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Parameter Optimization of Printcake Machine Using Full Factorial

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ABSTRACT

This research analyzes pancake batter and discovers the ideal printing parameters on the HALTech Printcake machine, the machine was newly developed and hasn't been optimize yet where the prior research on 3D Printing pancake batter never been done. This research aims to optimize the printing parameter in order to get pancake close to proposed design. 3 Level full factorial were carried out to understand the response of all the available combination of parameter. There are 2 parameters proposed on this research velocity: 50 mm/s, 60 mm/s, 70 mm/s, and micropump voltage: 3.5 volts, 4 volts, and 4.5 volts. Balance between two parameters needed in order to get the best printing result, Velocity refer to the movement speed of the axis and the micropump voltage refer to how many materials will be extruded or flow rate. Design specimen of a straight line 8 cm long and 0.35 cm wide proposed. The results showed that the length error was not significantly affected either by the velocity of the axis movement or the micropump voltage, whereas for the printed area error, it was significantly affected by the velocity, and for the micropump voltage, it did not have a significant effect. Optimized combination of parameter obtain in this research was velocity of 70 mm/s, and a micropump voltage of 4 volts and overall was able to print better specimen then the average experiment in term of printed area error.

1. Introduction

3D Printing Technology, or Additive Manufacturing (AM), is a trigger of industry 4.0 (Malik et al., 2022) (Vo, 2022), which has advantages in the form and personalization of materials (Desu et al., 2021) (Geisleir et al., 2022). The technology is based on computation to build 3-dimensional solid structures on a sheet-by-sheet basis (Portanguen et al., 2019) and is now widely used in the military (Campbell et al., 2012), medical (Liu & Evans, 2016), aircraft (Paolillo et al., 2021), materials science (Shen et al., 2023), and food (Piyush et al., 2019) (Kewuyemi et al., 2021) (Tejada-Ortigoza & Cuan-Urquizo, 2022).

Food 3D Printing is new technology (He et al., 2020) that is used to make food with custom forms and desired nutrients (Zhang et al., 2022) (Brunner et al., 2018). The research of ingredients used also continues to grow, starting from vegetables such as carrots (Guénard-Lampron et al., 2021), peas (Chuanxing et al., 2018) (Cheng-Rong TSAI & Yung-Kai LIN, 2022), and bok choy (Pant et al., 2021), then fruit such as mango (Montoya et al., 2021), lemon (Yang et al., 2018), strawberry (Tabriz et al., 2021), and cakes (Pulatsu et al., 2020), (Oliveira et al., 2021).

Current study on 3D Printing food can be categorized into 3 main shape of material, it is puree (Cazzaniga et al., 2021), gel (Cheng-Rong TSAI & Yung-Kai LIN, 2022) (Paolillo et al., 2021) (Maniglia et al., 2020), dough and batter (Pulatsu et al., 2020) (Pulatsu et al., 2021), the research focus on getting a proper ingredient (Derossi et al., 2020) or printing parameter such as nozzle size (Guénard-Lampron et al., 2021), printing speed, and extrusion rate (Yang et al., 2018) etc.

3D Printing in Indonesia is starting to develop, and this is indicated by the launch of Making Indonesia 4.0 on April 4, 2018, from the government to build five manufacturing sectors, namely food and beverage, textile, automotive, chemical, and electronics, using the Internet of Things (IoT) technology, Artificial Intelligence (AI), Human-Machine Interface, robotic and sensor technology, and 3D Printing technology (Kemenprin, 2019), Together with this government policy 3D printing of food become an opportunity and challenge (Burke-Shyne et al., 2020), there are many 3D printing startup companies are starting to develop in Indonesia.

HALTech is one of new start up in Indonesia, it is located in the Special Region of Yogyakarta and engaged in the 3D Printing production and education focus on various material from resin, PLA and even food such as chocolate and cake. Their latest work was a printcake it was 3D printing machine based on the x, y-axis, with a static z-axis working on a grbl firmware to make pancakes according to the desired design, the printing system work using batter pushed to the extruder using air compressor or pneumatic dispensing system. Until now the machine only been operated on a default setting parameter and haven't been optimize yet, similar research on optimizes 3D Printing using parameter such as printing speed and extrusion rate but never been used on a batter type material for pancake. Based on this background the research contribution is to optimize the parameter of the printcake and gain the ideal parameter to print custom pancakes.

2. Method

2.1. Research Procedure

The research begins with a literature study to determine the position of previous research, such as what materials were used, and whether similar research has been carried out. Next, the ingredients is determined to make the batter and the parameters needed in this study. The 3-level full factorial was carried out in this research to analyze the printed result. This method is often used in experiments involving many factors or parameters. Most studies use two levels, namely high and low (Tavares Luiz et al., 2021), while this study uses three levels it is high, medium, and low, then uses 3 times replication. the flowchart of the research can be seen on Fig. 1.

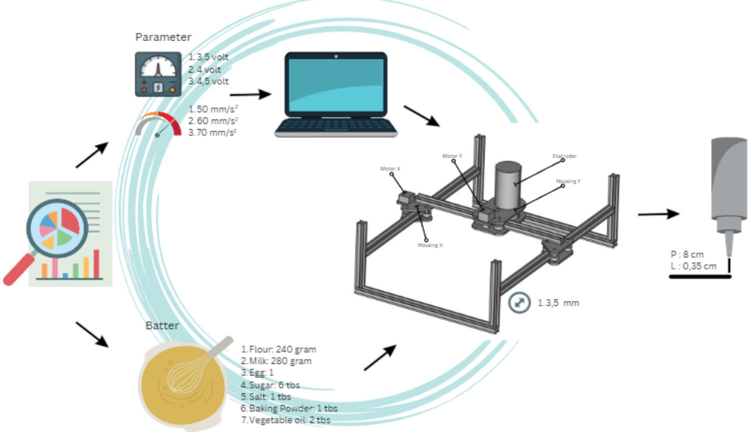

Fig. 1. Research procedure

The full factorial processing method uses Minitab 19 software which includes a normality test to find out whether the data is normally distributed. Then if it meets the requirements, it is continued with the analysis with the ANOVA test to find out the parameters that affect the extrusion result and interaction plot to understand the interaction of each parameter, and the final result is parameter optimization.

2.2. Parameter

Printcake operates using a grbl controller connected to a laptop to input the g-code. Besides the software, it is also necessary to set the engine parameters. In this study, the parameters used are velocity and micropump voltage, machine been run on a default minimum setting using velocity of 50 mm/s and the micropump voltage 3.5 volt. Velocity parameter refer to how fast the axis going to move and the micropump voltage refer to how many batter will be extrude. The available nozzle diameter was 3.5 mm and it's remained unchanged throughout the research same with the bed temperature. The research using 3-level full factorial then a 3-level different parameter needed, beside the default parameter the other 2 level parameter will be their increment, thus the combination of the study can be seen on Table 1.

Table 1. Parameter Combination

Parameter	Level 1	Level 2	Level 3
Velocity	50	60	70
Micropump Voltage	3.5	4	4.5

2.3. Material and Preparation

Default batter ingredients been use on the machine was consist of 240 grams of flour, 280 grams of white milk, one egg, six tablespoons of sugar, one tablespoon of salt, one tablespoon of baking powder, and two tablespoons of vegetable oil. The research will use the same ingredient as the default without any change on the composition. The ingredients are mixed evenly using a mixer for about 10 to 15 minutes and were obtained from a local cake supply store.

3. Results and Discussion

The specimens of a straight line 8 cm long, and 3.5 mm wide, with the dimensions of the specimens, have an area of 2.8 cm^2 were used in this research. Based on the experimental results, it is known that the lowest area error is 5.75%, and the highest area error is 74.11%, while for the lowest length is 0.00%, and the highest length error is 22.19%. Even though the lowest length error is 0%, this does not indicate that the parameter is optimal because it is still affected by the printed area error. Histogram of Length error and Printed area error shown in Fig. 2.

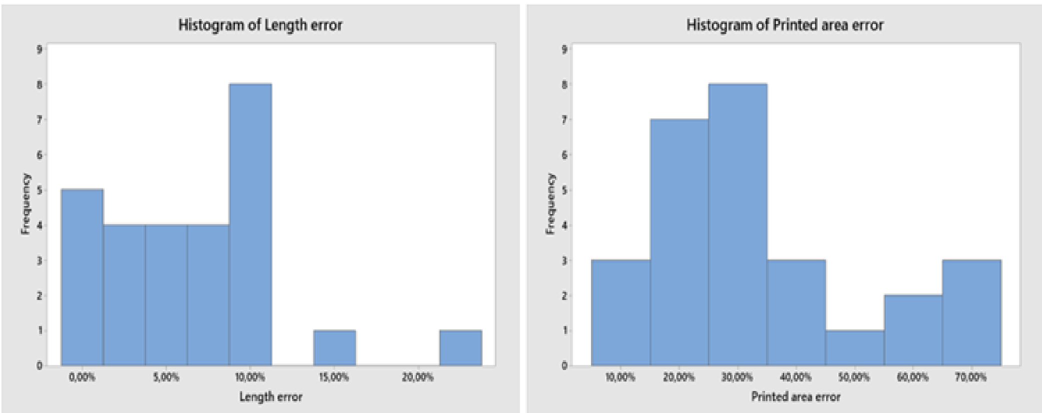

Fig. 2. Histogram of Length error and Printed area error

Based on the histogram, it can be concluded that most of the extrusion results have a length error value below 11.25% with 2 data above it, while for wide error, most of the data is below 35% with 9 data above it, when viewed from this it can be seen that the error results are stable in that area. The results of data extrusion can be seen in Table 2. The data was then tested using DOE Full Factorial on Minitab 19 software. Based on the normality test results, the P-value for the length error was 0.24, and the area error was 0.093. The data set has a P-value above 0.05, so it can be interpreted that the data set is normally distributed with a confidence level of 95% so that it meets the requirements for further testing using ANOVA to analyze the significance of each parameter. Pareto Chart of Length error and Printed area error shown in Fig. 3.

Table 2. Extrusion results

Velocity	Volt	Time	Length	Printed Area	Length Error	Printed Area Error
	3.5	9.27	8.35	3.343	4%	19%
50	4	9.27	6.225	4.848	(-)22%	73%
	4.5	9.27	7.47	3.335	(-)7%	19%
	3.5	9.21	8	3.378	0%	21%
60	4	9.21	8.7	3.677	9%	31%
	4.5	9.21	8.7	4.323	9%	54%
	3.5	9.16	8.787	3.042	10%	9%
70	4	9.16	8.27	3.309	3%	18%
	4.5	9.16	8.88	3.632	11%	30%
	3.5	9.27	8.825	3.62	10%	29%
50	4	9.27	8.7	3.441	9%	23%
	4.5	9.27	8.8	3.804	10%	36%
	3.5	9.21	8.2	3.921	2%	40%
60	4	9.21	8.19	4.593	2%	64%
	4.5	9.21	8.37	3.999	5%	43%
	3.5	9.16	9.119	3.531	14%	26%
70	4	9.16	8,677	3.686	8%	32%
	4.5	9.16	8.09	3.65	1%	30%
	3.5	9.27	8.25	3.432	3%	23%
50	4	9.27	8.729	4.748	9%	70%
	4.5	9.27	8.6	4.875	8%	74%
	3.5	9.21	8.4	3.528	5%	26%
60	4	9.21	7.945	3.284	(-)1%	17%
	4.5	9.21	8.68	4.511	9%	61%
	3.5	9.16	7.91	3.137	1%	12%
70	4	9.16	7.65	2.961	4%	6%
	4.5	9.16	7.94	3.647	1%	30%

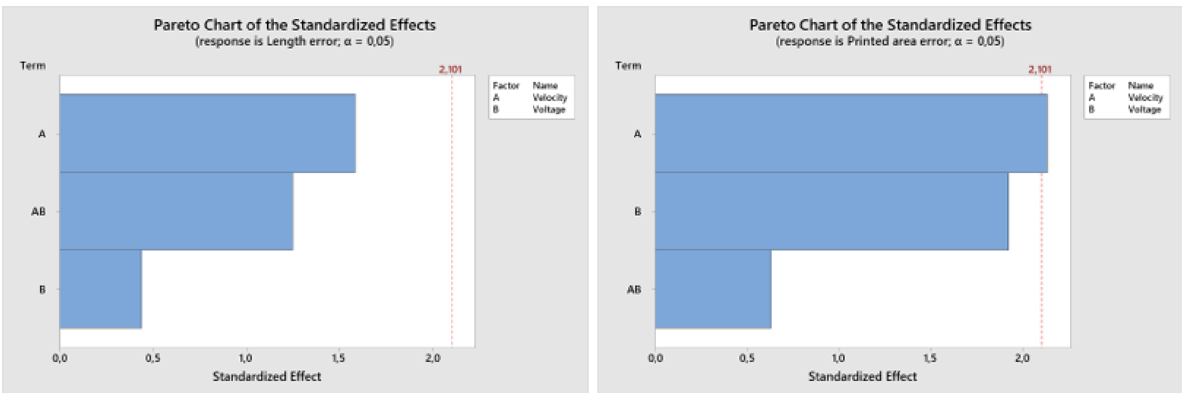

Fig. 3. Pareto Chart of Length error and Printed area error

The most significant parameter or the parameter that has significant influence can be read using ANOVA. It is shown with a p-value below 0.05, which means that the parameter significantly influences the extrusion result. Based on the Pareto chart, the parameter length error does not significantly influence. It can also be seen in the ANOVA results that the velocity parameter has a p-value of 0.13, and the voltage has a p-value of 0.665. On the other hand, the printed area error based on the Pareto chart, there is a parameter that has a significant influence. The velocity parameter has a p-value of 0.047. Interaction Plot for Length error and Printed area error shown in Fig. 4.

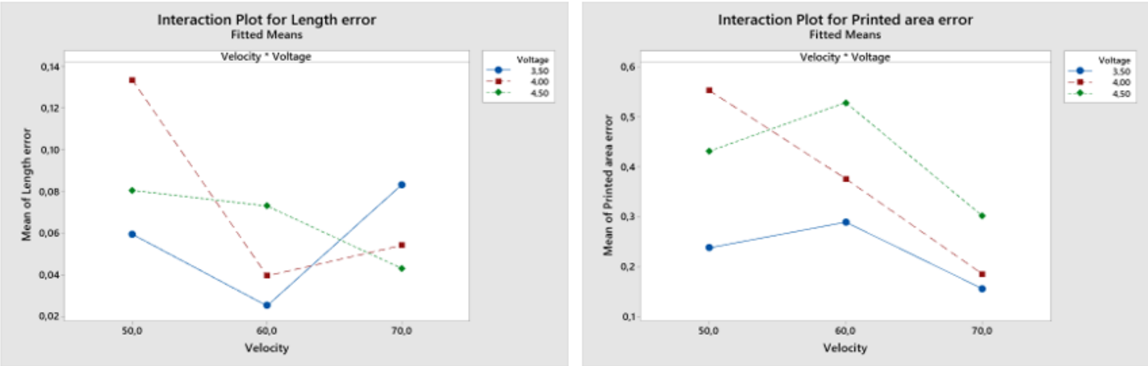

Fig. 4. Interaction Plot for Length error and Printed area error

When we analyze parameter using full factorial the interaction plot of each dependent variable will be created to identify, even based on the Fig. 3 dependent variable of length error doesn't have any significant influence it will be identified to understand the response or change parameter in length error, the only interaction seen on the length error was when we increase the velocity from 50 mm/s to 60 mm/s it will decrease the error value and the lowest error can be obtained using 3.5 volt of micropump voltage. On the other hand, he interaction of printed area error show regardless of the velocity used, the micropump voltage of 3.5 volt always give the lowest printed area error value and the combination with velocity 70 mm/s create the lowest printed area error value. Other relationship between parameters in the printed area error show that regardless of the micropump voltage when we increase the velocity from 60 to 70 the printed area error created will be lowered.

Based on these results, it can be interpreted that the extrusion of batter is suitable. The number of error values is generated when the velocity is not balanced with the value of the micropump voltage. The voltage of the micropump influence the amount of batter that comes out during extrusion, so when the velocity is not well balanced with the amount of batter being extruded, a printed area error will form. If the balance gap between velocity and voltage is big, then the resulting error will be significant also. The bigger the gap, the bigger error will occur this error also in line with the lemon gel system (Yang et al., 2018). Despite different material type were used but the main error happens to be the same

The optimal parameter can be determined with the lowest extrusion error value. This can be done using Minitab 19. In the full factorial test, there is a response optimization feature by obtaining desirability values for each data set. Optimization targets by minimizing the error value on area error and length error, a solution with a desirability value of 78% is obtained from the combination of velocity 70 mm/s and 4 volts voltage and the detailed solution can be seen on Table 3.

Table 3. Optimization parameter result

Solution	Velocity	Volt	Area Fit Error	Length Fit Error	Composite Desirability
1	70	4	0.185238	0.0540417	0.784269
2	60	3.5	0.288929	0.0250000	0.766103
3	50	3.5	0.237500	0.0593750	0.734533
4	70	3.5	0.155952	0.0831667	0.731522
5	70	4.5	0.301071	0.0429167	0.720537

Further experiment using optimized setting was carried out in order to validate the obtained parameter from the optimization. A 3 times replication of optimized parameter was done, average length error was 8.27% it is bigger than the average experiment and the prediction, but the printed area error was better because the error of the optimized parameter 13.6% where it was lower than the average experiment also lower than its prediction and the detailed result can be seen on Table 4. Although the research has been done properly to optimize the printing parameter, further research may need to optimize the batter properties same with the research on batter for a snack (Radoš et al., 2022) even though the material used was different but the main material was closely similar.

Table 4. Optimization printing experiment

Average Printing Result	Length Error	Printed Area Error
Experiment	6.6%	33.9%
Optimized Prediction	5.4%	18.5%
Optimized experiment	8.27%	13.6%

4. Conclusion

It was found that the optimized parameter for printcake using velocity of 70 mm/s and micropump voltage of 4 volt was suitable for the pancake printing in this study, even though the same material never been done before but the error occurred was closely related to other food printing material. Producing ideal printed pancake that similar with the proposed design was necessary to set the appropriate parameters to get ideal printed results, and a balance between velocity and micropump voltage obtained from the optimization parameter. From the research we can see that the result of optimized parameter was good, even the result of length error little bit bigger then the experiment and it's predicted optimized result but it was able to print pancake design with the average error of printed area 13.6% where the average experiment printed area error around 33.9% and prediction of optimization was 18.5%.

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