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Fluttering Effect of 3D Printing Part

Muhammad Danial Shamsuddin[1], Siti Juita Mastura Mohd Saleh[1*]

[1]Faculty of Mechanical Engineering,
University Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA.

*Corresponding Author Designation

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Abstract: 3D printing is an innovation in manufacturing industries that has the potential to usher in a new industrial look. Nevertheless, this technology has some limitations, for instance, the fluttering effect occurrence which being a crucial effect to obtain a good result. In this regard, the present study is aimed to identify the fluttering effect in order to prevent damaged printing parts during the 3D printing process. Three target quality parameters and six factors were chosen to be examined experimentally. In addition, three materials and two types of printers were used in this experiment in order to observe and derived the result from the evaluation of the 3D printing system. The result indicates that fluttering effects occur on few samples based on the observation made from target parameters chosen in terms of surface quality, warping and shifting layer. The presence of fluttering effects was analyzed in 5 out of 27 samples showing poor quality results It can be concluded that the model dimension and environmental error such as vibration on extruder during printing process are the main factors to the occurrence of fluttering effects.

Keywords: Fluttering, Parameters, Warping, Vibration

1. Introduction

3D printing is an innovation that has the potential to usher in a new industrial look [1]. This technology is increasingly being used in agriculture, healthcare, the automobile sector, and also the aircraft industry for mass modification and manufacture of open source ideas of all kinds [2] In the following, few main 3D printing technologies such as Stereolithography (SLA), Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Laminated Object Manufacturing (LOM) and Multi Jet Printing are widely used due to its availability for producing parts in a short amount of time while maintaining the appropriate level of quality in terms of effectiveness and materials.[3] The materials that used in 3-Dimension printing are considered within their characteristics.

At the same time, there is a limitation to the 3D printing technology's acceptance [4]. For example, the fluttering effect that occurs during the 3D printing process affects the smoothness of the printed parts and then produces defective components and no longer suitable for use. As a result, it will reduce manufacturing efficiency in terms of price and duration. Thus, this paper presents the study of the

**Corresponding author: juita@uthm.edu.my*

fluttering effect that occurred on 3D printing parts which causing damaged products. Therefore, the experiment using a 3D printer needs to be executed in order to understand the 3D printing process and its limitations based on the model designed.

2. Materials and Methods

To study the fluttering effect on the 3D printing part, an experiment was designed to deduct a process model of the printer. Within the experiment, four target variables were chosen to be taken into consideration which are surface quality, warping and layer shifting. The target variables were selected to enable an evaluation of the fluttering effects on the 3D printed model. The 3D models which were used within the experiments were the edges shape model and half-cylindrical shape model shown in **Figure *2*** and **Figure *3***. Both of the models had a variety of thicknesses including 0.5mm, 1.5mm, 2.5mm, 3.5mm and 4.5m. and also the different lengths which were 35mm and 15mm. The edges shape model had a height of 300mm while for the half-cylindrical shape model, it comes with two initial radius which were 0.25mm and 0.5mm.

2.1 Materials and equipment

For the purpose of this study, two types of 3D printers such as an Ender 5 Plus and X-Cube Plus 8.9 were used along with the software Cura. The Ender 5 Plus printer is a single-nozzle FDM printer meanwhile X-Cube Plus 8.9 is the SLA printer which use UV curing to create the model. Then, the materials that will be used were PLA filament, ABS filament and resin. These materials were chosen due to their capability to be fitted in the 3D printers that will be used.

2.2 Methods

The experiment was executed based on seven factors that had been chosen including the dimension of the printed model, printing speed, nozzle and bed temperature, platform type and infill percentage. All of these factors were considered as important elements affecting the surface quality, warping and layer shifting in order to study the fluttering effects. These seven factors will be adjusted in Cura software before the model was printed.

Print speed comprises a combination of the speed of the extruder and influences the speed with which material is deposited. So, this experiment will use a speed between 35mm/s to 80mm/s to observe the surface quality of the printed model. The temperature of nozzle describes the temperature of the nozzle thus affecting the viscosity of the melting polymer. The temperature of platform bed describes the temperature of the platform on which the part is printed during the printing process. The temperature of the nozzle and platform bed had been chosen which will be higher than 185°C and 60°C. Platform type is an option that could help to prevent the corner of the printed part from lifting during printing(warping). When selected, the printer prints a thin layer on the bed before printing the actual part upon this layer. The platform can be removed after printing. The platform type “skirt” and ‘‘brim’’ will be used in this experiment to had a different result in order to observe the occurrence of warping. The infill percentage determines the density of the printed part which to evaluate the strength and weight of the product. Thus, 20% of the filling percentage which generally be used in standard printing will be chosen along this experiment was conducted.

3. Results and Discussion

3.1 Result analysis

The result analysis obtained from the experiment using PLA filaments and FDM printer.

Table 1: The result analysis of variance (ANOVA) for edges shape models.

No. of Sample	Parameter					Result			
	Length (mm)	Speed (mm/s)	Temperature(°C)		Platform type	Surface quality		Warping	Layer shifting
			Bed	Extruder		Initial	Final		
1	35	80	210	70	Skirt	Smooth (from bottom until height of 61mm)	Rough (from height of 61mm to 300mm)	Yes	Yes (at height of 170mm)
2	35	80	185	60	Skirt	Rough (from bottom until height of 21mm)	Rough (from height of 21mm until 205mm)	Yes	Yes (at height of 95mm)
3	35	45	210	70	Skirt	Smooth (from bottom until height of 159mm)	Rough (from height 159mm until 300mm)	Yes	Yes (at height of 210mm)
4	15	80	210	70	Skirt	Smooth (from bottom until height of 92mm)	Rough (from height 92mm until 300mm)	Yes	Yes (at height of 128mm)
5	22.5	65	210	70	Brim	Smooth (from bottom until height of 150mm)	Smooth (from height 159mm until 250mm)	No	Yes (at height of 151mm)

Table 2: The analysis of variance (ANOVA) for half-cylindrical shape model for internal radius of 0.25mm.

No. of Sample	Parameter					Result		
	Initial radius (mm)	Thickness (mm)	Length (mm)	Temperature (°C)		Surface quality		Internal radius hole
				Bed	Extruder	Bottom layer	Top layer	
1	0.25	0.5	35	210	70	Smooth	Rough	No
2	0.25	1.5	35	210	70	Smooth	Rough	No
3	0.25	2.5	35	210	70	Smooth	Smooth	No
4	0.25	3.5	35	210	70	Smooth	Smooth	No
5	0.25	4.5	35	210	70	Smooth	Smooth	No
6	0.25	0.5	15	210	70	Smooth	Rough	No
7	0.25	1.5	15	210	70	Smooth	Rough	No
8	0.25	2.5	15	210	70	Smooth	Smooth	No
9	0.25	3.5	15	210	70	Smooth	Smooth	No
10	0.25	4.5	15	210	70	Smooth	Smooth	No

Table 3: The analysis of variance (ANOVA) for half-cylindrical shape model for internal radius of 0.5mm.

No. of Sample	Parameter					Result		
	Initial radius (mm)	Thickness (mm)	Length (mm)	Temperature (°C)		Surface quality		Internal radius hole
				Bed	Extruder	Bottom layer	Top layer	
11	0.5	0.5	35	210	70	Smooth	Smooth	No
12	0.5	1.5	35	210	70	Smooth	Rough	No
13	0.5	2.5	35	210	70	Smooth	Rough	No
14	0.5	3.5	35	210	70	Smooth	Smooth	No
15	0.5	4.5	35	210	70	Smooth	Smooth	No
16	0.5	0.5	15	210	70	Smooth	Smooth	No
17	0.5	1.5	15	210	70	Smooth	Rough	No
18	0.5	2.5	15	210	70	Smooth	Rough	No
19	0.5	3.5	15	210	70	Smooth	Smooth	No
20	0.5	4.5	15	210	70	Smooth	Smooth	No

Following the execution of the 25 experiments and the measurement of the printed parts, the experimental results were analyzed using the analysis of variance (ANOVA). **Table *1*** shows that 5 samples were printed had different results in terms of target parameters. The result of all samples shows that the printed models had a smooth surface when they reached a certain height before they become rough and they also had warping during the printing process. Sample 1 and sample 2 were differentiated by the temperature of nozzle and platform bed which results in a bad surface like the "woven mat" on sample 2. Then, sample 3 was printed with a lower speed of printing and the result from this sample shows that it has higher smooth surface compared to the other 4 samples. Sample 4 was designed with a length of 15mm which deliberately reduced the printed area and showed results that were slightly similar to the previous 3 samples. The fifth experiment for the edges shape model was sample 5 which the parameter was adjusted to be optimized and thus to be optimized. As a result, the observation shows that sample 5 did not have warping but it still has a rough surface when the model was printed at a height of 150mm. The layer shifting also starts to occur to all samples when they were reached their printing process at a certain height.

The result in **Table *2*** and **Table *3*** shows the 20 samples had been printed using a half-cylindrical shape with internal radius of 0.25mm and 0.5mm. Based on the result analysis, all the samples did not experienced layer shifting and warping during the printing process which concluded that the half-cylindrical shape did not face any problem to be printed without the fluttering effect. However, the difficulty of obtaining good surface quality arises when there were few samples such as samples 1, 2, 6,7, 12, 13, 17 and 18 that had a rough surface after the printing process reached 90% before completed.

3.3 Comparison between material

For ABS filaments, the experiment was performed with the same parameter settings as the experiments conducted for PLA filaments. However, the limitation of the current 3D printer which is Ender 5 Plus causing the filament not fitted to be print with a 3D printer. **Figure *1*** shows that the filament was not sticking to the platform bed causing the model cannot be printed. This condition is commonly known because ABS is one of the filament materials that need a suitable printer, a specific additional tool, a closed environment and a strict parameter set up to flow this material perfectly.

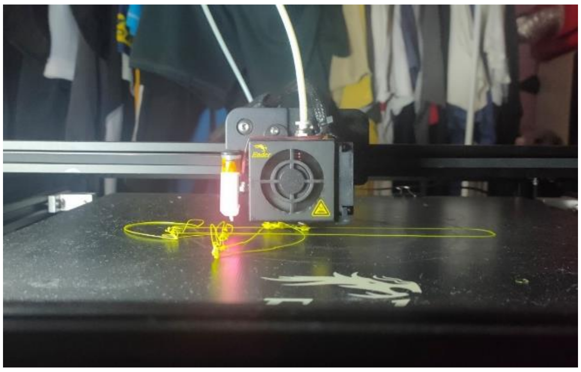

Figure 1: The printer failed to print the ABS filament.

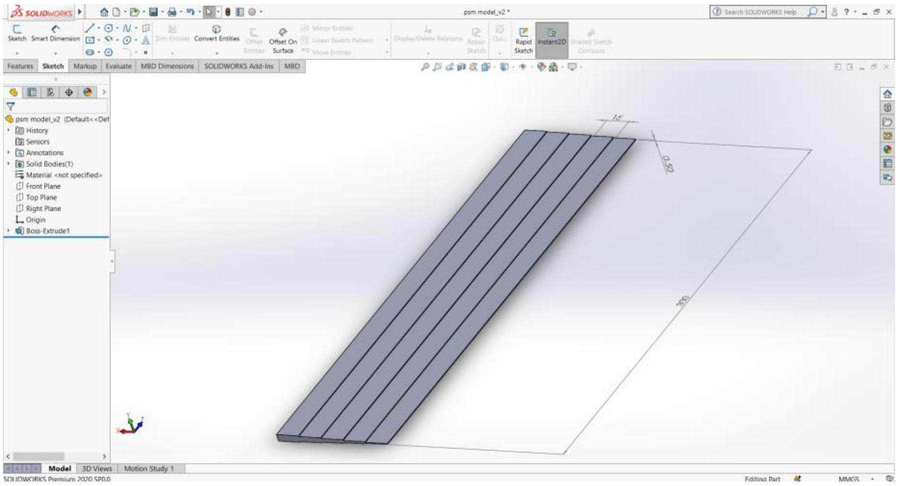

Figure 2: The edges shape model.

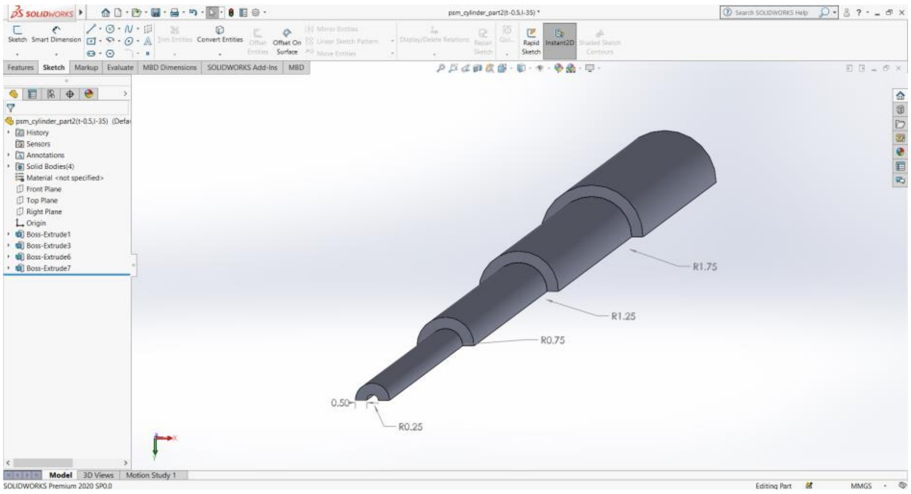

Figure 3: The half-cylindrical shape.

The experiment execution of two samples which had different length by using resin material and SLA printer were analyzed based on chosen three target parameters. The result analysis from **Table *4*** shows that both samples had great surface quality and absence of layer shifting occurrence. Unfortunately, the warping still occurred in sample 2 when the experiment was conducted. Based on **Table *5***, it shows that both printed samples were not printed perfectly where the models had stopped to be printed at a certain height according to different thickness.

Table 4: The result of analysis of variance (ANOVA) for resin material.

No. of Sample	Parameter				Result			
	Length(mm)	Speed(mm/s)	Layer height (mm)	Platform type	Surface quality		Warping	Layer shifting
					Initial	Final		
1	35	65	0.1	Skirt	Smooth	Smooth	Yes	No
2	15	65	0.1	Skirt	Smooth	Smooth	No	No

Table 5: The result of the maximum height model being printed for resin material.

No. of Sample		1	2	3	4	5	6	7	8	9	10
Parameter	Length (mm)	35	35	35	35	35	15	15	15	15	15
	Thickness (mm)	0.5	1.5	2.5	3.5	4.5	0.5	1.5	2.5	3.5	4.5
Result	Maximum Height (mm)	146	120	100	84	80	178	178	162	149	109

3.4 Discussion

From the result analysis, we could conclude that the target quality parameters including surface quality, warping and layer shifting is important in order to identify the existence of fluttering effects on 3D printing parts. The rough surface quality, warping and layer shifting occurrence on edges shape model show that fluttering effects occurred when 3D printed models were printed at extreme height. Other than that, high print speed could be one of the main factors that causing fluttering effects. The external factor that might be related in this issue was environmental error where the vibration from the extruder during the printing process due to the damage in equipment in the 3D printer. The result analysis for the half-cylindrical shape model shows that there were no signs of fluttering effects due to the absence of warping and layer shifting. However, the rough surface that occurred on few samples might be caused by the imperfect finishing of the 3D printer. The execution of experiments with different materials has yielded results where ABS materials failed printed due to it was not compatible with the available 3D printer used. For resin material, two samples were printed which gave good behaviour in terms of good surface quality and absence of layer shifting. Unfortunately, the warping still occurred which might be caused by pressure stress due to the large area used from the printed model.

4. Conclusion

In the presented work, experiments were conducted to identify the fluttering effect on the 3D printing part. Fortunately, the study manages to achieve all the objectives of the study. The first objective was achieved by designing and develop 3D printing parts of different materials and dimensions based on the data obtained for each parameter and material. The second objective was achieved by analyzed the 3D printing part behaviour based on target parameters such as warping of the prints, subjective surface quality and layer shifting. As for this work-study, six factors were varied in the experiments to study their effects and interaction on the mentioned target parameters: dimension, printing speed, the temperature of nozzle and bed, platform type and infill percentage. The third objective was achieved by evaluating the result and recommendation for preventing flutter effects which then the result analysis was discussed. From this study, 27 experiments were conducted by using material of PLA filament and resin in total and 5 samples were failed to be printed when using ABS filament. Seven test prints were executed using the edges shape model and the other 20 experiments were using the half-cylindrical shape model. To conclude, based on the result analysis and comparison, the fluttering effect will be occurred when the 3D printing part was printed at an extreme height. The other factors were parameter setting which the printing speed is much higher and environmental error such as the vibration of the extruder during the printing process.

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