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Analysis of Food Holder Design Parameters based on Fused Deposition Modelling (FDM) using Design of Experiment Method

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ABSTRACT

The limitations of food holders available in local food manufacturer companies make it difficult to produce varieties of the food pouch size. Since each size of the pouch requires a specific size of food holder, therefore, this paper aims to analyze and design of a new food holder for a food pouch with a 500g capacity to be used in the filling machine. The pouch, conveyor, and ball plunger were analyzed to help in designing the food holder. Then, critical criteria were identified such as the food holder's height, elbow length, and slotting length. After analyzing all the critical criteria, the design of experiment method (DOE) was used to identify significant parameters in designing the food holder. A dry run was done to test the holder, and as a result, it was identified that the food holder height was the most significant criteria, but other criteria also played an important role in the food holder.

1. Introduction

3D printing has become increasingly popular in a wide range of applications, and current manufacturing industries are keen to replace conventional techniques of fabricating tool fixtures with 3D printing technology [1-4]. The application of 3D printing technology can be extended into the food manufacturing industry since it reduces cost and time, is flexible, and allows durable and good quality products to be produced [5-11].

A lot of research has been done related to 3D printing technology to improve several desired outcomes such as mechanical properties and process monitoring [12,13]. Continuous research has been done with the aim to see any possible applications that can benefit various fields such as the food industry. In the food industry, materials used for the tools can be very crucial to ensure safety and compliance with the standard. The current trend of implementing 3D printing technology in the

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food industry brings new challenges to ensure it is safe and at the same time, it is practicable for industrial applications [14]. Some research has been done to investigate the printing parameters of food such as nozzle diameter path width and infill density [14]. The optimum value of these printing parameters needs to be investigated to get the desired product outcome [14].

In the local food manufacturing company such as Organic Gain Sdn. Bhd, the products produced by the company are packaged into two food pouch sizes which are 200 gm and 1 kgAt the food filling machine, fixed food holder jigs are used to hold the food pouches at the conveyor line. Each food pouch size requires a specific food holder. Since the design of the food holder needs to be custom-made, a design approach using the design of the experiment (DOE) method was applied to identify the most crucial dimensions that have a big impact on the food holder. This method has been widely used in various types of research where its use is very effective in producing accurate data and analysis [15-20].

The DOE method can reduce the time taken to respond to a problem and can reduce errors in production [21]. Therefore, to reduce the failure during the testing process, the DOE method is crucial to produce a functional food holder. The selection of control factors is the most crucial stage in the design of an experiment. In other words, the selection of the design parameters needs to be analyzed carefully to avoid any errors during designing and testing. Fused deposition modelling (FDM) was used to fabricate the food holder, and a dry run test was done to measure the effectiveness of the food holder.

2. Methodology

2.1 Background Study

The food pouch analysis was done to analyze the criteria and the dimensions of the pouch. Since this project was aimed to design a food holder for a food pouch with a 500g capacity, the measurement of 500g of the pouch is taken. There are three critical dimensions of the pouch which are the height, width, and maximum capacity that directly affect the successful design of the food holder.

Based on the height level of the filling machine, the maximum height that the pouch can be designed is up to 300mm. Above the maximum height, the pouch intersects with the sealer plate in the filling line. Next, the width of the pouch depends on the dimension of the slotting on the food holder itself. Since the pin on the conveyor is fixed, it is necessary to correctly design the pouch's width to make sure it is inserted fitly at the food holder. The side of the pouch will be sealed from 0.5cm to 1cm unit mm in width. During the filling process, the pouch will be filled with the product before being sealed. Therefore, the maximum percentage allowable for the product to be filled in the pouch is 80% of its total capacity. In other words, the maximum capacity for a pouch is only 80% of its overall height. The remaining 20% is for the width of the sealer process.

Then, the design of the conveyor and the ball plunger were analyzed as well. The conveyor has a fixed pin on top of it. Therefore, it needs to be taken into consideration before designing the food holder. The ball plunger is inserted at the bottom part of the food holder to stick the food holder with the pin on the conveyor. The ball plunger used is fixed. The ball plunger is used as a type of push-fit ball spring plunger made from stainless steel, and the dimension of the ball plunger is 6x7mm which is given by the supplier.

2.2 Design of Experiment

In this project, DOE was used to identify the critical parameters that contribute the most significant factor to the design of the food holder. The three parameters involved are food holder elbow length, slotting length, and height.To design the DOE, the 3-level Taguchi method in Minitab was chosen for the three parameters. Table 1 shows the total number of runs and the specific dimension for each parameter.

Table 1
Complete run of Taguchi method

Run	Parameters		
	Elbow length (mm)	Slotting length (mm)	Height (mm)
1	13	1	80
2	13	2	70
3	13	3	60
4	14	1	70
5	14	2	60
6	14	3	80
7	15	1	60
8	15	2	80
9	15	3	70

2.3 Food Holder Design

The three critical parameters involved in this project are food holder elbow length, height and slotting length as shown in Figure 1. These criteria are identified based on the analysis done on the dimensions of the 500g pouch capacity and design of the conveyor and filling machine. After completing the filling process at the filling machine, both the pouch and food holder would go to the sealer machine that is located on the same machine. The seal width would take up to 20% of the total height of the pouch. Therefore, there would be a remaining 80% of the total available height. In other words, the food holder needs to be designed below 80% of the total height of the pouch, and this issue is factored in to ensure that the sealer plate would not collide with the food holder. Moreover, the slotting dimension also needs to be observed before designing the food holder. The slotting dimension is vital to hold the pouch correctly to ensure that it will not slip from the food holder. Designing a too-wide slotting length will cause the pouch to be misplaced while limiting its length will make the pouch harder to open. The elbow length is another crucial criterion in designing a new food holder. If the elbow length is too long, the holder will not be able to hold the pouch, and a short elbow length will cause trouble during pouch opening.

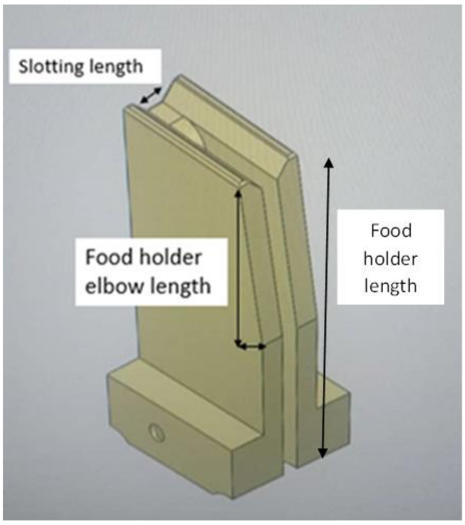


Fig. 1. Critical element in designing food holder

2.4 Prototype

The design of the food holder was done using Solidworks. The file was then saved as an STL file and transferred to a slicing software, IdeaMaker to generate the G-code for 3D printing. The prototype was printed using a 3D printer, Artillery Sidewinder X-1. The material used for the food holder prototype was polylactic acid (PLA) filament with a diameter of 1.75mm. The prototype was printed at the printing temperature of 200◦C, printing speed of 35mm/s, and printing bed temperature of 65◦C.

2.5 Dry Run Test

The dry run test was conducted after the prototype has been designed and printed out. The dry run is a test made to test the food holder, where the food holder is locked on top of the conveyor using the ball plunger, then the pouch is inserted at the slotting diameter of the food holder. The pouch was run dry, without any substance inside it to examine whether the holder can hold the pouch and whether the pouch can open perfectly. Figure 2 below shows the dry run test conducted to test the food holder for the pouch with 500g capacity. This dry run test aimed to analyze how the pouch will react along the production process, for example blowing, filling, and sealing process.

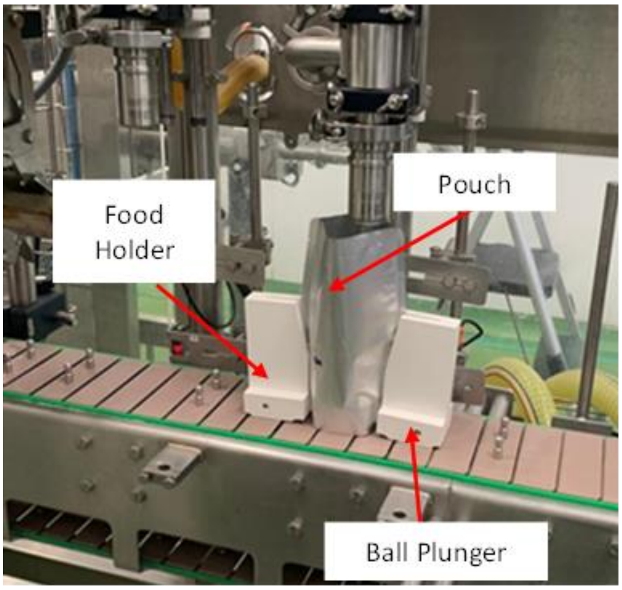
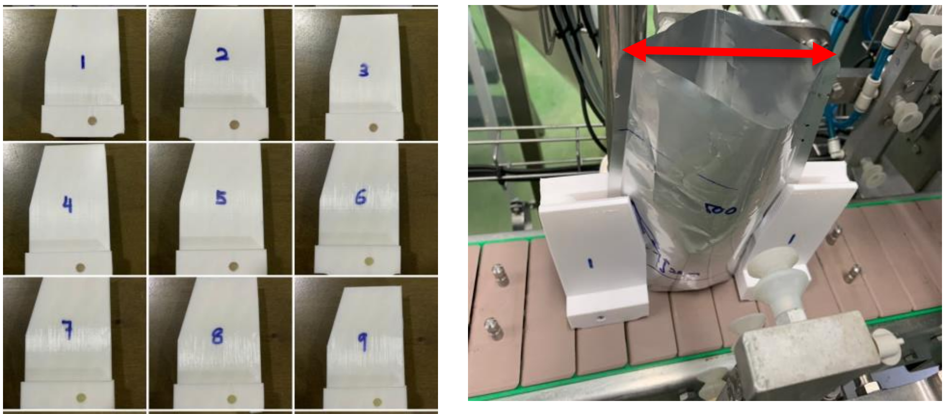


Fig. 2. Dry run test

3. Results

3.1 DOE Results

Figure 3(a) shows all nine printed samples based on the Taguchi design. All the samples were tested in the dry run to see which design parameters affect the pouch opening during the blowing process. The size of the opening was measured to identify the best possible dimension to ensure a smooth production process. Figure 3(b) shows the measuring process of the pouch opening after the blowing process. The result of the Taguchi method is shown in Table 2. The variable response of the Taguchi method is the pouch opening and it is concluded that 95mm is the maximum pouch opening followed by 80mm and 0 mm (pouch close). It is considered a failure if the pouch is not open as the filling process cannot be done.



(a) Nine printed samples for the dry run test

(b) Measure the size of the pouch opening (in red arrow)

Fig. 3. The printed parts of all samples and the opening pouch after the blowing process in the production line

Table 2
The result obtained from the Taguchi method

Run	Parameters			Result	Pouch opening (mm)
	Elbow length (mm)	Slotting length (mm)	Height (mm)		
1	13	1	80	Successful	95
2	13	2	70	Slightly successful	80
3	13	3	60	Failed	0
4	14	1	70	Slightly successful	80
5	14	2	60	Failed	0
6	14	3	80	Slightly successful	80
7	15	1	60	Failed	0
8	15	2	80	Slightly successful	80
9	15	3	70	Failed	0

Then, an ANOVA analysis was used to determine the p-value for all the parameters. Table 3 below shows the result of the ANOVA analysis. Based on the result, the most significant parameter is the food holder height, which should be 80% of the total height. Then, the slotting length and the food holder elbow length are located as the second rank, which indicates that these design parameters also contribute to the design of the food holder.

Table 3
ANOVA analysis

Parameters	f-value	R-sq	s	p-value	rank
Food holder elbow length (mm)	0.79	20.83%	0.889757	0.496	2
Slotting length (mm)	0.79	20.83%	0.889757	0.496	2
Food holder height (mm)	7.29	70.83%	0.540062	0.025	1

Figure 4 shows the graph of main effect plots for the food holder design parameters. The numbers 1,2, and 3 represent the value level that has been manipulated based on Taguchi's design. Food holder height at 80mm (number 1) shows the widest opening for the pouch followed by 70mm (number 2), and 60mm (number 3). ANOVA analysis shows that the food holder elbow and slotting length are not significant, but these two parameters can also be considered to achieve the optimum design of the food holder. Based on the ANOVA analysis, it could be identified that the successful dry run is when the pouch was open at 95mm wide and when the food holder height is at 80mm.

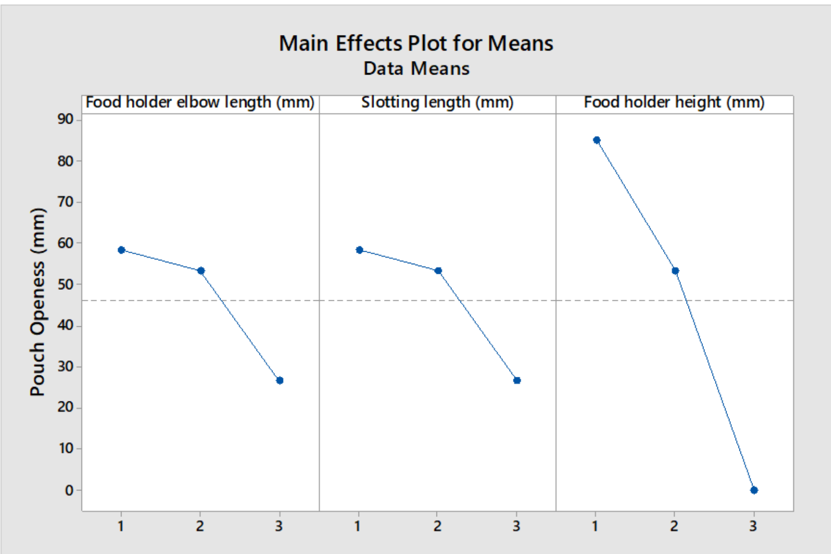


Fig. 4. Main effect plot for response graph

3.2 Final Design

The final design of the food holder was based on the data analyzed from the Taguchi results. Figure 5 shows the complete CAD drawing of the food holder for a food pouch of 500g capacity.

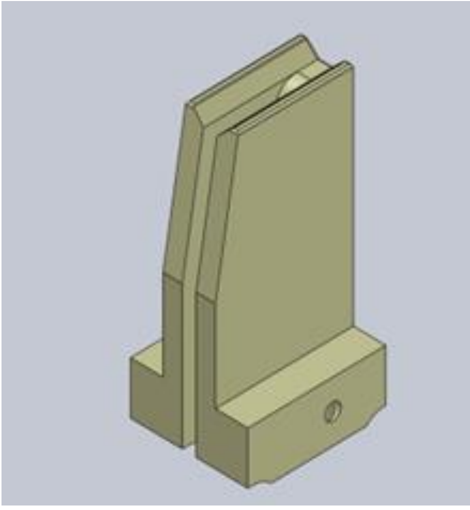


Fig. 5. CAD drawing of the food holder

3.3 Prototype

Figure 6 shows the successfully printed food holder made from PLA. The food holder is unique and specific for each size of the pouch.

Fig. 6. Prototype of food holder

3.4 Dry run

The result of the dry run is shown in Table 4 below. Based on the dry run test, it was concluded that the food holder has been successfully designed to cater for the 500g food pouch since the testing of the filling process ran smoothly at the conveyor. Therefore, the food holder for size 500g can proceed to be fabricated.

Table 4
Dry run result

Item	Parameters	Critical criteria	Failed criteria
500g food holder	Food holder height	80%	<60% >80%
	Slotting length	1mm (±0,5)	>3mm
	Food holder elbow length	13mm (±1)	<3mm >15mm

4. Conclusions

From the result obtained in the experiments, it can be concluded that:

i. The food holder's height has the most significant impact on the design of the food holder.
ii. Other parameters which are the slotting length and food holder elbow length also contributed to the design of the food holder.
iii. The food holder height should be 80% of the total height of the pouch, the slotting length should be 1mm ±0.5, and the food holder elbow length should be 13mm.
iv. The food holder was fabricated using FDM and the dry run test was successful.

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