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Overhang Analysis Fabricated Using Fused Deposition Modeling Technique

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Abstract: Additive manufacturing (AM) is a process using layer by layer additive technique to fabricate the entire 3D models into a functional component. One of the most popular AM technology is fused deposition modeling (FDM) that utilizes thermoplastic filaments as the materials. AM has the ability to produce complex structure easily without additional tool and fixture, therefore, it can save the overall manufacturing process. However, without optimum design and parameter settings, FDM has a limitation in printing overhang structures. Therefore, this study aims to analyze three types of pass-fail overhang features which are draft angle, overhang length and overhang angle varied accordingly to their respective length and angle. These pass-fail features were fabricated using the FDM 3D printer with standardized 3D printing parameters. The dimensional accuracy of these features was evaluated using an image analyzer. The results showed that the allowable overhang length to be produced is starting from the length of 0.5 mm to 1.5 mm. Meanwhile, for the draft and overhang angles, the allowable angle to be produced is ≥ 50.00 mm and ≤ 45.00 mm, respectively. From this study, it highlights the limitations of the overhang pass-fail features and provide the designer with the design information to help them designing the optimal design solution using FDM.

Keywords: FDM, overhang, overhang angle, draft angle, overhang length, manufacturability analysis

1. Introduction

Additive manufacturing (AM) is a manufacturing technology that uses layer-by-layer processing technique to build the entire parts based on its 3D CAD model as input. According to ISO/ASTM 52900:2015, there are seven types of AM technologies. They are selective laser sintering (SLS), direct metal laser sintering (DLMS), fused deposition modeling (FDM), material jetting, binder jetting, directed energy deposition (DED) and sheet lamination [1]. AM provides a lot of potential and benefits, however, the technology still requires high experimental works especially for the development of quality end-use parts. There are a few factors that affects the fabrication process of the printed part especially when using the fused deposition modeling (FDM) technique. FDM utilizes the material extrusion technique of thermoplastic materials to develop the parts. One of the limiting factors that suppress the establishment of AM in the industry is insufficient of comprehensive design rules and design guidelines for AM [2]. Therefore, the manufacturability study of AM was performed using the benchmarking model. Benchmarking is referred as a level of

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quality that can be used as a standard when compared with other mechanism. It can also be referred as a standard point of references in measuring the quality of the printed parts [3]. Benchmarking is classified into three types which is geometric benchmark, mechanical benchmark and process benchmark. Geometric benchmark measures geometric features or part that includes tolerance, accuracy, repeatability and surface finish. Whereby, mechanical geometric analyzes the mechanical properties such as tensile strength and compressive strength. Meanwhile the process benchmark focuses to optimize the parameter settings to determine the optimum setting for process fabrication [4].

Nowadays, materials for FDM technique is not only restricted to thermoplastic materials such as acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA), but, the composite materials have been introduced to reinforce and consolidate the printed part to improve their strength and stiffness [5]. FDM offers big advantages, especially in producing the prototypes at a lower manufacturing cost and small batch production. However, one of huge limiting factors using this process is the need of structural supports for overhanging geometries. In these geometries, the building angle becomes more acute and the support structure need to be diminished [6]. Previously, the manufacturability of the overhang structure has been discussed that involves the features such as bridges [1] [7] and angles [8]. The main discussion of the overhang is the need of support structures to ensure the geometries are successfully fabricated without any defects and disability. However, the support structures take a longer time to build, thus, adding the material costs. Worsen, once the support structures removed from the parts, it may affect the dimensional accuracy and surface finish of the printed part, hence, the post-processing process needs to be executed for bringing the components to the desired quality. One of the known post-processing techniques is by using the chemical treatment [9] that can improve 90% of the surface finishing of the parts. Therefore, in this study, overhang structures with three types of pass-fail features were developed, fabricated and analyzed in order to measure the allowable measurement length and angle. The main aim is to produce a successful overhang without the support structures. The part's investigated include overhang length, overhang angle and draft angle. The detail descriptions of the respective overhangs are discussed further in the methodology sections.

2. Literature Review

According to Adam and Zimmer [1], overhang is an aggregated structure that needs to be designed with element orientations that does not require the support materials. A study by Johnson et al. [10], evaluated the benchmarking using various types of manufacturing features in one built platform. The results showed the overhang angles can only be fabricated with the measurements of 45 degrees and 50 degrees. Besides that, other basic manufacturing features were also investigated such as cube, ring, cylinder and slot to study the dimensional accuracy and surface roughness of the parts [11]. The process parameter optimization towards different manufacturing features was also studied. For example, Miguel et al. [7] investigated the process parameters that affect the fabrication of overhang structures using FDM. Overhang angles and bridges were fabricated and the results showed that the layer thickness has a great influence to produce the successful overhang printed part. The investigation of process parameters in FDM is not only focusing on the overhang structures only, but, other manufacturing features were also reported. Variable parameters to validate the pre-process design have been conducted to achieve better manufacturability in AM [12]. Besides FDM, other AM technology such as selective laser melting (SLM) or selective laser sintering (SLS) also undergone similar design constraints. In SLM, variety of elemental metals and alloys are used because they can produce excellent surface finish compared to FDM. This is due to the laser-based processing technique if compared to the nozzle-based from FDM. Moreover, the laser used in SLM has also proven to be industrial safe [13-15].

Literally, few attempts have been made to cater the overhanging problems in various types of AM processes [6] [16-17]. For example, Leary et al. [6] developed a strategy to minimize the use of support material using the geometric limits comparison that integrated with the feasible building orientation. Besides that, a tool to improve the surface finishing of overhang parts was also developed to eliminate the staircase effects that also support marks [16]. Topology optimization is one of the design methods to improve an overhang structure. A study by Leary et al. [6] modified the theoretical optimal topology to ensure the manufacturability of overhang structures without requirements of additional support materials. A case study presented the modified topology optimization can successfully enable the support-free AM of FDM structures. The other simplest method to improve the overhang quality is by using the optimization of process parameters. Various printing parameter settings such as layer thickness, road width and speed deposition were studied [13]. The optimization of process parameter was executed to get the optimal results of the printed part qualities such as dimensional accuracy, mechanical strength and surface finish [18-19].

In this study, the manufacturability analysis of the overhang structure was analyzed based on three types of overhang design which are overhang length, overhang angle and draft angle. The design development of the overhang and parameter selections were determined.

3. Methodology

Several overhang structures, as shown in Table 1, were developed. Each of the structures consists of various dimensional measurements. Table 1 provides a visual presentation of the CAD model envelope that was designed using

Solid works. Three different types of pass-fail features of overhang were prepared for the experiments. They are overhang length, overhang angle and draft angle.

Table 1 - 3D CAD of overhang features

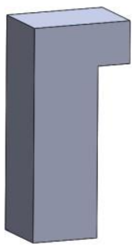
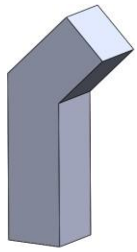
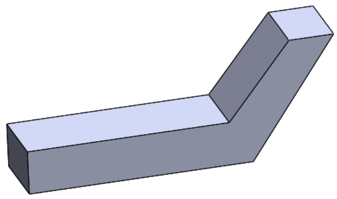
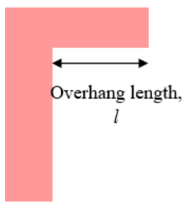
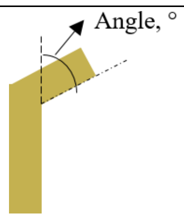
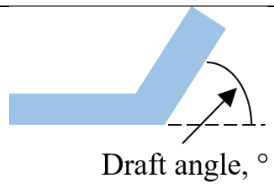
Geometry feature	Overhangs (Length)	Overhang angle	Draft angle
3D CAD			

Table 2 - Details descriptions of overhang structures

Geometry feature	Overhangs		
	Length	**Angle**	**Draft angle**
Design			
Group	Aggregated structures	Aggregated structures	Element transition
Pass-fail features	Overhang length	Overhang angle	Draft angle
Guide	Length, *l*	Angle, °	Draft angle, °

In Table 2, each of the overhang types has been categorized according to their respective pass-fail features. Generally, pass-fail feature was defined as a feature that has the possibilities to be successfully fabricated or not successfully fabricated using AM. These terms provide a grading to determine the manufacturability and quality of the printed part. Overhang is categorized as an aggregated structure which can also be described as a bridge. The first testify overhang is the overhang length. In this experiment, overhang length referred at length (*l*), which the measurements were varied from 0.5 mm to 4.0 mm. Meanwhile, the overhang angle with the guide, angle (°), has a measurement from 10 to 70 degrees as well as the draft angle. Overhang angle and draft angle shared the same guide which is "angle", however the different between these two features is the position of the angle in the features. Compared to injection molding, the draft angle is referred as a slant that is applied to each side of most features of an injection molded part, where the angle is positioned to run towards the directions of a mold's pull and parting line that helps to release the part from the mold. Therefore, it was called as an injector draft angle. Meanwhile, for draft angle in AM, the slant is measured from the horizontal surfaces from the bottom side to the upwards position and mostly recognized as the self-support draft angle. Figure 1 shows the comparison of the draft angle between injection molding and AM. Finally, the overhang angles measured based from protruding features to the curve upwards (see Table 1).

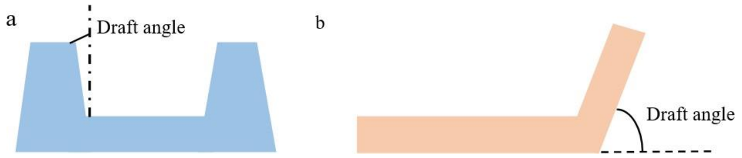


Fig 1- (a) draft angle in injection mold; (b) draft angle in AM

3.1 Experimental Setup

FDM 3D printer using material extrusion technique (see Figure 2) was used to carry out the experiments. The build area for this printer is 250 mm width x 250 mm length x 200 mm height. All of the parts to be printed must be less than this calculated area to produce successful printed parts. The material used in this experiment is thermoplastic Polylactic Acid (PLA) with the filament diameter of 1.75 mm and extrusion temperature is between 195 and 215 degrees. PLA is used in these experiments because compared to ABS or other commercialized 3D printing material, PLA has a low temperature, which gives the better adhesion for the overhang layers. In addition, when using PLA, the fan needs to be always functioning to improve the solidification process. If using ABS for example, it was not recommended to use fan because it increased the warping percentage of the printed parts. Therefore, PLA is a suitable material to be used in these experiments. To start printing, the 3D objects need to be sliced using Slicer to convert the layers into G-code format. The actual setting of print parameters is shown in Table 3.

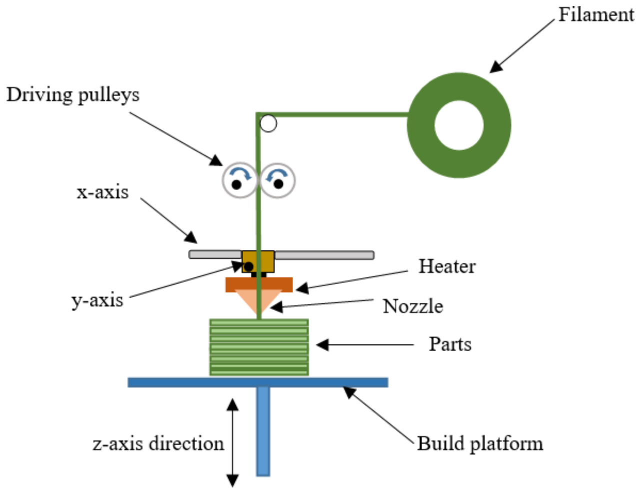


Fig 2 - FDM 3D printer using material extrusion technique

Table 3 presents the selection of parameter settings used in these experiments. The process parameter optimization has firstly conducted using Taguchi analysis. Three levels have been used and three factors were considered which is layer thickness, printing speed and temperature. Meanwhile, the other parameter settings were selected based on the defaults given in the software. The overall discussion on the parameter optimization process do not comprehensively discussed in this paper. Therefore, the optimal results were selected based on the analysis conducted via Minitab software.

Table 3 - Print parameter settings

Parameter settings	Parameter value
Layer thickness (mm)	0.15
Fill density (%)	20
Temperature (Celsius)	195
Fan (mm/s)	225 (maximize)
Print speed (mm/s)	40

In Table 3, the selected parameter setting was used to fabricate the parts. The most important parameter was the layer thickness which was given a smaller value for the thickness (using 0.15 mm) with 0.4 nozzle diameter. This selected value is to give an optimal result for the surface finishing. The selected fill density is 20/100 because the fill density would not affect the end results of the overhang fabrications. However, infill density will impact the mechanical strength of the parts. If the parts require higher strength as the end results, maximum value of infill density must be assigned. In this experiment, the temperature used is 195 degrees because the optimization of process parameter has been conducted as the preliminary results. In addition, the fan must always be turned on with the maximize speed because it speeds up the solidification process of the printed materials. Therefore, the lower the cooling fan speed means the higher the possibility of the filaments to be in the liquid state. Each of the overhang structure was fabricated using this standardize parameter to all of the pass-fail features. After that, each of the respective overhangs was measured using the image analyzer, where the schematic diagram showing the process of capturing the images is shown in Figure 3. This study involves the edges, curves and angles, therefore, image analyzer has been chosen as the most suitable method that can capture the data of those features. This device is able to be zooming up to 0.6 time of magnificent details showing all the layers closely from the parts. Generally, image analyzer using the same concept with the conventional microscope, however, the image can be captured and measured because it was displayed from the LCD screen.

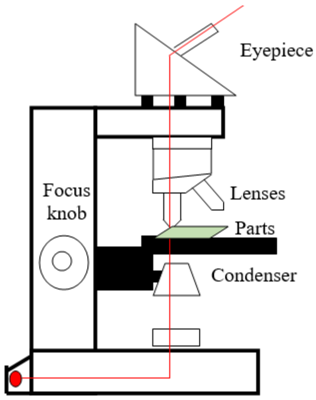


Fig 3 - Image analyzer on the right side

4.0 Results and Analysis

In order to compare the obtained results, image analysis using image analyzer was carried out. The results were based on the deviation value between the actual measurements (printed part) and the CAD data.

4.1 Overhang length

AM printing overhang structures are described as any parts of the print that extending outwards beyond the previous layer, without any direct support structure such as a raft. Rafts and support were very difficult to remove and would contribute to the waste in materials and it is not recommended to be generated unless the functions is necessary. In this experiment, the overhangs tested have twelve different overhang length values starting from 0.5 mm to 4.0 mm. However, the results showed that maximum overhang length that was able to be produced was ≤ 2.00 mm only. Higher than this value, the overhang length started to produce unwanted sagging that slack off under the designed parts. A schematic diagram shown in Figure 4 was designed to illustrate the problems when overhang length was produced more than 2.00 mm.

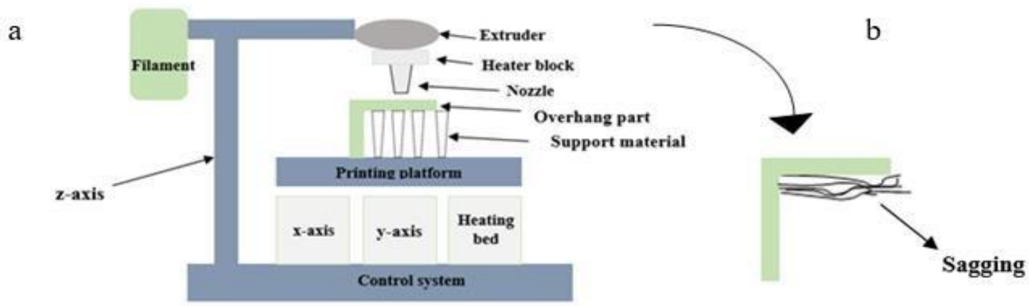


Fig 4 - (a) Overhang successful printing with support; (b) overhang without support

Figure 4 presents two scenarios for overhang fabrication. Figure 4(a) describes the successful fabrication using the generation of support materials, meanwhile Figure 4(b) describes the failure fabrication of overhangs that produced the sagging when support material was degenerating. Sagging of filament is the condition when the filament is drooping from its origin. After it drips, it often leaves agglutinated materials under the original parts. However, the overhang can be successfully fabricated without using the support materials, with some length limitations. In this study, twelve overhang lengths were fabricated and the overall measurements are tabulated in Table 4. The inspection describes whether the overhang is successfully fabricated or not. The results of the inspection were determined by observing the condition of agglutinated filament under the microscope. The higher observation of agglutinated material shows the unsuccessful fabrication of the overhangs part. In addition, Figure 5 shows the successful fabricated overhangs and unsuccessful overhang condition after printing. Table 4 describes the measurements between the CAD data and actual data measured in mm, however, only the measurements from 0.5 mm to 1.5 mm were collected. For the rest of the measurements, proper data could not be collected because there is the disturbance of sagging filament.

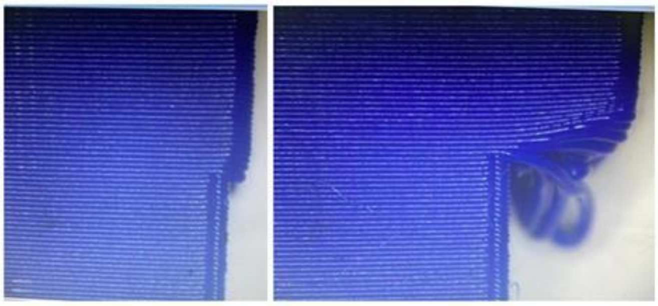


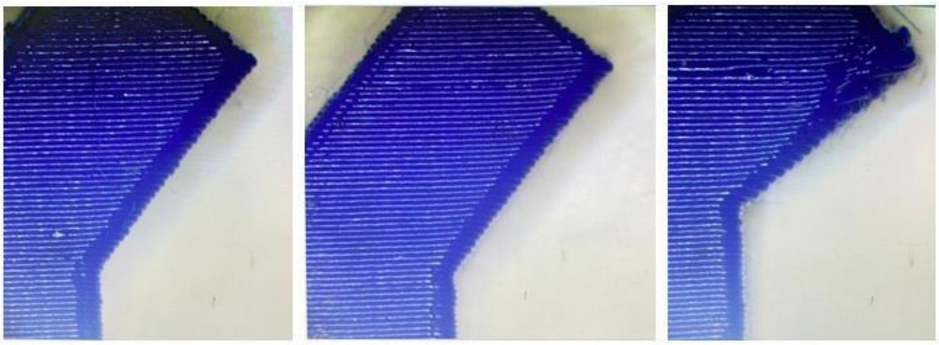
Fig 5 - Examples of successful and unsuccessful overhang length

Table 4 - Overhang length, *l* measurements

CAD data (mm)	Actual data (mm)	Inspection
0.5	0.41	Successful
0.6	0.52	Successful
0.7	0.53	Successful
0.8	0.73	Successful
0.9	0.81	Successful
1.0	0.89	Successful
1.5	1.34	Successful
2.0	-	Unsuccessful
2.5	-	Unsuccessful
3.0	-	Unsuccessful
3.5	-	Unsuccessful
4.0	-	Unsuccessful

4.2 Overhang angle and draft angle

In this study, there are two types of angles to be investigated; overhang angle and draft angle. Overhang angle is measured from the vertical axis, meanwhile the draft angle is measured from the horizontal axis. Both of these features were fabricated using the angle measurements from 10 degrees to 70 degrees. As a result, thirteen samples of overhang angles and draft angles were fabricated, respectively. Figure 6 and 7 present the conditions of the pass-fail features of the overhang angles and draft angles, respectively.



a b c

Fig 6 - (a) Successful overhang angle with 35 degrees; (b) 45 degrees and (c) fail print with overhang angle 70 degrees

Figure 6 presents the results from the image analyzer for the overhang angle that consists of an angle of 35, 45 and 70 degrees. From the figure, it can be observed that the successful overhang angle which is 35 and 45 degrees produces smooth surfaces at the top of the edges. Meanwhile, for the unsuccessful overhang angle, the material lump can be observed on the top of the edges. Therefore, the measurements could not be taken due to the disturbances.

Table 5 and 6 tabulated the overall measurements from the experiments. According to Table 5, overhang angles ≤ 45 degrees were successfully produced. This is because, any layer that is up to 45 degrees has been supported by at least 50% of the layer beneath the structure. In the other words, each new layer to be printed has enough support to remain intact and produce successful overhang angle without any loss of quality. However, for the angles exceeding 45 degrees, the layer is approaching the horizontal and becomes difficult to print. These types of overhang angles are prone to curling, sagging and also de-lamination. Exceeding the 45-degree overhang angles means that the new layer does not have a strong support to bond with which led to a poor quality of printed part with a drooping filament strands and unwanted sagging. The same situation may also be applied to fabricate the draft angles. In contrast with the overhang angles, the draft angle must be designed with more than 70 degrees in order to be successful because it was measured from the horizontal axis instead of the vertical axis.

Table 5 - Overall measurements and inspection for overhang angles

CAD data (mm)	Actual data (mm)	Inspection
10	6.46	Successful
15	12.31	Successful
20	16.48	Successful
25	26.01	Successful
30	30.87	Successful
35	36.84	Successful
40	37.16	Successful
45	37.64	Successful
50	-	Unsuccessful
55	-	Unsuccessful
60	-	Unsuccessful
65	-	Unsuccessful
70	-	Unsuccessful

Draft angles usually known as a self-supporting angle may be varied from the materials, layer thickness and also the other factors in the Slicer or any other 3D printing software. By default, the software itself does not generate the supports where there are self-supporting angles. Therefore, it truly depends on the user to take control over this issue by avoiding to design any parts that contain less than 70 degrees of self-supporting angles (draft angles). However, if those overhangs are deemed necessary to be used, the support material needs to be generated and proper cautions to dissolve the supports without destroying the actual design of the printed parts. Figure 7 and Table 6 respectively presents the pass-fail features of overhang-draft angles types conditions after the printing process. Figure 7 (a) presented the total failure of the draft angle with 10 degrees because the filaments are melting down and destroying the actual images of the angles. Therefore, the allowable data to be measured is from 50 degrees to 70 degrees.

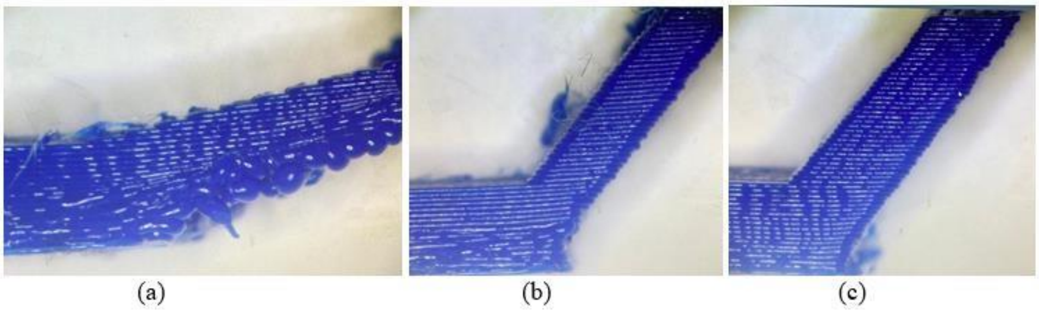


Fig 7 - (a) Fail draft angle at 10 degrees; (b) successful print at 50 degrees and (c) 70 degrees

Table 6 - Overall measurements and inspection for draft angles

CAD data (mm)	Actual data (mm)	Inspection
10	-	Unsuccessful
15	-	Unsuccessful
20	-	Unsuccessful
25	-	Unsuccessful
30	-	Unsuccessful
35	-	Unsuccessful
40	-	Unsuccessful
45	-	Unsuccessful
50	51.77	Successful
55	54.69	Successful
60	61.05	Successful
65	65.84	Successful
70	70.03	Successful

Besides that, the overhang can also be successful if printing by using the proper selection of process parameters. Four types of parameter settings having the significant factors in producing the overhangs. They are printing speed (mm/s), nozzle temperature (degrees), and fan speed (mm/s). The first factor that is significantly affects the process of overhang is the solidification process which mainly influences from the cooling factors such as fan speed. It is good to have the maximum speed of fan which can provide the higher cooling effects. For example, in the Slicer, the maximum fan speed selected is 225 mm/s to speed up the solidification process and prevent the filaments from kept falling down. Besides that, the low temperature was recommended, especially when using PLA to prevent over extrusion and to maintain the excellent layer adhesion. This is also the trick to minimize the stringing because the viscosity of the filaments if consistent and would not leave stringing. Overall, rapid cooling is very important to develop the successful overhangs, correspondingly with the printing speed. Reduce the printing speed can help the cooling fan to spend more time directing the air flow over the particular layers of the objects. By reducing the printing speed, the build printing time is then increased. However, this extra time allows the printing to have a better layer adhesion resulting a stronger and neater overhang.

5.0 Conclusions and future recommendations

In this study, three types of overhang pass-fail features were investigated which are overhang lengths, overhang angles and draft angles. The experiments showed that the overhangs can be successfully fabricated, however, there is always a length limitation especially when using the material extrusion technique such as FDM. The overhangs were fabricated using PLA materials consisting of thirteen parts with different measurements. The results showed that the overhang length can be produced successfully when the length is below than 1.5 mm. Meanwhile for overhang angle and draft angles, the allowable measurements are ≤ 45 degrees and ≥ 50 degrees, respectively. Other than that, factor considerations to produce overhangs are by reducing the printing speed, lowering the nozzle temperature and maximizing the fan speed to speed up the solidification process. In conclusion, overhang still can be considered for fabrication using FDM, however, the user need to select the proper measurements and parameter settings to eliminate the possibility of producing the failure printed parts.

In addition, future research will be conducted to testify on the newly introduced material such as carbon fiber reinforced polymer (CFRP) such as CFRP-ABS and CFRP-PLA. This two carbon fiber material are a composite type which having a higher melting temperature compared the standard polymer. However, the hypothesis stated that the CFRP will produce a better quality of overhang due to the blending of the carbon fiber powder in the filament which will speed up the solidifications of the melting filaments and produces a better overhang. Further findings and experiments will be conducted in other discussions.

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References

[1] *Additive Manufacturing-General Principles-Terminology*, ISO/ASTM 52900:2015.
[2] Adam, G.A.O., & Zimmer, D. (2014). Design for Additive Manufacturing-Element Transitions and Aggregated Structures. *CIRP Journal of Manufacturing Science and Technology*, *7*(1), 20-28.
[3] Hopkinson, N., & Dickens, P. (2007). Rapid Prototyping for Direct Manufacture. *Rapid Prototyping Journal*, 197-202.
[4] Mahesh, M. (2002). *Rapid Prototyping and Manufacturing Benchmarking*. Ph.D. Thesis, National University of Singapore.
[5] Ning, F., Cong, W., Qiu, J., Wei, J., & Wang, S. (2015). Additive Manufacturing of Carbon Fiber Reinforced Thermoplastic Composites using Fused Deposition Modeling. *Composites Part B, 80*, 369-378.
[6] Leary, M., Babaee, M., Brandt, M., & Subic, A. (2013). Feasible Build Orientations for Self-Supporting Fused Deposition Manufacture: A Novel Approach to Space-Filling Tessellated Geometries. *Advanced Materials Research*, *633*, 148–168.
[7] Miguel, F-V., Miquel, C. & Andress, C. (2015). Identifying Limitations for Design for Manufacturing with Desktop FFF 3D Printers. *International Journal of Rapid Manufacturing*, *5*, 116-128.
[8] Yang, L., & Anam, M.A. (2014). An Investigation of Standard Test Part Design for Additive Manufacturing, *Proceedings of the Solid Freeform Fabrication Symposium*, Austin, Texas, 901–922.
[9] Galantucci, L.M., Lavecchia, F. & Percoco, G. (2010). Quantitative Analysis of a Chemical Treatment to Reduce Roughness of Parts Fabricated using Fused Deposition Modelling. *CIRP Annals–Manufacturing Technology*, *59*(1), 247–250.
[10] Johnson,W.M., Rowell M., Deason B. & Eubanks, M. (2014). Comparative Evaluation of an Open-Source FDM System. *Rapid Prototyping Journal*, *20*(3), 205–214.
[11] Bakar, N.S.A., Alkahari, M.R. & Boejang, H. (2010). Analysis on Fused Deposition Modeling Performance. *Journal of Zhejiang University- Science. A*, *11*(12), 972–977.
[12] Ranjan, R., Samant, R. & Anand, S. (2017). Integration of Design for Manufacturing Methods with Topology Optimization in Additive Manufacturing. *ASME Journal of Manufacturing Science and Engineering, 139*(6), 1–14.
[13] Gibson, I., Rosen, D.W. & Stucker, B. (2010). *Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing*. 1st ed., Springer: New York, NY, USA. pp. 103–135.
[14] Gebhardt, A. (2012). *Understanding additive manufacturing: Rapid Prototyping, Rapid Manufacturing, and Rapid Tooling*. Hanser: Cincinnati, OH, USA, pp. 40–44.
[15] Guo, N. & Leu, M.C. (2013). *Additive manufacturing: Technology, Applications and Research Needs*. Frontiers.
[16] Armillotta, A., Cavallaro, M. & Minnella, S. (2013). A Tool for Computer-Aided Orientation Selection in Additive Manufacturing Processes. High Value Manufacturing: Advanced Research in Virtual and Rapid

Prototyping. *Proceedings of the 6th International Conference on Advanced Research in Virtual and Rapid Prototyping*. CRC Press, Leiria, Portugal, 469–475.

[17] Sood, A.K., Ohdar, R.K. & Mahapatra, S.S. (2010). Parametric Appraisal of Mechanical Property of Fused Deposition Modelling Processed Parts. *Materials & Design*, *31*(1), 287-295.

[18] Sahu, R.K., Mahapatra. & Sood, A.K. (2013). A Study on Dimensional Accuracy of Fused Deposition Modelling (FDM) Processed Parts using Fuzzy Logic. *Journal of Manufacturing Science Production, 13*(3), 183–197.

[19] Luzanin, O., Movrin, D. & Plan, M. (2014). Effect of Layer Thickness, Deposition Angle, and Infill Density on Maximum Flexural Force in FDM-Built Specimens. *Journal of Technology Plastic*, *39*(1), 49-58.