

An exploration of polymer adhesion on 3D printer bed

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Abstract. One of the problems in Fused Deposition Modelling (FDM) 3D Printing process is that the extruded plastic filament tends to shrink and warp from the printing platform. The purpose of this research is to explore the warping deformation problem in four aspects i.e. curling, pincushion effect, trapezoid deformation and blocked shrinkage that usually occur in the process. Epoxy resin based adhesive was applied onto the printing platform to reduce and eliminate the warping deformation. Afterwards, by applying the adhesive, the 3D printed models were measured their curling, pincushion, trapezoid and blocked shrinkage using laser scanner and metrology software. The result shows that the pincushion and trapezoid has low deformation compared to curling and blocked shrinkage. Blocked shrinkage effect shows the highest warping deformation value. In comparison of materials, PLA shows the best geometry result with low warping deformation value and the best surface finish.

1. Introduction

Fused deposition modeling (FDM) is one of the most widely used technique to produce object or part in the field of 3D printer area [1-2]. 3D printer machine use three dimensional CAD data and form layer by layer process to produce prototype part. 3D printer generally use thermoplastic plastic materials such as Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS) materials. These materials are melt and extruded by the printer extrusion head and moves correspondingly to the coordinate and position that been set in certain speed [1].

One of the problems in the 3D printing field especially FDM process is that the plastic filament which is extruded from the machine nozzle tends to shrink and warp from the printing bed platform [3]. This has been highlighted by several researchers that an adhesive layer between the first layer and printing platform is required to counter the problem [4-6]. This problem can be reduced by applying heat to the printing bed where the higher the bed temperature is, the less the deformed shape will be [7]. Moreover, the warping deformation has also showing warping reduction when applying epoxy resin based adhesive onto the printing bed [3].

The printing process involved printing onto the printing platform for the first layer of the formation until the last layer. Each of the layer from the molten plastic is solidified either naturally or by the help of external cooling process. Due to the cooling effect, the warpage problems are sometimes occur where it definitely affecting the printed part especially in the geometry size and manufacturing quality.

The warpage problem happens because of the first layer is not stick well and peeled away from the printing platform due to the adhesion of the first layer with the printing platform such in figure 1 and 2. Young et al [7] has stated that in 3D printer it is an undesirable shape error which is occurred in the



product due to the heat shrinkage phenomenon. The paper also stated that the main reason for inhomogeneous shrinkage of the parts in the 3D printing process are due to time delayed for the solidification of the layers. Moreover, the problem is caused by force transmission between the layers since phase of change from molten plastic to solid during building process. Some of examples of warpage problems occur in the FDM process are pincushion, trapezoid, curling and blocked shrinkages [5].

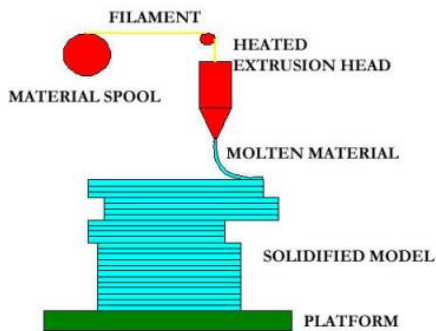


Figure 1. Fused deposition modeling process [2]

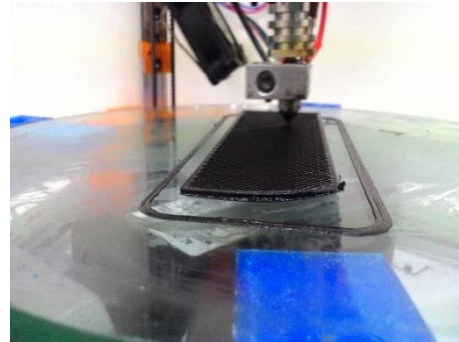


Figure 2. Warpage affect during printing process

Epoxy resin adhesive is an adhesive that has been used widely all over the world. The adhesive is proven to be suitable for the repair and restoration of the glass substance in several problem [8-9]. The epoxy has declared containing 5.0% of organic solvents and 56.5% water based that soluble inside the water and have non-toxicity effect to the human and environment [10]. By referring to the safety data sheet, epoxy resin has zero hazard and has harmful effect if it used and handled accordingly to necessary regulation. The epoxy resin based adhesive used in this experiment is shown as in figure 3 [11].



Figure 3. Epoxy resin based adhesive

Thus, the purpose of this paper is to study the relation and the performance of the epoxy resin based adhesive through the surface preparation for the printing platform during the process. In addition, this research also study the warping deformation that occur through pincushion, curling, trapezoid, and blocked shrinkage effects using PLA and ABS material either printing with and without applying heat on bed.

2. Experiment characteristics

2.1. Sample Preparation

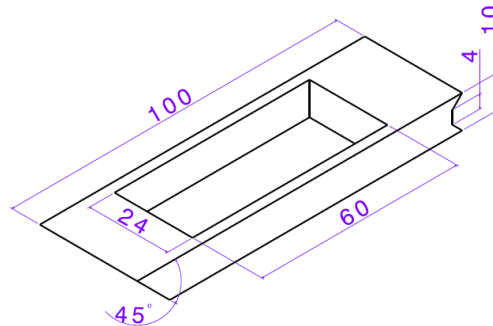


Figure 4. Dimensioned isometric view with angle 45° of specimen

The experiment was started by sketching the solid model of specimens using solid modelling software, CATIA V5 with its dimension shows in figure 4. The solid model was sketched with three different angles of 30°, 45° and 60°, to investigate the warping deformation effect in various angle. Next, the solid model was sliced by using 3D printer slicer software, Repetier Host that was built with Slic3r engines to create machine language, G-Code for 3D printer path direction. This slicing process was required to set up the 3D printer specifications where the infill density, layer temperature, printing speed and layer height need to be defined. Thus, table 1 shows the printing settings that being used for this experiment.

Table 1. Printing setting

Preferences	Materials	
	PLA	ABS
Infill density (%)	13	13
First layer temperature, T (°C)	235	235
Other layer temperature, T (°C)	193	230
Printing Speed (mm/s)	40	40
Layer Height (mm)	0.2	0.2

The printing experiment was conducted by using a FDM 3D printer machine, Pursa i3 model 3D printer machine that has printing area of 180mmx180mmx150mm with glass as the material of printing platform. Before the printing process began, the printing platform was prepared by applying the epoxy resin based adhesive and spreading onto the printing area of printing platform. Four specimens type i.e. ABS without the use of heat bed printing platform, ABS with use of heat bed, PLA without heat bed, and PLA with heat bed has been print by using 3D Printer for each angles of 30°, 45° and 60°. Table 2 shows the label for type of specimens used on the experiment.

Table 2. Labelled type of specimens based on material and heat bed

Specimens	Material	Heat bed
1	ABS	Without
2	ABS	With
3	PLA	Without
4	PLA	with

In addition, the printing setting for the layer temperature was set differently between PLA and ABS material. This is because of the different melting point and different material properties. The bed temperature setting has been set for ABS and PLA are 100°C and 60°C respectively.

2.2. Warping Deformation Preparation



Figure 5. Scanning process by Solutionix Rexscan CS2+ laser scanner

After the printing process completed, the next process was scanning the geometry shape that been printed using the 3D printer. The specimens was scanned using laser scanning and metrology software; Solutionix Rexscan CS2+ 3D scanner machine and Geomagic Quality 2013 tools software to compare with the sketched theoretical geometry from drawing. The warping deformation that was measured are shown in figure 6. The geometry of the sample was compared using 3D and 2D compare tools that available in the Geomagic software. Moreover, the result also has been figured using coordinate method which is similar to the conventional method of Coordinate Measuring Machine (CMM).

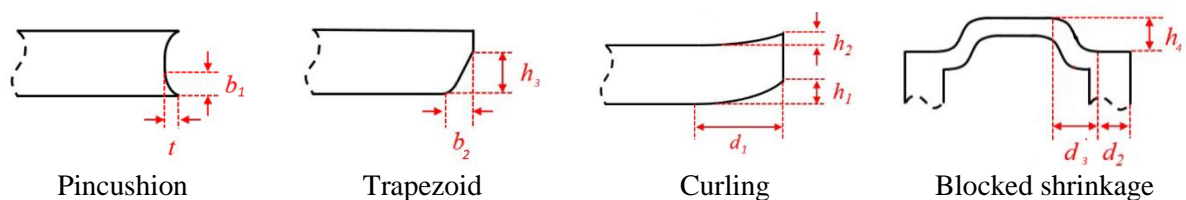


Figure 6. Description of warpage deformation [5]

3. Results and discussions

All the sample of specimen is completely printed using the Pursa i3. However, the printing process of using ABS material without external heat bed had failed where they peeled away from the printing platform. Therefore, the result of the experiment is only presented with 3 type of printing; ABS with heat bed, PLA without heat bed and PLA with heat bed.

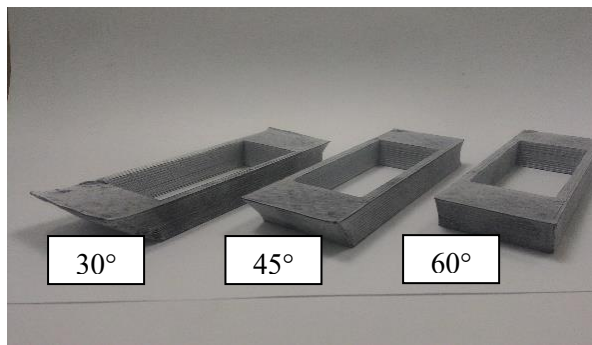


Figure 7a. Photograph of specimens (front view) from left 30°, 45° and 60°

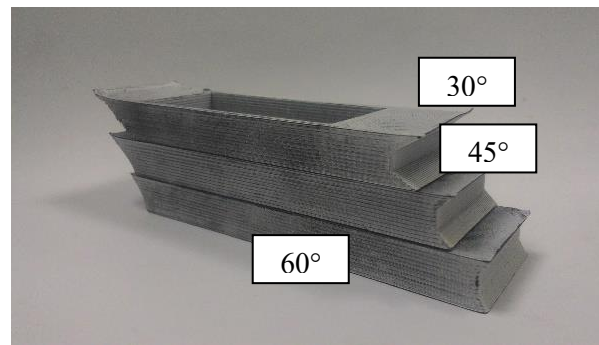


Figure 7b. Photograph of specimens (back view) from top 30°, 45°, and 60°

Figure 7a and 7b shows the photograph of printed specimen with angle 30°, 45° and 60°. As shown in the photograph, the specimen with 30° of angle shows the fewest shape error especially in the front view of the specimens.

3.1. Measurement results

Data of the measurement has been obtained from the process of laser scanning and metrology process. It has shown that there is some geometry error based on shape.

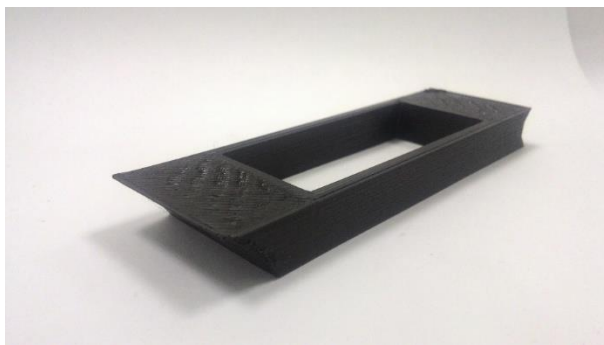


Figure 8. Photograph of specimen with angle 45° printed using Polylactic Acid (PLA) material

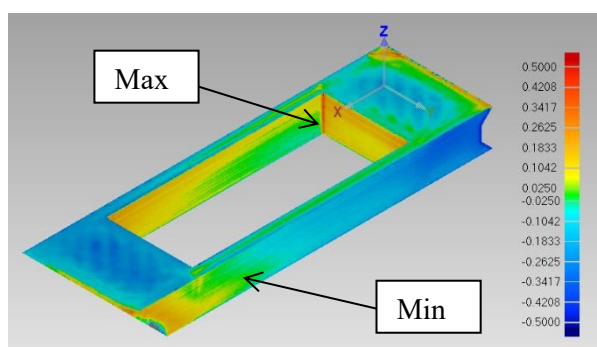


Figure 9. 3D comparison between actual drawing and scanned specimen that has been analyzed using the metrology software with minimum and maximum labeled for the spectrum level

Figure 8 and 9 shows an example from one of the printed specimen that went through the 3D comparison analysis between the actual drawing and the scanned printed specimen. The spectrum colors shows the comparison of the geometry for each of the specimen. As in the figure, the maximum and minimum of deformation spectrum are 0.5 mm and -0.5 mm corresponding to the tolerance of the analysis. The red color shown the positive of deformation spectrum while blue color is the negative of deformation spectrum and then green color is nearly to the dimension of theoretical. Based on the analysis data, the maximum and average of the deformation are 0.4994 mm and 0.1388 mm. As in the figure 9, the rectangular shaped at the center of specimen is shows few of red area while most of top

surface shown blue color and green. Table 3, 4 and 5 shows the result of deformation error from measurement of metrology process.

Table 3. Deformation error from measurement from specimens with 30° of angle

Specimens	Pincushion		Trapezoid		Curling		Blocked shrinkages			
	t	b_1	h_3	b_2	h_1	h_2	d_1	d_2	d_3	h_4
1	0.8168	0.2683	0.4080	0.5732	0.1497	0.0864	9.2111	21.3766	3.1463	0.0833
2	2.4176	1.7934	0.7086	1.2975	0.0179	0.0087	1.6314	17.2267	9.8791	0.0936
3	-	-	-	-	-	-	-	-	-	-
4	0.7832	0.2176	0.3149	0.0469	0.0376	0.1213	1.0110	20.0640	12.9380	0.0356

Table 4. Deformation error from measurement from specimens with 45° of angle

Specimens	Pincushion		Trapezoid		Curling		Blocked shrinkage			
	t	b_1	h_3	b_2	h_1	h_2	d_1	d_2	d_3	h_4
1	0.1721	0.1225	0.0076	0.1154	0.0459	0.0219	1.9968	21.8371	0.8987	0.0043
2	0.2115	0.1331	0.0883	0.3917	0.0682	0.0437	1.6837	11.6780	22.9900	0.1041
3	-	-	-	-	-	-	-	-	-	-
4	0.1699	0.5910	0.1518	0.0508	0.0604	0.1357	10.9160	17.8978	14.0234	0.0284

Table 5. Deformation error from measurement of specimens with 60° of angle

Specimens	Pincushion		Trapezoid		Curling		Blocked shrinkage			
	t	b_1	h_3	b_2	h_1	h_2	d_1	d_2	d_3	h_4
1	0.4654	0.3159	0.3007	0.5037	0.0564	0.0077	0.0199	20.5490	2.2459	0.0160
2	1.1335	1.2020	0.6418	0.2787	0.0464	0.0137	0.3373	14.7331	14.9542	0.0927
3	-	-	-	-	-	-	-	-	-	-
4	0.2526	0.4126	0.3976	0.8385	0.2993	0.1957	10.9160	19.8973	3.1310	0.0439

3.2. Effect of angle

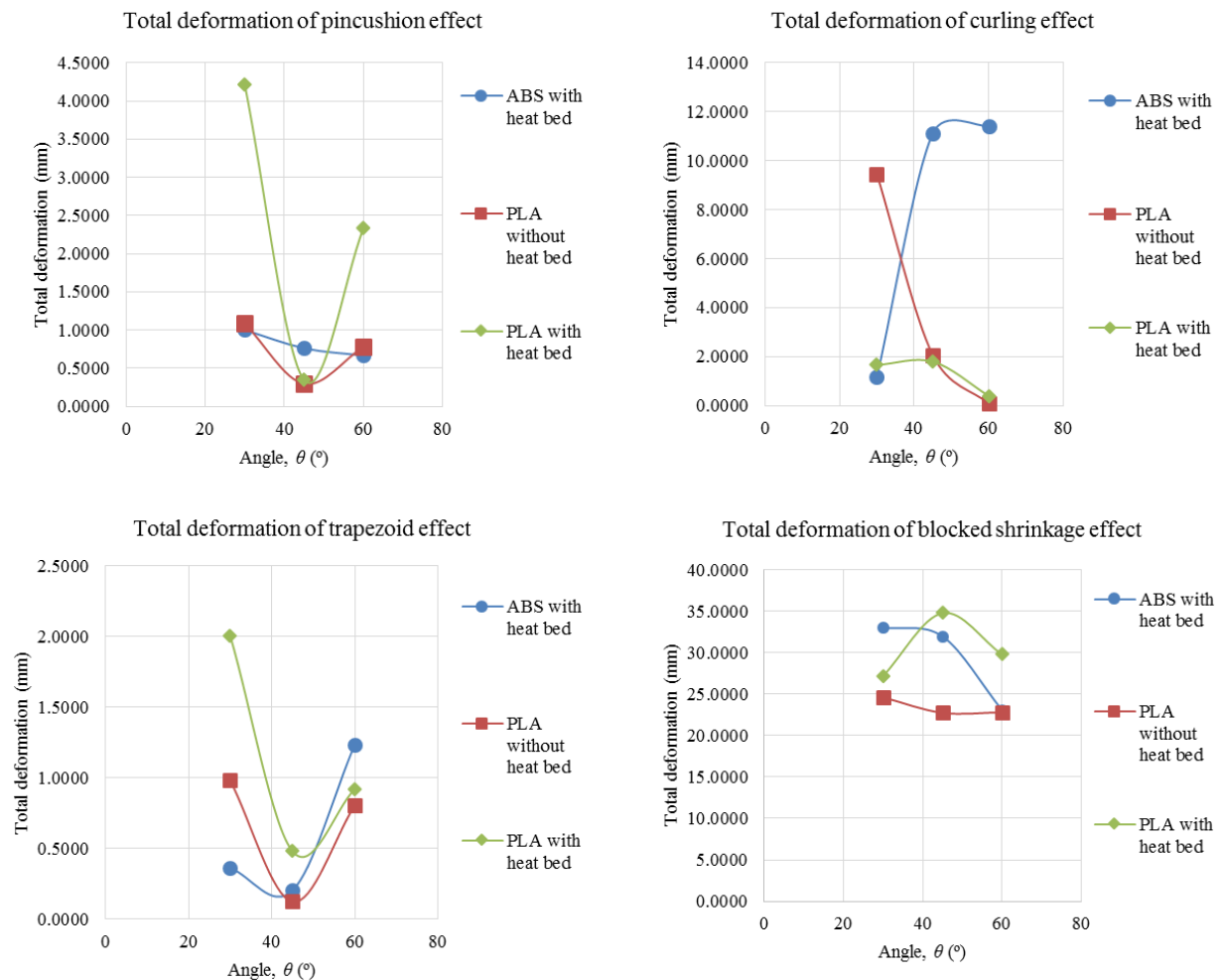


Figure 10. Total deformation of pincushion, curling, trapezoid and blocked shrinkage effects.

Figure 10 indicate the results to the pincushion, curling, trapezoid and blocked shrinkage effects that tabulated from the experiments. The graph was plot based on the total deformation for each effects. By referring to the plotted graph, pincushion and trapezoid effects resulted from PLA with heat bed type of specimen has the highest value of deformation especially for the specimens that was built with 30° of angle. Moreover, based on the result for PLA without heat bed, most of graphs shows has lower total deformation than other type of specimens. ABS material that has been printed using heat bed shows that it has lower total deformation compared to PLA with heat bed.

For the curling effect, the result shows that the ABS material that printed using heat bed has high deformation since it has been built with 45° and 60° of angle. This maybe because of the environmental factors that has affecting result to the printing process where the solidification of the material might be different from each other. The ABS material has known issue of solidification in 3D printing.

The effect of the angle shows that the total deformation has lower value when it built with angled 45°. Therefore, it may conclude that best angle of printing with those material is by using 45° of angle while the other angle is resulted has higher value of total deformation.

3.3. Type of error

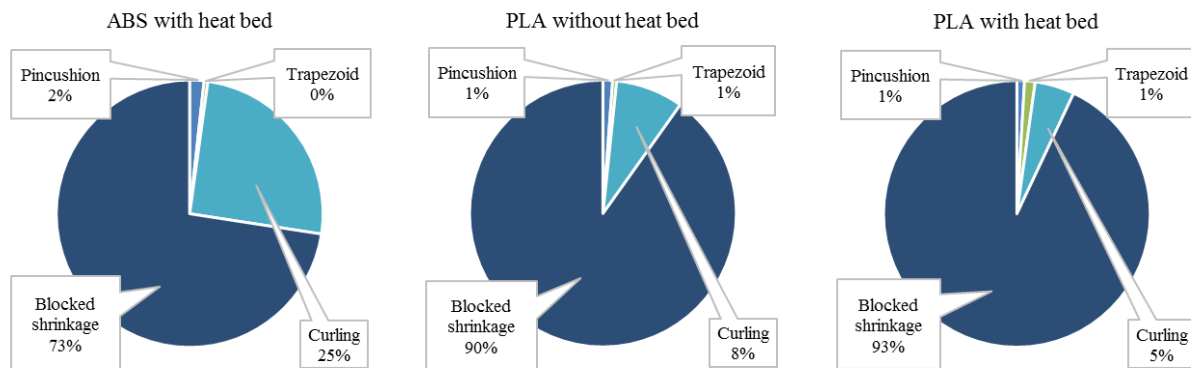


Figure 11. Total of warping deformation by type of error from specimens with 45° of angle

Based on the previous result, the experiment shows that the specimens with 45° of angle are the best compared to the other angle. Thus, figure 11 generally shows the result of total error for the four type of warping deformation. The pie chart shows the total warping deformation that separated by type of material and method of printing. This chart shows that most of experiment has high blocked shrinkages effects. ABS with heat bed shows 2%, 0%, 73% and 25% of pincushion, trapezoid, blocked shrinkage and curling effects. Respectively. PLA material that printed without heat bed and with heat bed shows higher blockade shrinkages where 90% and 93% respectively. Apart from that, the pincushion and trapezoid effects has the lowest deformation among the specimens which is less than 2%. The curling effect shows that ABS material has 25% of deformation while PLA with and without heat bed has 8% and 6% deformation.

3.4. Effect of material

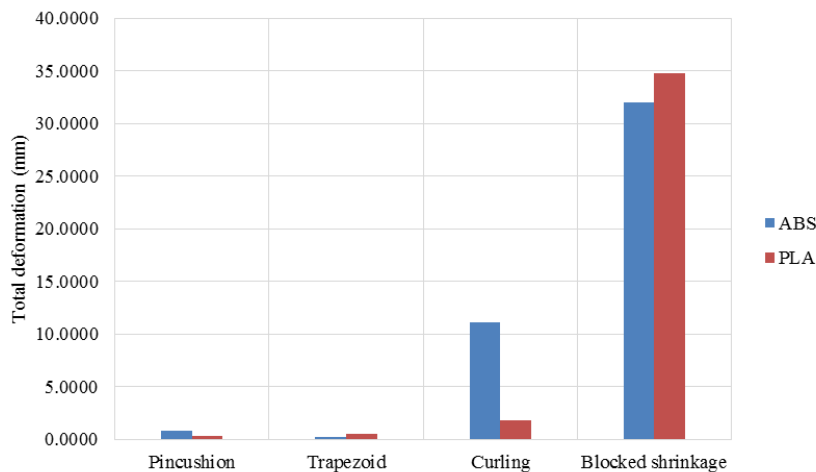


Figure 12. Influence of deformation based on total deformation from material ABS and PLA with heat bed

The measured total deformation of the overall effects are shown through the bar chart as in figure 12. The bar chart has shown the pincushion and trapezoid effect has lower deformation than curling and blocked shrinkage. This result came out similar for both of ABS and PLA material that been print with heat bed. Moreover, the result shows the blocked shrinkage effect have the highest total deformation for the both material. Moreover, the ABS material has less deformation compared to PLA material for the blocked shrinkage effect. However, the ABS exhibit higher deformation for the curling and pincushion effects compare to PLA material. Based on the chart and the observation, PLA

material gives the best result where the surface finish and the warping deformation is better than ABS material.

4. Conclusion

Based on the results, it shows that the highest value of deformation is, the lower quality of printing. In the experiment of the geometry shape, the specimen built with 45° of angle that was been print using PLA material without heat bed shows the lowest warping deformation. In addition, the results also shows that blocked shrinkage effect has the highest value of deformation compare to curling, pincushion and trapezoid. In addition, PLA material has the best material where it has low deformation for the curling and pincushion effect compared to ABS material. PLA material printed without heat bed have the lowest total deformation of pincushion, trapezoid and blocked shrinkage effects with 0.2946mm, 0.1230mm and 22.7401mm respectively.

References

- [1] Solidwild.wordpress.com, 2017, *Additive Manufacturing / SolidWild*. [online] Available at: <https://solidwild.wordpress.com/category/3d-printing-2/additive-manufacturing/> [Accessed 12 Mar. 2017]
- [2] Yifan J, Yi W, Bing Z and Zhanqiang L 2017 *Journal of Mechanical Processing Technology*, **240** 233-239
- [3] M A Nazan, F R Ramli, M R Alkahari, M N Sudin and M A Abdullah 2016 *Proc. of Mechanical Engineering Research Day 2016* 71-72
- [4] Wohlers T, 2012. Wohlers Report 2012: Executive Summary.
- [5] W Z Wu, P Geng, J Zhao, Y Zhang, D W Rosen and H B Zhang 2014 *Materials Research Innovations*, **18** 12-16
- [6] F R Ramli, M I Jailani, H Unjar, M R Alkahari and M A Abdullah 2015 *Proc. of Mechanical Engineering Research Day 2015* 77-78
- [7] Christoph S, Alexander Z, Michael F Z 2016 *48th CIRP Conference on Manufacturing Systems 2015* 1017-1022,
- [8] Jane L D 2010 *The Yellowing of Epoxy Resin Adhesives: Report on Natural Dark Aging* **29** 63-76
- [9] Davison S, 2010, The problems of restoring glass vessels 3-8
- [10] UHU Stic safety data sheet, 2015, **12**
- [11] M A Nazan, F R Ramli, M R Alkahari, M N Sudin and M A Abdullah 2017 *Proc. of Mechanical Engineering Research Day 2017* 145-146.