DIMENSIONAL ACCURACY OF FUSED FILAMENT FABRICATION BY CASSAVA ADHESION ON PRINTING PLATFORM

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ABSTRACT: This paper examined the dimensional accuracy of fused filament fabrication (FFF) model when cassava based adhesive was moistened onto the printing platform. The cassava based adhesive was prepared by mixture of 0.1M of hydrochloride (HCl) , 0.1 g of cassava starch and 0.15g sodium borate and the bonding strength of 3D printing part and glass with cassava based adhesion were obtained using ASTM D2095. Test specimens model of 100×30×10mm^3 with centre cavity of 24x60mm^2 were fabricated by Pursa i3 machine using both ABS and PLA and varying side angles with by cassava pre-moisted on the heated printing platform. The dimensional accuracy of the warping deformations of curling, overhang, side and internal shrinkage were measured. The results show that cassava based adhesives has generally successfully reduced the curling effect for both ABS and PLA material. There was a downward trend for increasing side angles for curling, overhang and internal shrinkage but for all test specimens has lower percentage error of less than 10%. In addition. the internal shrinkage had not be affected by variation change of angles. Though the finding shows warping deformation still existed in FFF, cassava starch adhesive can be recommended as promising replacement to synthetic based adhesive.

KEYWORDS: *Fused Filament Fabrication; Cassava Starch; Bio-Based Adhesive; Layer Adhesion; 3D Printing*

1.0 INTRODUCTION

Additive manufacturing or best known as 3D printing is a process of fabricating prototype, object or part where the process starts from solid modelling drawing before the digital file is transferred to 3D printer machine where process parameters are set up. Then, material either in the shape of filament, powder or liquid is printed in which layer by layer technique is utilized. Lastly, as it undergoes the post processing step, support structures are removed, surface finish is improved and parts are completely fabricate.

There are many 3D printer technologies around, however fused filament fabrication (FFF) remains the most common techniques. The recent growth of open source 3D printer is mainly due to this technology alone since it is simple to use and regarded as an eco-friendly machine. FFF works on the principle of extruding a thin layer of plastic material on the printing platform before it is slowly lowered down and the sequence layer is continually added and bonded with the previous layer. The process is repeated and the desired model is gradually built up from the bottom. However, as the layer of plastic material harden, plastic filament which is extruded from the machine tends to shrink and warp due to uneven distribution of heat and generates internal stresses from the printing bed platform [1]. This behavior is known as curling effect in FFF where the dimensional accuracy of the fabricated part is highly affected. Besides the curling effect, other warping effects such as trapezoid deformation, pincushion and blocked shrinkage may exists and would prevent acceptable end product [2].

Although the process of FFF fabrication is simple and automated, the dimensional accuracy and the quality of the end product sometimes frustrated consumer which lack the knowledge of engineering process and the drawback of FFF process. Furthermore consumer may be unfamiliar with the process parameter and the material of FFF, thus this might limit the user to machine control of 3D printer. In order to reduce the warping deformation in FFF, some manufacturer suggests on using synthetic adhesives and applied them onto the printing platform. Moreover, manufacturer may suggest using heated printing platform to improve the first layer adhesion. Other researcher such as Galantucci et al. [3] moistened the printing platform with dimethylketone (acetone). Nazan et al. [4] had tested synthetic adhesive and also bio-adhesive of soy and cassava to minimize the curling effect in FFF and recommended them as promising replacement. In addition, improvement in dimensional accuracy of open source FFF machine has been reported in [5-8].

Therefore, the purpose of this study is to examine the dimensional accuracy of FFF part by the percentage error of curling, overhang, side shrinkage and internal shrinkage when cassava based adhesive is pre-moistened onto the heat printing platform before deposition started.

2.0 METHODOLOGY

2.1 Tensile Bond Strength of Printing Part

In order to obtain the bonding strength of 3D printing part and glass with cassava based adhesion, standard test method for Tensile Strength of Adhesive by Means Bar and Rod Specimens was employed such in Figure 1 [9]. This test had been performed using Instron 5582 Universal Testing Machine. The cassava based adhesive was prepared based on Akhabue et al. [10] where 0.1M of hydrochloride (HCl) acid was pre-heated to 100˚C and then mixed together with 0.1g of cassava starch and 0.15g sodium borate. The mixture was stirred until a homogeneous mixture was obtained. Afterwards, it was left to cool at the room temperature , 30°C for 2 hours. The substrate for tensile test consists of a 12.7 x 12.7 x 3mm^3 glass which was moistened with cassava based adhesive before a bar with size of 12.7 x 12.7 x 5mm^3 was printed onto the glass using Pursa i3 FFF machine. Both the top and bottom adherend held the substrate together by epoxy glue and then underwent tensile strength testing. The maximum stress and maximum strain was recorded.

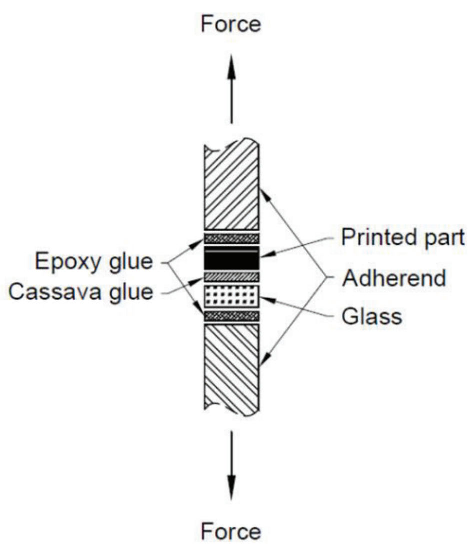


Figure 1: The setup of ASTM D2095 tensile strength of adhesive by means bar and rod specimens for cassava based adhesive

2.2 Test Specimens Preparation

A CAD solid model for the test specimens was proposed as shown in the 2D drawing of Figure 2. The model had outer dimensions of 100 x 30 x 10mm^3 where each of the side angle, θ was varied by 15º, 30º, 45º and 60º. On the top view of the drawing, a cavity with rectangular size area of 24 x 60mm^2 was designed at the centre. The reason for the varying angle and the cavity design was to investigate the effect of overhang and shrinkage due to the FFF process.

The model was prepared by CATIA V5 software and it was sliced by Repetier Hosts software. The parameter slicing of infill density, layer temperature, printing speed and layer height was set to 13%, 190ºC, 40mm/s and 0.2mm respectively and with no additional support structure. Pursa i3 FFF machine was used to fabricate the model where the maximum built area of glass printing platform was 180 x180 x 150mm^3. Before the printing process began, the printing platform was applied thoroughly with cassava based adhesive. Overall, eight test specimens were produced where θ value and the ABS and PLA filaments were varied. In addition, the printing platform is heated at 60ºC and 100ºC for ABS and PLA, correspondingly.

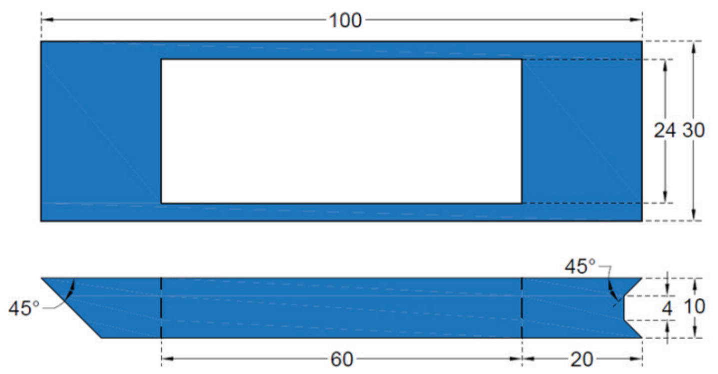


Figure 2: The test specimens is based on the CAD solid model size where the dimensions are represented in the 2D drawing

2.3 Warping Deformation Measurement

Test specimens of 3D printing were measured their dimensional accuracy by using Rexscan CS2+ laser scanner and Geomagic Quality 2013 software. Four areas such as curling effect, overhang effect, side shrinkage and internal shrinkage had been quantified such as illustrated in Figure 3. The errors for each of the warping deformation were calculated based on Schmutzler et al. [2] and presented in Equations (1)-(4).

The curling errors were obtained by Equation (1) which is the differences of deflection, ΔH in the printed model at y-direction where is H1 is the distance the last layer from the printing platform and H2 is the length of the side.

$$\text{Percentage of curling error, } \Delta H = \left|\frac{H_1-H_2}{H_1}\right| \text{ x } 100\% \quad (1)$$

Whereas, the overhang effect is considered when the elements of frame extend outward over and was measured by the percentage of overhang error, Δh is obtained by the difference of overhang height in the printed model, h and original height in CAD, hCAD in Equation (1).

$$\text{Percentage of overhang error, } \Delta h = \left|\frac{h-h_{CAD}}{h}\right| \text{ x } 100\% \quad (2)$$

The side shrinkage errors and the internal shrinkage errors were measured by the difference of length element, l and the cavity areas, A of printed model and CAD, respectively.

$$\text{Percentage of side shrinkage error, } \Delta l = \left|\frac{l-l_{CAD}}{l}\right| \text{ x } 100\% \quad (3)$$

$$\text{Percentage of internal shrinkage error, } \Delta A = \left|\frac{(bd)-(b_{CAD}\,d_{CAD})}{(bd)}\right| \text{ x } 100\% \quad (4)$$

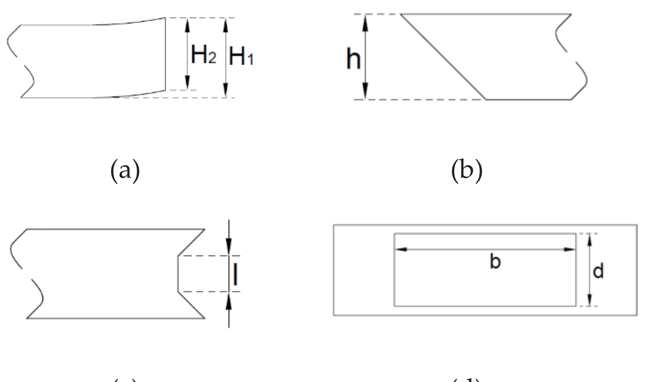


Figure 3: Warping deformation of (a) curling effect, (b) overhang effect, (c) side shrinkage effect and (d) internal shrinkage effect

3.0 METHODOLOGY

3.1 Result of Tensile Bond Strength

Figure 4 demonstrates the effect of cassava adhesion when printed part attached to glass. The obtained maximum stress, σmax = 0.3236 MPa while the maximum strain, ε = 0.0221. The tensile part is failed at the cassava adhesive layer and not at the printed part. This shows that the bonding strength of cassava between printing part and glass is weak but it is good enough to support the first layer from warping and peel away completely. In some experiment without any pre-applied adhesion on heat printing platform, the printed part was unable to stick with the glass at all and part unable to be printed. Hence it is suggested that the first layer didn't need to be completely bonded with the glass to reduce warping deformation. Moreover, if the adhesive is stronger than the bonding within the printing layers, the post-processing difficulty of removing the adhesion between printed part and glass will be high.

In comparison to Nazan et al. [5], the cassava adhesion is considered slightly weaker compare to the epoxy adhesion (σmax = 1.2233MPa). However, the cassava adhesion performed twice better compared to soy based adhesive (σmax = 0.1917MPa). Therefore, cassava adhesive could be more preferable bio-based adhesive.

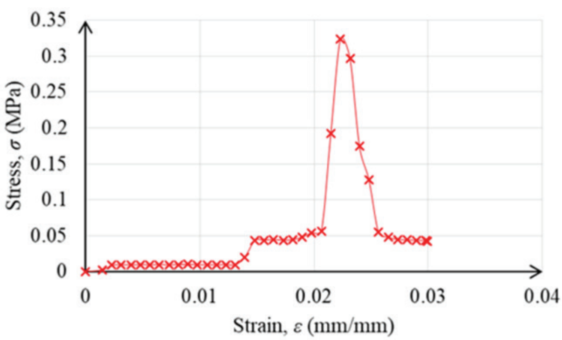
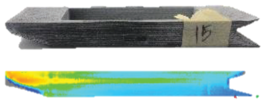
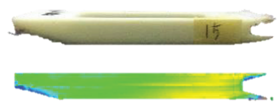
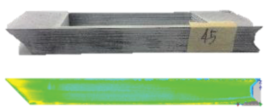
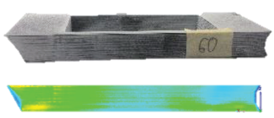
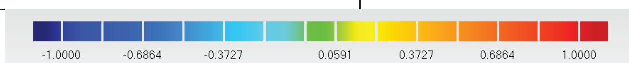


Figure 4: Stress-strain curve for cassava adhesion of PLA printed part and glass

3.2 Effect of Printed Part

Table 1 shows the result of eight printed test specimens. It can be illustrated from the deviation spectrum that generally both PLA and ABS has low warping deformation. However, at θ = 15°, there was a higher overhang effect. This shows that with both heated printing platform and cassava based, overhang was not fully solved.

Table 1: Differences of printed test specimens for PLA and ABS from 15º to 60 º

Angle	FFF Materials	
	PLA	**ABS**
15 º		
30 º		
45 º		
60 º		
 **Deviaton spectrum**		

3.3 Dimensional Accuracy of Printed Part

Figure 5 indicates the results for all warping deformation that was attained from the experiments. In Figure 5(a), the result shows that there was a downward trend for both ABS and PLA material when the side angle increased from θ = 15º to θ = 60º. Moreover, it can be seen that ABS generally had higher percentage error. This is due to higher shrinkage properties of ABS compare to PLA material Although there was a slight differences, the percentage errors for all test specimens were rather acceptable with value of less than 9%.

The overhang effect in Figure 5(b) also shows the same downward trend as curling effect. For both ABS and PLA, when θ = 15º, the percentage of errors were about 60% which were considered failure. In contrast, for other overhang degree, the percentage of error was acceptable with value less than 10%. This results show that the use of cassava adhesive able to fabricate overhang structure when the θ value was more than 30º. For all experiments that implement θ = 15º, it is suggested the use of support structures.

For Figure 5(c) the side shrinkage has also downward trend with percentage error value of less than 10%. It was thinkable that the higher the side angle was, the higher the length, l would get shorten. While for result of internal shrinkage in Figure 5(d), the percentage of errors for both ABS and PLA might be insignificant which were quite low at less 3%. This might be due to the internal shrinkage in this study may not be one of the warping deformation factor in FFF. Since the design location of cavity was at the center and curling only occurred at the end of the specimens, the specimens may not be influenced by the curling effect and would result a low deformation.

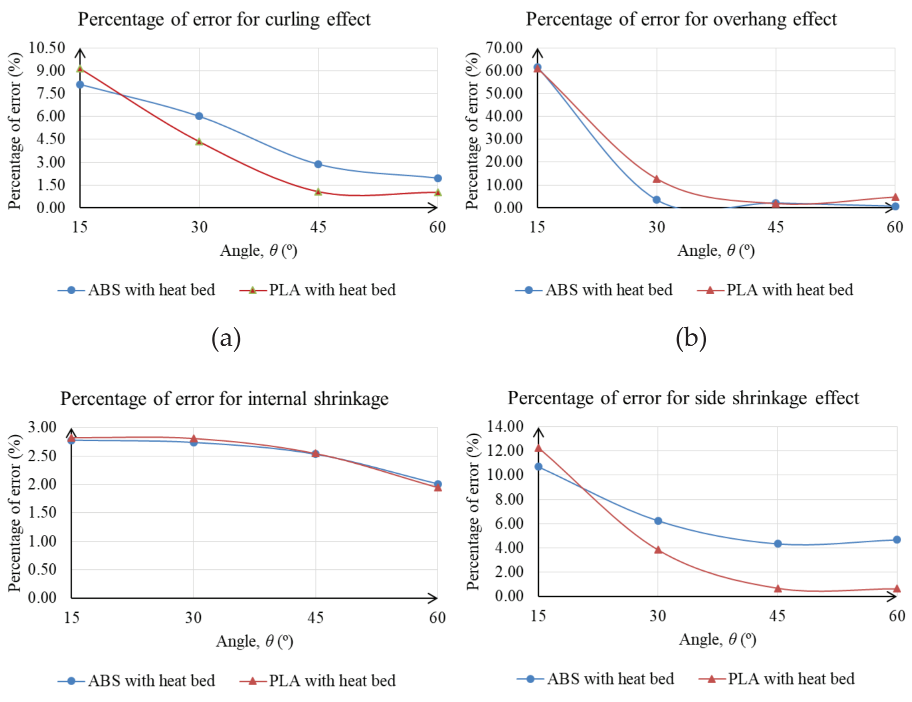


Figure 5: Percentage of error for (a) curling effect, (b) overhang, (c) side shrinkage and (d) internal shrinkage

4.0 CONCLUSION

Based on the results, it shows that cassava based adhesives had generally successfully reduced the warping deformation both ABS and PLA material. Although its weak bonding at between printed part and glass, it is good enough to support the first layer from warping and peel away completely. The part with less than 15º, might not be effectively printed by FFF due to the overhang effect. There was a downward trend for increasing side angles for curling, overhang and internal shrinkage but for all test specimens has lower percentage error of less than 10%. Lastly, the internal shrinkage had not be affected by variation change of angles. Although the finding shows warping deformation still existed in FFF, cassava starch adhesive can be recommended as promising replacement to synthetic based adhesive.

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