduce bridging which results in a more prominent shape up to a height of 6.979 mm. Forces of 1.0 N, 2.0 N, 3.0 N and 5.0 N are used in this test. Results of stress test simulation for T2 module are exhibited in Figures 9 to 12.

7.3 T3 Module
From the results of the two stress simulations of the two previous modules is that some weaknesses were found in the strengths and the printing process. Improvements were made in the tilt angle with more parts touching the printer's build plate area. No significant changes are imposed on the form, but only the tilt angle adjustment was made. Thence the T3 Kawung module and stress simulation testing is carried out using a force of 1.0 N, 3.0 N, 5.0 N and 13.0 N, as portrayed in Figures 13 to 16.
Figure 6. Stress test simulation of T1 module with N=1.0

Figure 7. Stress test simulation of T1 module with N=2.0

Figure 8. Stress test simulation of T1 module with N=3.0
Figure 9. Stress test simulation of T2 module with N=1.0

Figure 10. Stress test simulation of T2 module with N=2.0

Figure 11. Stress test simulation of T2 module with N=3.0

Figure 12. Stress test simulation of T2 module with N=5.0
The same type of material for the three modules were then tested with several force variations to compare the range of stresses that were developing. From this test, especially by observing the maximum stresses, it is expected to find the indication on the possibility of module damage. Comparison of simulation results is contained in Table 4.
Table 4. Simulation result comparison

| Module   | Material        | Yield Strength (MPa) | Force (N) | min. stress | max. stress |
|----------|-----------------|----------------------|-----------|-------------|-------------|
| T1 module| Polypropylene   |                      | 1.0       | 0.003505    | 8.601       |
|          |                 |                      | 2.0       | 0.007010    | 17.200      |
|          |                 | Yield Strength:      | 3.0       | 0.010570    | 25.800      |
|          |                 | 20.67 MPa            |           |             |             |
| T2 module| Polypropylene   |                      | 1.0       | 0.001201    | 3.824       |
|          |                 |                      | 2.0       | 0.001994    | 7.606       |
|          |                 | Yield Strength:      | 3.0       | 0.002992    | 11.410      |
|          |                 | 20.67 MPa            |           |             |             |
|          |                 |                      | 5.0       | 0.004983    | 19.030      |
| T3 module| Polypropylene   |                      | 1.0       | 5.74E-04    | 1.624       |
|          |                 |                      | 3.0       | 0.001724    | 4.881       |
|          |                 | Yield Strength:      | 5.0       | 0.002874    | 8.139       |
|          |                 | 20.67 MPa            |           |             |             |
|          |                 |                      | 13.0      | 0.007475    | 21.170      |

Notes:
- Force (10 N) = 1 kg/cm³
- Break point when Yield Strength < von Mises
- Yield Strength is the maximum point of material deformation.

From the strength test, the T3 Kawung module was found to be the strongest amongst other module varieties using the material Polypropylene (a recycled PP Material from a local vendor, Robries) with a yield strength of 20.67 MPa and withstanding a stress of 13 N with a breakpoint module or maximum stress of 21.17 MPa. Meanwhile, the T1 module has the lowest level of strength among other modules. This can be seen from the T1 which only withstands up to 3 N of pressure, and a breakpoint module or a maximum voltage of 25.800 MPa even though the used material were the same as the other modules.

8. Conclusions
All three modules had polypropylene material. The differences were the angles, where T1 was at 15 degrees, T2 was at 45 degrees, and T3 was at 60 degrees. The conclusion of the experiment result is that the wider the angle, the longer the time it consumed, and had a heavier printed result. However, due to the wider angle, the printed result had a higher strength level. In this case, T3 consumed the longest time in the printing process. Thus, the weight was the heaviest, and that resulted as the strongest module among others.

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References
[1] Purmundus. (2017). Fusion – 3D printing intelligently combined. Purmundus challenge, Feb, retrieved from: https://purmundus-challenge.com/en/2017.php.
[2] Safiera. (2018). Perkembangan busana futuristik dari teknologi printer 3D di industri mode. Wolipop, Feb, retrieved from: https://wolipop.detik.com/read/2014/12/15/155352/2777769/2332/perkembangan-busana-futuristik-dari-teknologi-ltigprinterltigt-3d-di-industri-mode#picmp.
[3] Marcincinova, L.N. (2012). Application of Fused Deposition Modeling Handbook. The Netherlands: 3D Hubs. Manuf. and Ind. Eng, Amsterdam, vol. 11.

[4] Falashifa, D.I. (2013). Kerajinan Tenun Ikat Tradisional Home Industry Dewi Shinta Di Desa Troso Pecangan Kabupaten Jepara (Kajian Motif, Warna, dan Makna Simbolik). Universitas Negeri Yogyakarta, Indonesia.

[5] Faruq, H.A. (2017). Pengertian motif dan pola ragam hias. Habibullahurl, Feb, retrieved from: http://www.habibullahurl.com/2017/08/pengertian-motif-dan-pola-ragam-hias.html.

[6] Kuswanto, D., Iftira, N.J. and Hapinesa, O.M. (2018). “3D printing for fashion development”. Int. Conf. on Science and Techno (ICST) 1-6. IEEE.

[7] Martowibowo, S.Y. and Daa’i, W.R. (2017). “Pembuatan perangkat lunak CAM untuk mesin CNC freis 3 sumbu pada AutoCAD”. Mesin 19(1):12-19.

[8] Yan, C.S. (2016). 3D Printing in Design Research Document of 3D Printing 2016. NSCAD University Press, Canada.

[9] Allen R.J. and Trask, R.S. (2015). “An experimental demonstration of effective curved layer fused filament fabrication utilising a parallel deposition robot”. Additive Manufacturing (8).

[10] Chua, C.K., Leong, K.F. and Lim, C.S. (2010). Rapid Prototyping: Principles and Applications. World Scientific. Co. Pte. Ltd, Singapore.

[11] Redwood, B., Schöffer, F, and Garret, B. (2017). The 3D Printing Handbook: Technologies, Design, and Applications.3D Hubs, Amsterdam, Netherlands.