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Design and manufacture of polylacticacid (PLA) filament storage for 3-dimensional printing with composite material.

G Suharjanto[1], J P Adi [2]

[1] Architecture Department, Faculty of Engineering, Bina Nusantara University, Jakarta, Indonesia 11480
[2] Product Design Engineering Program, Industrial Engineering Department, BINUS ASO School of Engineering, Bina Nusantara University, Jakarta, Indonesia 11480

Corresponding author: gatotsuharjanto@binus.edu

Abstract. 3-dimensional printing is an additive manufacturing (AM) method using polylacticacid (PLA) filaments. However, PLA filaments still have limitations such as the hygroscopic properties of the material. This type of filament easily absorbs air from air humidity, so it will have an impact on the chemical damage of PLA. In this research, a composite file storage area will be designed. The method of making this file storage area will use a composite material Medium Density Board (MDF) with a simple manufacturing method. The filament storage area is expected to prevent and reduce air absorption and the lifespan of filaments in PLA filaments, thus helping users of 3-dimensional printing produce better results.

Keywords. *3D Printing, Filament Storage, Polylacticacid (PLA)*

1. Introduction

Additive Manufacturing (AM) technology is an manufacturing activity that build 3D components using materials in the form of polymers, concrete, metal or composite materials [1]. Based on research conducted by Herianto, in his journal entitled "The framework predicts the use of 3D printing in Indonesia in 2030", 53% of additive manufacturing methods are predicted to be used in industrial processes [2]. This shows that technology Additive manufacturing is one of the options in product manufacturing. The most common problem in using 3D printing is wet filaments. One of the effects of absorbing water into the 3D printing filament is to make components brittle, produce porosity, and affect the flow characteristics and macrostructures produced from FDM parts [3].

2. Literature Review

2.1. Additive Manufacturing

Additive Manufacturing (AM) is a manufacturing activity that build 3D components with materials in the form of polymers, concrete, metal or composite materials [1]. Additive manufacturing involves 3 important aspects, namely making designs with a computer or Computer Aided Design (CAD), cutting and manufacturing 3D lines with slicing software and printing using 3D printing methods [1].

Common methods in 3D printing consists of Stereolithography (SLA), Selective Laser Sintering (SLS), Digital Light Processing (DLP), Fused Deposition Modelling (FDM), Selective Laser Melting (SLM), and Electron Beam Melting (EBM) [2]. However, according to global technology & telecommunications research expert Thomas Alsop, the FDM method is the most used method since 2020 as a 3D printing method.

2.2. PLA Material Characteristic

Polylactic acid (PLA) is a bioplastic material made from organic materials such as corn, sugar cane and wheat [1]. Based on the nature of the material, PLA is a hygroscopic material, which means that it can absorb water contained in air humidity, thereby reducing the quality of the filament [4].

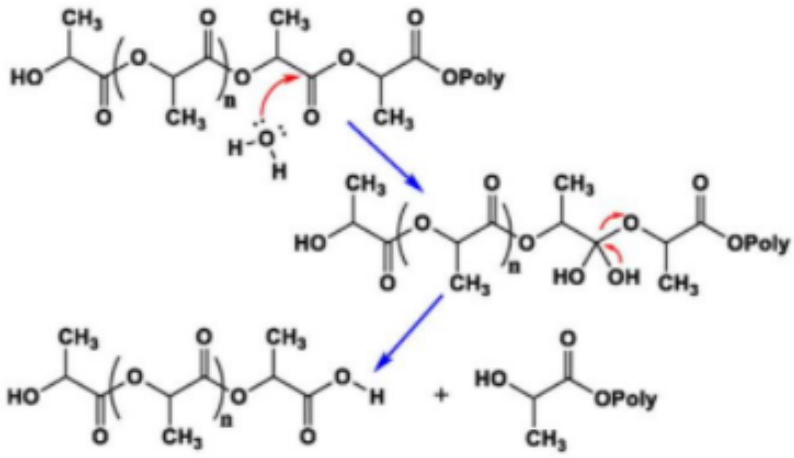

Figure 1. Chemical structure and degradation of PLA.

PLA has hydrolytic properties which are material properties which can be degraded by water [5]. According to Victor Ugaz, a teaching lecturer in chemical engineering from A&M university as stated on the youtube channel "Victor Ugaz", the hydrolytic degradation process of PLA as illustrated in figure 1 above begins with the input of water chemical groups (H2O) into the PLA chemical groups (C3H4O2). The H20 group then breaks the bonds of the C3H4O2 group into C3H5O2 bonds, resulting in the degradation of the PLA material [6].

2.3. MDF material

To keep the temperature in the filament storage from getting too hot, the material used is engineered wood material such Medium Density Fiberboard (MDF). MDF is an engineered wood product made by breaking hardwood or softwood into wood fibers, and combined with a resin binder to form wood panels [7]. Based on MDF standardization data (SNI - 01-4449-2006), the suitable MDF material to be used is MDF type 30 material which has a fracture modulus (MOR) of 30 Kgf/cm^2 and a modulus of elasticity (MOE) of 2500 Kgf/cm^2.

2.4. Aesthethic Quality Index

One of the problems that occur in 3-dimensional printing is the problem of aesthetic quality.

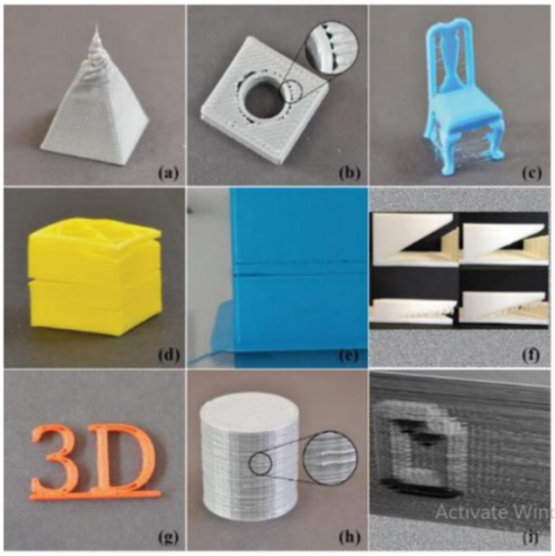

Figure 2. Bad 3D printing illustration.

According to the research conducted by Galati Manuela in a journal entitled "A methodology for evaluating the aesthetic quality of 3D printed parts", common problems that often arise in FDM printing as shown in Figure 2 are as follows [8]:

- Overheating, (Figure 2-a) is a condition that occurs when the next layer is deposited while the polymer material in the previous layer has not cooled.
- The gap between the contour and the fill, (Figure 2-b) is the gap formed during filling even though the Infill strategy setting is at 100%
- Stringing, (Figure 2-c) is a thin filament plastic left by the extruder during the extrusion process.
- Layer separation (Figure 2-d) is a condition which occurs because the extrusion temperature is too low.
- The missed layer (Figure 2-e) is a mechanical fault condition in which there is a problem in the filament drive mechanism that prevents the material from being extruded and deposited properly.
- Whiskers on the overhang (Figure 2-f) is a condition where the machine fails to print the hanging feature properly, Overhang itself is a condition of the layer that is not properly supported by the support layer.
- The gap in the wall layer (Figure 2-g) is a condition where the width of the wall in the design is not an integer multiple of the nozzle.
- Blobs and pimples (Figure 2-h) are referred to as excess material that can be observed at the beginning or end points of the printing path in the same layer.
- Rings (Figure 2-i) which are wavy patterns that appear on the printed surface.

Based on an experiment conducted by Stevan on his YouTube channel "CNC Kitchen", one of the phenomena that occurs in wet PLA filaments is foaming and hydrolysis [8]. Foaming is a condition where water evaporates inside the filament when the filament is heated through the hot end and produces holes and results inconsistent extrusion. Hydrolysis occurs when the polymer chain contained in the filament PLA becomes damaged by water and causes the filament to become brittle. One of the signs that can be seen in wet filament printing results is that there is stringing in the printing results even though the machine is properly calibrated.. To evaluate the aesthetic quality in 3-dimensional printing, the Aesthetic Quality Index (AQI) calculation method is used where this calculation method can be determined by the following equation as shown on figure 3 [9].

$$AQI = OH + GACL + STR + DEL + NOWH + \mathrm{NOSUPbridge} + \mathrm{NOSUPshell} + \mathrm{BL} + \mathrm{RIN}$$

Figure 3. Aesthetic Quality Index Equation

In this method, AQI is assumed to have a value ranging from 0 to 18 where 0 is the worst value. Definitions of other equation components can be seen in table 1 below.

Table 1. Aesthetic quality index component definition table

Type	Component Name	Indicator Level		
		High (2)	Medium (1)	Low (0)
Overheating	OH	No Effect	Slightly	Print deformation
Gaps between contour	GACL	No gaps	Slight gaps within range of 5% but below 10% of printing surface	Gaps with more than 10% of printing surface
Stringing	STR	Limited Stringing	Slightly Stringing	Stringing all over printing surface
Layer Skipping	DEL	No Effect	One Layer Skipping	More than one layer skipping
Printing without whisker	NOWH	No Whisker Effect	Whisker on slopped 30° angle surface	Effect visible within all surface
Bridge without support	$NOSUP_{bridge}$	Bridge printed perfectly	Bridge is partially missing	Bridge Collapsed
Gaps between shell	$NOSUP_{shell}$	Printed perfectly	There is gap in the print surface but the component didn't collapse	Component Collapsed
Blob	BL	No effect	Blobs only on upper surface	Theres blob effect in all surface prints
Dering	RIN	No effect	Partially effect	Effect is significantly seen

3. Data Collecting Process

3.1. Design Process

The procedure for design process of PLA filament storage are as shown on figure 4 below:

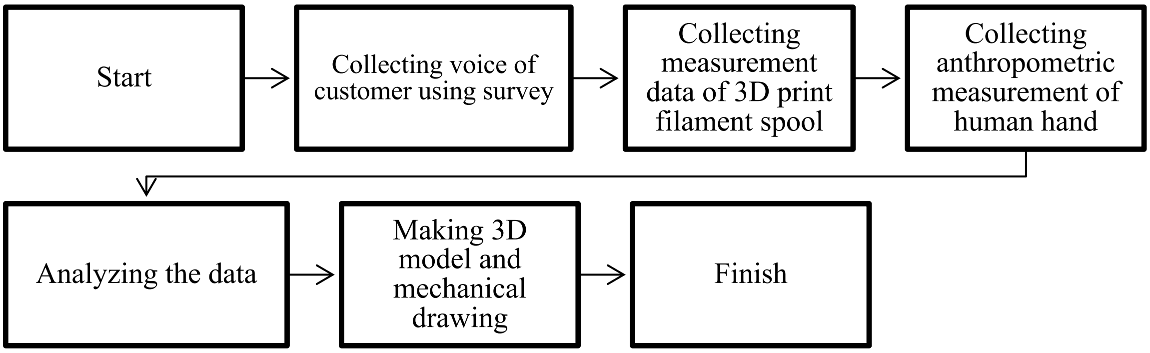

Figure 4. Design process flow chart

Design process for design and manufacturing of PLA storage begin with collecting voice of customer via survey on 3d printing community in Indonesia. The data gathered from survey will consist of which brand of PLA are used often, which problem that frequently occurs in the community and which function they want the most in PLA filament storage. The data collection then continued with gathering measurement data of operator hand and dimension of filament spool that are available on the market. The data then analyzed using kano model and Pugh matrix method to determine which function should be prioritized before making 3D model and mechanical drawing of the product.

3.2. Data collection diagram of 3dimensional printing
The procedure for data collection of 3D printing results is as shown on figure 5 below:

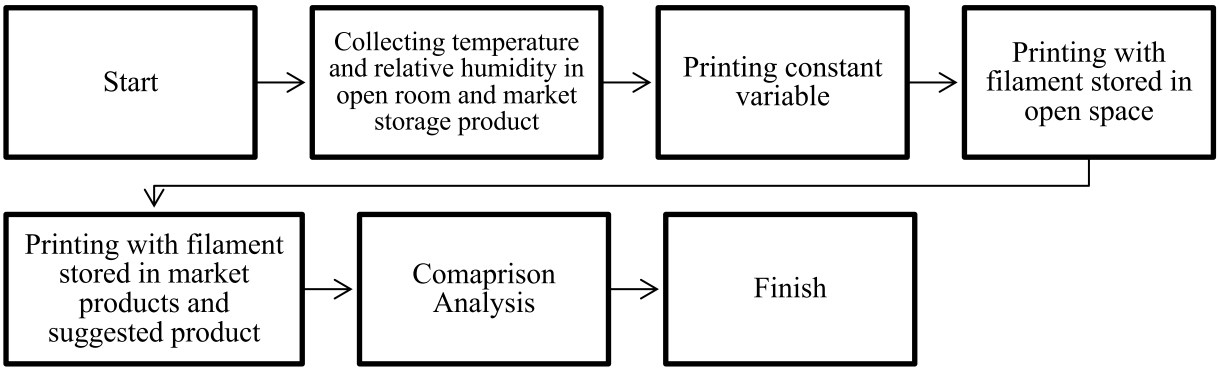

Figure 5. Experimental procedure flow chart schematic

Normal room temperature and humidity data collection is done to get the average normal room temperature and humidity within 1 hour 40 minutes. This data will then become a constant variable which will be compared with the humidity conditions in the filament storage on the market and with the proposed product. The printing will use a “benchy” 3D dimensional design. 3D benchy is used because it has geometric features that are challenging to print, such as curved surfaces (hulls), small surface details (writing on the stern of ships), cylindrical shapes (chimneys), flat overhangs (rectangular roofs and window tops), sloping surfaces low, and circular horizontal holes (windows) [10].

4. Analysis Moisture Effect on PLA Filament Storage
Based on research procedure above, the analysis of moisture effect on PLA Filament aesthetic quality are as following.

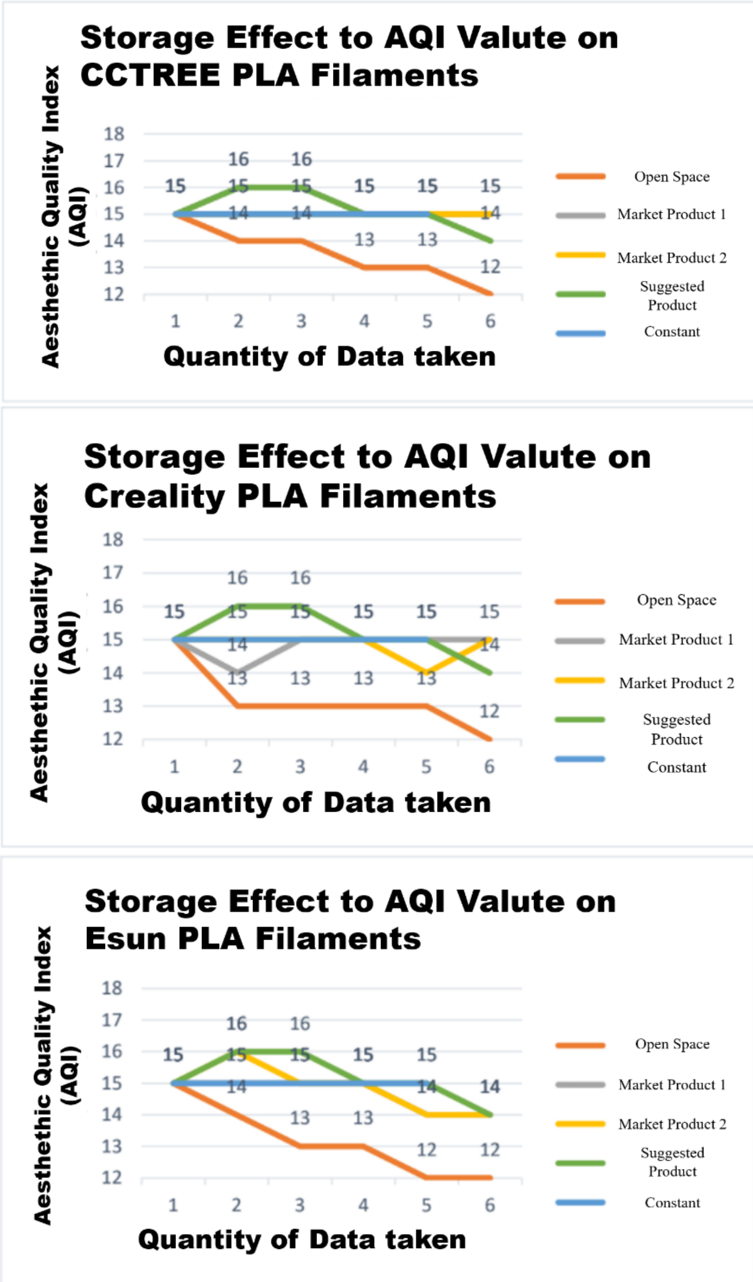

Figure 6. Effect of AQI Value of storage condition

Open space refers to the filament that stored in open space area and exposed to humidty in open air. Market product 1 refers to drybox and market product 2 refers to vacuum bag used in this research. Suggested product refers to the filament storage box which is made using MDF material and Egg incubator heater. The filament brand used in this research are CCTREE, ESUN and Creality. The moisture level during this research range from 60-70%. In CCTREE filament, the AQI value will be constant at 16 if stored in Fillabox and drybox products rather than open space. This shows that the Suggested product is equal to market product 1 in terms of value aesthetic quality index (AQI) and is able to improve quality printing. When compared to storage in market product 2, the suggested product is superior because it can produce quality values good aesthetics and stable. In addition to the creality filament, the AQI value will be constant at 16 if stored in the suggested product. When compared to the increase scores from 14 to 15 on market product 1, the suggested product is superior. This indicates that for the creality filament, storage at suggested products increase AQI scores more effectively than with storage in market product 1. In addition, the AQI value of the suggested product is at a stable value and close to market product 2. This shows that the filament that has produced bad printing quality can produce good quality if using the suggested product.

For esun filament, the AQI value will be constant at 16 before dropping to a value of 15. When compared to the market product 2 or 1 which there is a decrease in value from 16 to 15 Suggested products are superior in increasing the AQI value. This shows that for esun filament, storage on the proposed product will increase the value AQI more effectively.

5. Analysis of MDF material of suggested product

In determining a good MDF material for filament storage, the material specifications are focused on the modulus of fracture (MOR) and modulus of elasticity (MOE) which have specifications that match or are close to the specifications of Type 30 MDF. MDF materials are divided into several variations based on the constituent materials. including the following [7].

Table 2. MDF material specifications based on the constituent materials

Materials	Adhesive	MOR (MPA)	MOE (MPA)	Water Absorbtion (%)	Thickness Increase (%)
Hazelnut stray	Urea Formaldehyde	18.6-20.3	2320-2852	69-86	-
Hazelnut husk	Urea Formaldehyde	13.9-27.8	1481-2635	78-98	21-23.5
Bagasse	Urea Formaldehyde	24.3-27.7	2850-4443	84-92.7	7.8-15.9
Kenaf	Urea Formaldehyde	24-48	2669-3775	63.2-92	14.6-21
Corn stalk	Urea Formaldehyde	22.10-22.6	1795-1950	-	25.21-25.55
Cotton stalk	Urea Formaldehyde	17.61-22.40	1494-1896	-	29.35-31.37
Wheat stalk	Urea Formaldehyde	16-30	2500-3200	-	3.0 – 33.0
Soybean stalk	Urea Formaldehyde	17.5-30	2250-3100	-	2.5-1.7
Peanut husk	Urea Formaldehyde	13.52-13.86	2054-3344	43.34-73.34	8.13-12.08
Canola straw	Urea Formaldehyde	17-21	1750-2250	-	33.96-37.34
Oil palm empty fruit bunch	Urea Formaldehyde	13.4-43.4	1183-2838	51-88.3	14.8-30.69
Sisal	Urea Formaldehyde	42.9-52.3	3799-4730	22-54	8.0-24.0
Coconut coir	Urea Formaldehyde	0.8-0.5	100-2250	-	-

Based on the results of the material specifications in table 2 above, the type of MDF used will be based on material from bagasse. MDF board made of bagasse has a relatively high fracture modulus of 13.9 - 27.8 MPA and a relatively low modulus of elasticity of 1481-2635 MPA. In addition, MDF made from bagasse material has a low thickness addition of 21-23.5%. This is also in accordance with the SNI specification standard for MDF material (MDF) Type 30 where type 30 MDF material has a fracture modulus for dry MDF of 30.0 Kg/cm^2 , 306.0 Kg/cm^2 and wet of 15.0 Kg/cm^2 , ≥ 153.0 Kg /cm^2 . while the modulus of elasticity is 2500 Kg/cm^2.

6. Conclusion

Based on the results of the analysis carried out, the following conclusions are as follows:

- Filaments stored in the proposed product will be more effective lowers stringing, blobs compared to filaments which left in the open.
- Filaments that are left in the open will reduce the quality of the printing results when left for 2 weeks with 60-70% humidity.
- MDF material was chosen because it is flat, cheap and easy to work with. The type of MDF used is bagasse-based MDF material.

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