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Optimization of Vacuum Forming Parameter Settings to Minimize Burning Defect on Strawberry Packaging Products Using the Taguchi Method

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Abstract

Packaging products are being developed by PT. ATMI IGI – Center. The process of making these products uses the Vacuum forming method. The packaging product is made of PP (Polypropylene) and is used to pack strawberries. There are several problems during the production process, one of which is that there are still product defects burning or often called burn marks. These problems are caused by the machining parameters that have not been standardized, and based on trial eror or experience of the operator. The vacuum forming machine used in this production is the Formech 508FS Vacuum Forming machine. The optimized parameters are heat zone, heat time, and stand by temperature. Optimizing these parameters using the Taguchi method, with an orthogonal array with 9 trials, and the selected signal to noise ratio (SNR) is smaller is better. The response of this research is the reduction of burn mark product defects. The results showed that to reduce burn mark product defects, is to set the parameter heat zone 1 by

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90%, heating zone 2 is 80%, heating time 45s, and stand by temperature 60%. Based on this arrangement, the product defects obtained only reached 13%. PT. ATMI IGI-Center is expected to be able to use these parameter settings for the strawberry packaging production process.

Keywords: vacuum forming, defect product, Taguchi method, smaller is better

1 Introduction

PT ATMI-IGI Center is a company that engaged in the manufacture of Molding for plastics production and plastic product molding. Beside producing Mold and molding of plastic products with Injection method, the company is currently also starting to try to get into the field of Vacuum Forming production is in the form of Mold for Strawberry packaging products made with aluminum material. Production is carried out using the Thermoforming process, which is apply the Vacuum Forming system in the Formech 508FS machine. Thermoforming is an industrial process in which a thermoplastic sheet (or film) is processed into a new shape using heat and pressure [1].

The problem that occurs in the production of strawberry packaging is that the product often experiences burning defects or often called burn marks, as shown in Figure 1. Burn marks are product defects, where the product changes colour such as burning, dimensions, and weight [2]. Burn marks in the packaging process happen because there is no standardization for the operation of the parameters, so the operation is only based on the estimation and experience of the operator. This certainly affects the length of time and cost of the experiment because it is done by finding the right estimate of the number of parameter variables that can be used for production. On the Formech 508FS engine, the machining parameters used are heating zones, heating time and stand-by temperature. also stated that the parameters on the vacuum forming machine that need to be optimized include temperature, heating time, and heating zone [3].

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Figure 1. Burning problem on the strawberry packaging product

This research was conducted focusing on optimization parameter setting, to find the parameter that optimal in overcoming the burning defect that often occurs in the production process of strawberry packaging. This research result later can be used for strawberry packaging production, and the method can be used to find optimal parameters of the next mold in the future produced by PT ATMI-IGI Center.

2 Methodology

2.1 Research Methodology

2.1.1 Taguchi Methods

The Taguchi method is used to optimize the parameters contained in the Formech 508FS. The Taguchi Method is one of the methods in experimental design that can be used to control product quality, such as to obtain optimal parameters and material compositions [4] [5]. The Taguchi method belongs to the DOE (Design of Experiment) realm, in which there are two main variables, namely the response variable and the independent variable [6].

In this study, the manufacture of Strawberry Packaging used 3^k factorial design, where at each level identify low, medium, and high. Characteristics in search of strawberry packaging product parameters using the smaller is better type, namely the characteristics of quality with a value limit of 0 and non-negative so that the value of which is getting smaller or closer to zero is the value that desired [7].

In this study the independent variables consist of three variables, namely heating zones, stand-by parameters, and heating time, each variable has 3 levels, low, medium,

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high. Determination of the value of the independent variable level for stand-by temperature and heating time according to machine manuals, work journals and manuals, by conducting initial experiments.

The first step is to look at the temperature recommendation on TDS (Technical Data Sheet), parameter journal and the Formech 508FS engine operating manual, which will be medium level with forecast best setting, as shown in Figure 2. Next, to determine the high and low levels is to add a value according to the range obtained in the initial experiment. Results from initial experiments obtained parameter level for stand-by temperature 40% for low level (range -20% of the experiment) , 60% medium level, and 80% high level (range +20% of test). Heating time is 45s (low level according to trial), 50s (medium level according to the manual use of the Formech 508FS engine), and 55s (high level according to experiment). Medium level heating zones already available in the initial settings (which is usually used for PP material) and high and low levels are obtained through initial trial. The heating zone used is 40%, 60%, and 80%. In Zone 2 in heating zones the temperature increased by 10% due to the need to form more complicated clamping contour than the center of product.

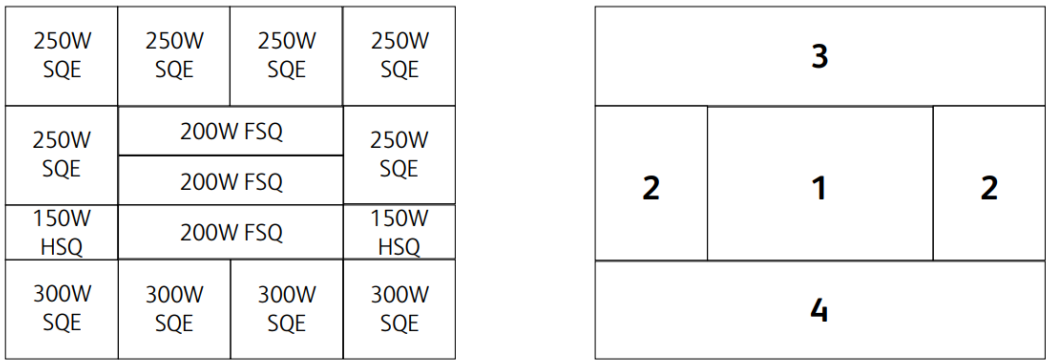

Figure 2. Heating Zone formation on Formech 508FS machine

2.1.2 Orthogonal Matrix

The use of the Taguchi method in design experiment based on Orthogonal Array (OA) in order to obtain the optimal amount of information with minimal trials. Orthogonal array is a matrix of a number of rows and columns [8]. Each column

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represents a certain factor or condition that can change from one experiment to another, and the row represents the level of the factor in the experiment being performed.

Selection of the type of Orthogonal Array used in the experiment depends on the number of degrees of freedom. Determination of degrees of freedom means to see how many minimum numbers of experiments performed [9].

The formulation can be seen in the following equation:

Degrees of freedom = $\sum_{k=1}^{n}(l_k - 1)$ (1)

with, k = 1, 2, ... , n

Research conducted using 3 independent variables with each parameter having 3 levels.

2.1.3 Experimental Result Analysis

The analysis used to determine the effect relative of the various controls in this study is to use the analysis of the average (Analysis of Mean/ ANOM).

ANOM or mean analysis, is used to looking for a combination of control parameters so that optimal results are obtained as desired [10].

2.1.4 Average Value (Mean)

The average or complete average of calculations, for quantitative average contained in a sample calculated by dividing the number of data values by lots of data [11]. Suppose there is a data distribution $y_1, y_2, y_3, \ldots\ldots\ldots y_n$. So, the average is:

$$\bar{y} = \frac{y_1+y_2+y_3+\cdots+y_n}{\text{n}} = \frac{\sum_{i=1}^{n} y_i}{\text{n}} \quad (2)$$

2.2 Data Collection Process

2.2.1 Matrix Orthogonal Selection

Orthogonal Matrix Selection is done by MINITAB 15 software assistance, according to the number of Independent Variables/Factors and Levels used in study. Research conducted using 3 independent variables with each parameter having 3 levels. The degrees of freedom (dof) obtained in this study are:

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DoF = Independent variable * (level-1)

DoF = 3 x (3-1) = 6

The value 6 of the degrees of freedom is the sum of minimum for the experiment to be carried out. Study it uses an orthogonal array L9 which has The number of experiments is 9. Based on these choices, on the Taguchi Design – Design table on MINITAB, column L9 is selected.

The research carried out took the L9(3^3) orthogonal matrix with a total of 9 trials. The table of variations of the orthogonal array matrix is shown in table 1 has been entered according to the variation of parameters.

Table 1 Parameter Variations

No	*Heating Zones*	*Stand-by Temp*	*Heating Time*	Cacat Produk (%)
1	40	40	45	...
2	40	60	50	...
3	40	80	55	...
4	60	40	50	...
5	60	60	55	...
6	60	80	45	...
7	80	40	55	...
8	80	60	45	...
9	80	80	50	...

2.2.2 Vacuum Forming Trial Process

The materials used in this research are Polypropylhene (PP) plastic sheet with size 530x470mm for each sheet.

As for the machine used is a machine Vacuum Forming Formech 508FS. The machine has prepared in advance with the heating stage heater with high heating parameters. Then Parameters according to Orthogonal Matrix are inputted and stored in machine memory. Setting according to independent variable and level to the parameters of the Heating Zone, StandBy Temperature and Heating Time.

Determination of Assessment Aspects is determined based on finished product requirements, initial trial results, and requirements list from PT ATMI-IGI Center. Aspect The assessment uses the percentage of damage, for qualifies Taguchi Smaller is

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Better Method. There are 5 Aspects that are the basis for the assessment the success of an experimental specimen, namely Burning/Not Burning, Thickness, Contour, Angle and Lock Holes/Pins.

2.3 Experimental Result Data Analysis

Assessment based on the assessment aspect is carried out after all parameter variations and all replications have been completed. The assessment data uses percent (%) units to mark the percentage of damage that occurs in vacuum forming printed products.

Analysis of Experimental Results was carried out using manual calculations in Microsoft Excel and confirmed by calculations on the MINITAB 15 software.

2.3.1 Analysis on Top Section

After the experiment was carried out, the average of the experimental results was obtained to determine the parameters that had the most influence on defects in the Top part of the product. The experimental data are shown in table 2.

Table 2 Top Section Experimental Data

No	*Heating Zones*	*Stand-by Temp*	*Heating Time*	Cacat Produk (%)
1	40	40	45	60%
2	40	60	50	47%
3	40	80	55	60%
4	60	40	50	60%
5	60	60	55	47%
6	60	80	45	47%
7	80	40	55	60%
8	80	60	45	7%
9	80	80	50	40%

The calculation of the average manually for the response to product defects as follows:

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- Average for response in Heating Zones Level 1

Holding Time Lvl.1 = (60%+47%+60%)/3 = 56%

Then the average table for the product defect response is obtained (Table 2.4)

As for the calculations in the effect table, shows the variables with the greatest effect on product defects are as follows:

- Variable Effects of Heating Zones:

Highest Response for Means – Lowest Response for Means

56%-36% = 20%

Then the magnitude of the effect on each factor is obtained as shown in table 3 below.

Table. 3 Response for Means (Smaller is Better)

Level	*Heating Zones*	*Stand-by Temp*	*Heating Time*
1	56%	60%	38%
2	51%	33%	49%
3	36%	49%	56%
Efek	20%	27%	18%
Optimum Level	3	2	1

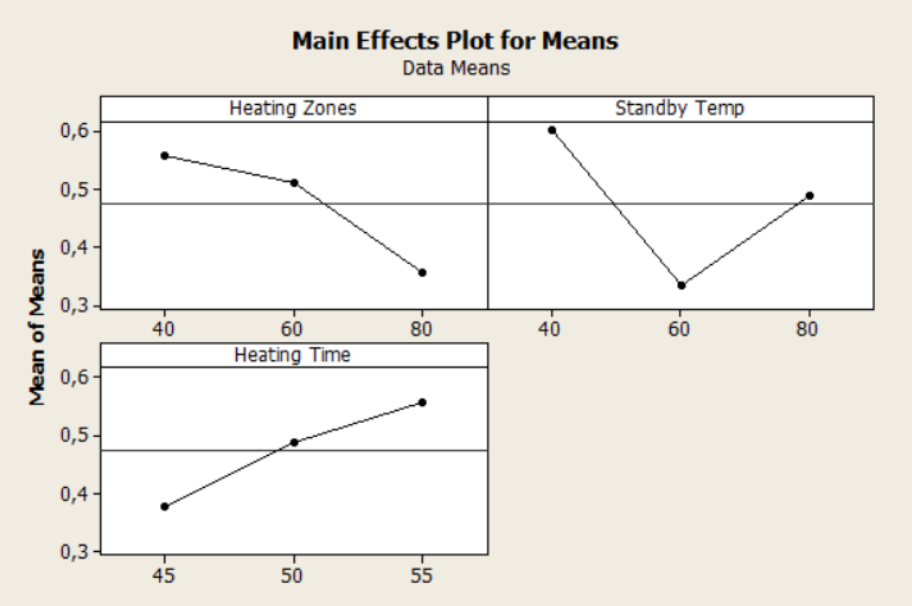

Figure 3. MINITAB calculation for Response for Means

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Figure 3 above shows the results of the average graph (means) in the Top section which is processed using Minitab 15 software.

Parameter Heating Zone The means graph shows the lowest value is at level 3, which is 36%. While the StandBy Temperature parameter shows the lowest value is at level 2, which is 33%. Then the Heating Time parameter shows the lowest value is at level 1, which is 38%.

2.3.2 Analysis on Base Section

After the experiment was carried out, the average of the experimental results was obtained to determine the parameters that had the most influence on defects in the Base part of the product. The experimental data are shown in table 4.

The calculation of the average manually for the response to product defects as follows:

- Average for response in Heating Zones Level 1

Holding Time Lvl.1 = (20%+33%+60%)/3 = 38%

Then the average table for the product defect response is obtained (Table 5)

Table 4 Base Section Experimental Data

No	*Heating Zones*	*Stand-by Temp*	*Heating Time*	Cacat Produk (%)
1	40	40	45	20%
2	40	60	50	33%
3	40	80	55	60%
4	60	40	50	60%
5	60	60	55	60%
6	60	80	45	33%
7	80	40	55	33%
8	80	60	45	13%
9	80	80	50	40%

As for the calculations in the effect table, shows the variables with the greatest effect on product defects are as follows:

- Variable Effects of Heating Zones:

Highest Response for Means – Lowest Response for Means

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51%-29% = 22%

Then the magnitude of the effect on each factor is obtained as shown in table 5 below.

Table 5. Response for Means (Smaller is Better)

Level	*Heating Zones*	*Stand-by Temp*	*Heating Time*
1	38%	38%	22%
2	51%	36%	44%
3	29%	44%	51%
Efek	22%	9%	29%
Optimum Level	3	2	1

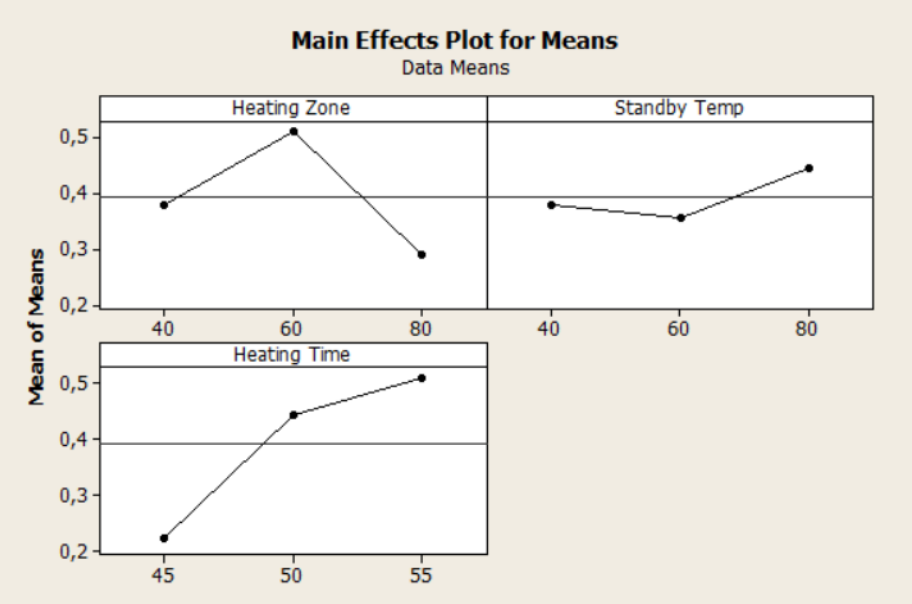

Figure 4. MINITAB calculation for Response for Means

Figure 4 above shows the results of the average graph (means) in the Top section which is processed using Minitab 15 software.

Parameter Heating Zone The means graph shows the lowest value is at level 3, which is 29%. While the StandBy Temperature parameter shows the lowest value is at level 2, which is 36%. Then the Heating Time parameter shows the lowest value is at level 1, which is 22%.

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3 Results and Discussions

3.1 Research Result on Top Section

The results of processing experimental data and after the validation process is carried out, it shows that parameters that result in a formable product according to predetermined aspects and does not occur defect burning is parameter no.8. Process parameters vacuum forming for experiment no.8 has setting as follows:

- Heating Zone = Level 3 = 80%
- StandBy Temp. = Level 2 = 60%
- Heating Time = Level 1 = 45s

Table 2 shows the experimental data where parameter no.8 has a product defect percentage rate the smallest is 7%.

3.2 Research Result on Base Section

The results of data processing experimental results and after the validation process is carried out, it shows that parameters that result in a formable product according to predetermined aspects and does not occur defect burning is parameter no.8. Process parameters vacuum forming for experiment no.8 has setting as follows:

- Heating Zone = Level 3 = 80%
- StandBy Temp. = Level 2 = 60%
- Heating Time = Level 1 = 45s

Table 4 shows the experimental data where parameter no.8 has a product defect percentage rate the largest is 13%.

3.3 Validation of Research Result

Validation of research results from parameter recommended showing results that have the most perfect formation and still can maintain thickness and there are no parts which has defect burning. Finished products that have been cut according to the part used as strawberry package and already assembled like shown in Figure 5, Table 4 shows the experimental data where parameter no.8 has a product defect percentage rate the largest is 13%.

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Figure 5. Assembling result on Validation Product

4 Conclusions

Based on the research that has been done, then can be concluded as follows:

- Optimal parameter setting to minimize product defects burning and able to shape the product during the vacuum forming process on the Formech 508FS machine for Strawberry Packaging products on the Top is a combination of parameters in the Heating Zone by 80%, StandBy Temperature by 60%, and Heating Time by 45s which resulted in an average percentage of product defects of 7%. As for the Base part is with a combination of parameters in the Heating Zone of 80%, StandBy Temperature of 60%, and Heating Time of 45s which results in an average percentage of product defects of 13%.
- Setting parameters that affect the process of making Strawberry Packaging products from the Top section on Burning product defects and being able to shape the product based on the results of calculations carried out, contained in Table 5.5 are StandBy Temperature which has an effect of 27%, then there is Heating Zone which has an effect of 20%, and followed by Heating Time which has an effect of 18%. Meanwhile, for setting parameters that affect the process of making Strawberry Packaging products from the Base section on Burning product defects and being able to form products based on the results of calculations carried out, contained in Table 5.7 is Heating Time which has an effect of 29%, then there is Heating Zone which has effect by 22%, followed by StandBy Temperature which has an effect of 9%.

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