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Optimization of Material Usage Using Green Manufacturing Technique for Automotive Supplier Part

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ABSTRACT

This study aims to apply green manufacturing technique in the product production by utilizing the Taguchi optimization method. By adopting L_9 orthogonal array, products of panel instrument cluster finish were made from various compositions of virgin and recycled plastic (PP) by injection moulding. Three controllable factors (i.e., barrel temperature, injection pressure and holding pressure), each at three levels are tested to determine the optimal combination of factors and levels in the manufacturing process. The visualised quality of the product produced and percentage of cost saving also investigated.

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INTRODUCTION

Automotive as one of the most important and strategic industry for manufacturing sector faces increasing regulatory and social pressures to improve both the sustainability of its product and environmental issues. According to National Automotive Policy (NAP), Malaysian automotive industries must focus on strengthening the competitiveness market by implementing an effective green design framework or green manufacturing (GM) practice. However, the motivation among the Malaysian automotive companies to benefit from the reuse or recycle of automotive components is rather low (Lily Amelia *et al*. 2009). Green practices enable the companies to move beyond compliance to cost reduction and increased profitability. At the same time, it can maximize the environmental performance of company (Juriah, 2012).

This paper emphasized the effects of processing parameters on the quality of products produced from recycled plastic in various compositions without the addition of addition of stabilizers. The quality of products is determined through visual inspection. By adoption of GM technique, the parameters setting become the significant factors that may reflect to the quality of the products and needs for consideration in order to obtain best quality of product and cost efficiencies (Z.A. Khan *et al*., 2010). Barrel temperature and injection pressure contributes the highest output response of optimization parameter (M.V.Kavade, 2012). Ozcelik and Sonat (2009) reach a conclusion that holding pressure is the most important parameter for quality of injected parts. The Taguchi method is used to optimize the quality of products made from recycled plastic. The L_9 orthogonal array is used as an experimental design for the three controllable factors of barrel temperature, injection pressure and holding pressure, each at three level to find the optimal combination of factors and levels. The effects of costing based on materials consumption are also investigated for effective cost determinant.

Methodology:

In this study, two types of resin were used to produce the parts (MC) which are virgin PP and recycled PP. It is noted that recycled PP is obtained from recycling of virgin PP's unwanted parts such as scraps. The virgin PP was manufactured by Propelinas Propylene Malaysia with the trade name PP Cosmoplene Grade BRE62. It comes out with black color (136B PK). The mixtures of virgin and recycled PP in various percentages were prepared for injection as Table 1.

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Table 1: Mixture Percentages of Virgin and Recycled PP

Designation	Virgin PP (%)	Recycled PP (%)
X	100	0
Y	70	30
Z	0	100

The panel instrument cluster finish or meter cluster with various compositions of virgin and recycled PP, as indicated in Table 1 were injected by MA470 injection molding machine. The experiment was conducted with three controllable three-level processing parameters as Table 2. Other processing parameters such as mold temperature (60°C), cooling time (35s), injection time (12s), back pressure (10bar) and stroke distance (465mm) were kept constant during experiment.

The Taguchi method designs an orthogonal array (OA) to simplify the large number of experiments and allocates them into smaller number of trials to run the experiment. L_9 OA as shown in Table 3 was conducted to study the three processing parameters.

Table 2: Control Factors and Their Levels

Injection Molding Parameters	Symbol	Level		
		Level 1	Level 2	Level 3
Barrel temperature (°C)	A	180	200	220
Injection Pressure (bar)	B	45	50	55
Holding Pressure (bar)	C	5	10	15

Table 3: Taguchi L_9 Orthogonal Array Design

Experiment Trial	A	B	C
1	180	45	5
2	180	50	10
3	180	55	15
4	200	45	10
5	200	50	15
6	200	55	5
7	220	45	15
8	220	50	5
9	220	55	10

The quality of panel instrument cluster finish was evaluated in term of defects (short mold, sink mark, flashing etc) and non-defects through visual inspection which is then converted into S/N ratio for variance analysis (ANOVA to determine the optimal processing parameters/levels and the impact of each processing parameter on the quality characteristics being studied. The optimal materials usages were then analyzed via weight of materials to determine lower manufacturing cost and life cycle cost.

Manufacturing Cost (C_M) = DM + DL + OH (1)

Where DM: Direct Material Cost
DL: Direct Labor Cost
OH: Manufacturing Overhead Cost

$$\min C = \min (Cp + Cm + Ct + Cr) \quad (2)$$

Where Cp : Purchase Cost
Cm: Process Cost
Ct : Transport Cost
Cr : Recycle Cost

Results:

The result of acceptable performance of injected panel instrument cluster were based on mean value of five samples at each set of experimental conditions for each process parameter variable as shown in Table 4.

Table 4: Visual Inspection for Three Compositions of Materials

Exp.	A	B	C	Total of Accepted		
				X	Y	Z
1	180	45	5	0	0	0
2	180	50	10	0	0	1
3	180	55	15	0	0	0
4	200	45	10	0	0	2
5	200	50	15	0	0	4
6	200	55	5	1	1	2
7	220	45	15	1	3	1
8	220	50	5	4	2	1
9	220	55	10	2	1	0

*UD: Undefined S/N Ratio

Table 5: S/N Ratio for Composition X, Y and Z

Exp.	A	B	C	Total of Accepted		
				X	Y	Z
1	180	45	5	UD	UD	UD
2	180	50	10	UD	UD	6.990
3	180	55	15	UD	UD	UD
4	200	45	10	UD	UD	13.010
5	200	50	15	UD	UD	19.031
6	200	55	5	6.990	6.990	13.010
7	220	45	15	6.990	16.532	6.990
8	220	50	5	19.031	13.010	6.990
9	220	55	10	13.010	6.990	UD

Discussions:

2.1 Signal to Noise Ratio (S/N):

The S/N ratio is used to convert the trial result data into a value for the evaluation characteristics as the optimum setting analysis as in Table 5. In this study, the visual inspection against the output is to determine the quality characteristics considered of the product. To analyze and determine which the optimal parameter factors for the manufacturing process involve, the reject should be in minimum as the acceptable of output. The S/N ratio selected for this study is larger-the-better quality characteristics. The calculation and equation for S/N ratio is as following:

Larger- the- better**:**

$$S/N = -10 \log (\Sigma (1/yi2) / n) \quad (3)$$

Where,

yi = each observation value

n = number of observation (values at each trial condition)

2.2 Rank of Factor:

The factor is ranked based on Δ value (max-min) of S/N ratio. Basically, the larger the Δ values, the greater influences of factor. Through the ranking method, the most significant factor for this project for each composition can be determined and the optimize parameter were selected.

Table 6: Rank of Factor for Composition X

	A	B	C
Level 1	0.000	6.990	26.021
Level 2	6.990	19.031	13.010
Level 3	39.031	20.000	6.990
Max-min (Δ)	32.041	13.01	19.031
Rank	1	3	2

Table 7: Rank of Factor for Composition Y

	A	B	C
Level 1	0.000	16.532	20.000
Level 2	6.990	13.010	6.990
Level 3	36.532	13.980	16.532
Max-min (Δ)	29.542	3.522	13.010
Rank	1	3	2

Table 8: Rank of Factor for Composition Z

	A	B	C
Level 1	6.990	20.000	20.000
Level 2	45.051	33.011	20.000
Level 3	13.980	13.010	26.021
Max-min (Δ)	38.061	20.001	6.021
Rank	1	2	3

Table 6, Table 7 and Table 8 indicate that the barrel temperature has the most significant factor which influences the quality of the output for all three compositions (X, Y and Z) by giving highest delta (Δ) values. The optimum parameters setting level for each composition were classified as composition X ($A_3B_3C_1$), composition Y ($A_3B_1C_1$) and composition Z ($A_2B_2C_3$).

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2.3 Main Effect of Signal-to-Noise Ratio (S/N) Response:

The main effect plot is a plot of the mean response values at each level of design parameter or process variables. The sign of the main effect indicates the direction of the effect, whether the average response value is increases or decreases. The magnitude indicates the strength of the effect.

Fig. 1 shows S/N graphs for panel instrument cluster finish manufactured using three compositions. The graphs for composition X and Y are quite similar. It reveals that the trend of barrel temperature is slightly increased from 180°C to 200°C then squally increased and approach to the maximum of the S/N ratio value at 220°C. For holding pressure, the S/N ratio is smoothly decreased between 5 bar and 10 bar, and approach to the minimum of S/N ratio at 15 bar. The S/N ratio for injection pressure is slightly increased between 45 bar and 50 bar then smoothly increases to maximum S/N ratio at 55 bar. For composition Z, it is obviously that barrel temperature and injection should be set at level 2 to give the significant effects on optimal parameter with holding pressure level 1.

In the analysis of variance, the effects of barrel temperature, injection pressure and holding pressure were assessed and α-level of 0.05 was chosen. The results indicate the p-value the barrel temperature factor is lower than other factors for each composition. This means the effect of barrel temperature on composition is significant. As long as the p-value is greater than 0.05, indicating that factors is not significant.

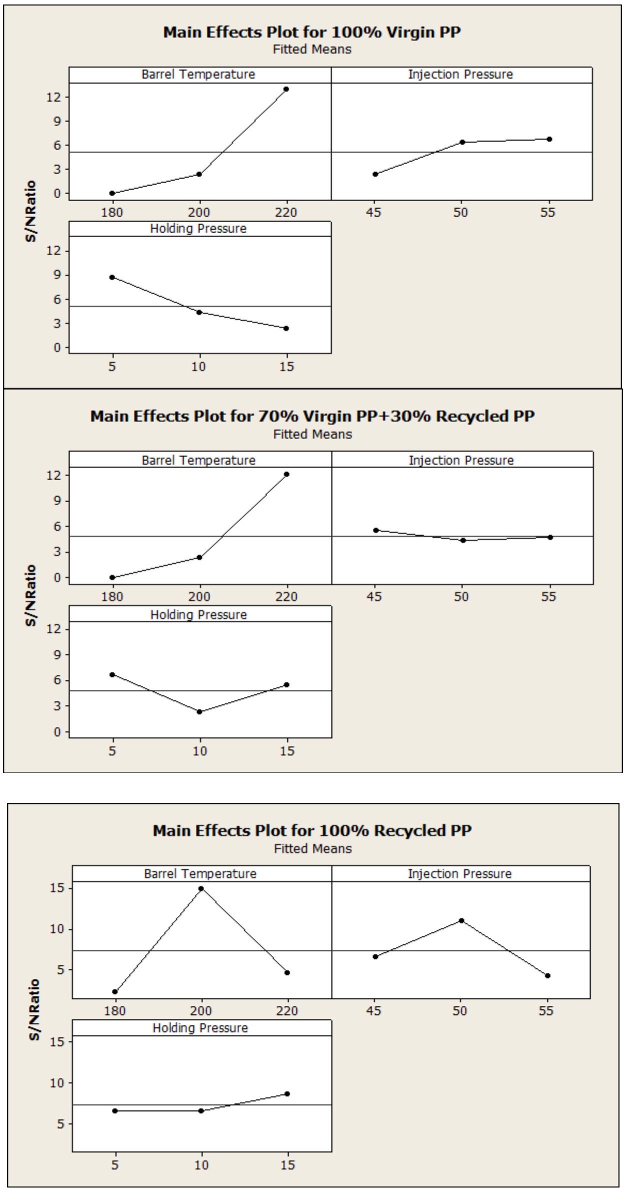

Fig. 1: Main Effects Plot for S/N Ratio

2.4 General Linear Model:

Factor Type Levels Values
Barrel Temperature fixed 3 180, 200, 220

Injection Pressure fixed 3 45, 50, 55
Holding Pressure fixed 3 5, 10, 15

Analysis of Variance for 100% Virgin PP, using Adjusted SS for Tests
Source DF Seq SS Adj SS Adj MS F P
Barrel Temperature 2 288.767 288.767 144.384 41.45 0.024
Injection Pressure 2 35.021 35.021 17.510 5.03 0.166
Holding Pressure 2 63.078 63.078 31.539 9.05 0.099
Error 2 6.967 6.967 3.484
Total 8 393.833
S = 1.86646 R-Sq = 98.23% R-Sq(adj) = 92.92%

Analysis of Variance for 70% Virgin PP+30% Recycled PP, using Adjusted SS for Tests
Source DF Seq SS Adj SS Adj MS F P
Barrel Temperature 2 250.69 250.69 125.34 5.37 0.157
Injection Pressure 2 2.21 2.21 1.10 0.05 0.955
Holding Pressure 2 30.26 30.26 15.13 0.65 0.607
Error 2 46.67 46.67 23.34
Total 8 329.82
S = 4.83074 R-Sq = 85.85% R-Sq(adj) = 43.40%

Analysis of Variance for 100% Recycled PP, using Adjusted SS for Tests
Source DF Seq SS Adj SS Adj MS F P
Barrel Temperature 2 273.656 273.656 136.828 21.77 0.044
Injection Pressure 2 68.687 68.687 34.344 5.46 0.155
Holding Pressure 2 8.056 8.056 4.028 0.64 0.609
Error 2 12.572 12.572 6.286
Total 8 362.971
S = 2.50715 R-Sq = 96.54% R-Sq(adj) = 86.15%

Material Usage Analysis:

Weight will be the output response to study the variation in output due to changes in the levels of process parameters. The average weight of panel instrument cluster finish (as shown in Table 9) is used to determine the cost efficiency of green manufacturing technique, recycle by using two different analysis methods, manufacturing cost and life cycle cost.

Table 9: Average Weight for Different Composition

Exp.	A	B	C	Average Weight, W (g)		
				X	Y	Z
1	180	45	5	0.000	0.000	0.000
2	180	50	10	0.000	0.000	301.600
3	180	55	15	0.000	0.000	0.000
4	200	45	10	0.000	0.000	302.950
5	200	50	15	0.000	0.000	303.900
6	200	55	5	312.000	302.600	302.150
7	220	45	15	300.200	306.900	297.600
8	220	50	5	313.050	305.300	302.600
9	220	55	10	310.200	301.100	0.000
Total				1235.450	1215.900	1810.800
Mean				308.862	303.975	301.800
Average						304.879

2.2.1 Method 1: Manufacturing Cost:

Based on accounting principle, manufacturing cost is the sum of costs of all resources consumed in the process of making a product. The manufacturing cost which is also called as processing cost is classified into three categories includes direct materials cost, direct labor cost and manufacturing overhead.

a) Current Production:

Based on current production, it is noted that the manufacturing cost for panel instrument cluster finish is RM 4.359. As long as 25 kg of PP materials produce 72 pieces of panel instrument cluster finish, the weight of panel instrument cluster finish per pieces is considered as 347.2 g. It is noted that cost of 25000 g of PP are RM 250. Hence, the direct material cost for one pieces of panel instrument cluster finish equal to RM 3.472. In order to determine the labour cost and overhead cost, the manufacturing cost is minus direct materials cost. Hence, the direct labour cost and overhead cost for panel instrument cluster finish is RM 0.887.

C_M = DM + DL + OH
RM 4.359 = RM 3.472 + DL + OH
DL + OH = RM 0.887

a) Experimental Production (Green Manufacturing Technique)

The experimental productions are based on three different compositions of materials (X, Y and Z). It is figure out that the average weight of panel instrument cluster finish produced is 304.879 g per pieces hence the cost of materials used is calculated to determine the manufacturing cost.

Composition X
25000 g = RM 250
304. 879 g = RM 250/25000 g x 304.879
304.879 g = RM 3.049

C_M = DM + DL + OH
C_M = RM 3.049 + RM 0.887
C_M = RM 3.936

Composition Y
70 % of 304.879 g = 213.415 g
25000 g = RM 250
213.41 = RM 250/25000g x 213.415
213.415 g = RM 2.134
C_M = DM + DL + OH
C_M = RM 2.134 + RM 0.887
C_M = RM 3.021

Compositions Z
304.879 g (recycled PP) = RM 0
C_M = DM + DL + OH
C_M = RM 0 + RM 0.887
C_M = RM 0.887

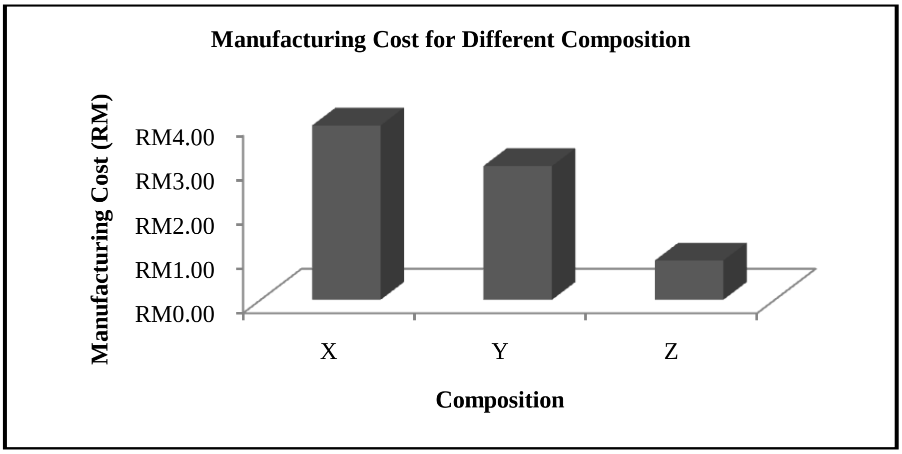

Fig. 2: Manufacturing Cost for Experimental Production

Fig. 2 displays the summary of manufacturing cost for experimental production. High manufacturing cost, high selling price. If the selling price is constant but manufacturing cost is variety, low manufacturing cost can generate more profits. Figure 3 stimulates the summary of profit margin. The profits is generating to RM 3.049 by using fully recycled materials. In other words, by using 100% recycled PP, the cost can be save up to RM 3.049.

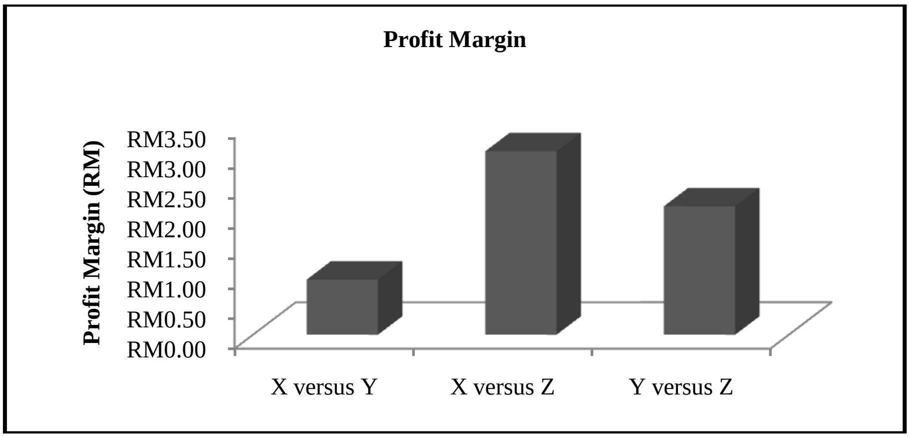

Fig. 3: Profit Margin

Method 2: Life Cycle Cost Analysis:

The lowest life cycle cost of material is defined as min C = min (Cp + Cm + Ct + Cr). By using the formula, the life cycle cost of materials for three composition materials that being tested is calculated. The summaries of life cycle costing are shown as Figure 4. It is noted that the recycle cost equal to RM 0.10 per pcs. For composition X, no recycle cost and transport cost involve while for composition Y and Z, only transportation cost is not involved. Hence the calculation of life cycle cost as below:

Composition X
min Cx = min (Cp + Cm + Ct + Cr)
= RM 3.049 + RM 0.887 + RM 0 + RM 0
= RM 3.936

Composition Y
min Cy = min (Cp + Cm + Ct + Cr)
= RM 2.134 + RM 0.887 + RM 0 + RM 0.10
= RM 3.121

Composition Z
min Cz= min (Cp + Cm + Ct + Cr)
= RM 0 + RM 0.887 + RM 0+ RM 0.10
= RM 0.987

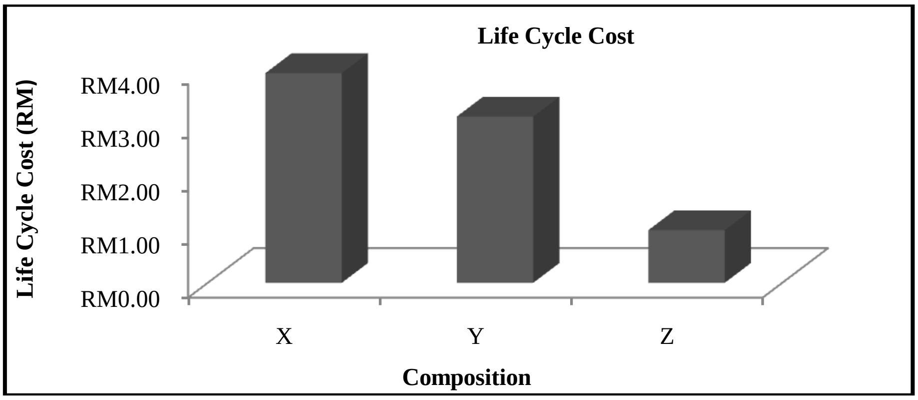

Fig. 4: Life Cycle Cost for Composition X, Y and Z

Conclusion:

According to the experiment, the main objectives of the project were to optimize the material usage by using DOE and then analyze the material costing. The following conclusions are drawn based on the results throughout this experiment in injection molded meter cluster with different compositions of PP by using different parameters condition.

i. Results show that the green manufacturing technique can be implemented using recyclable material such as PP so that the material utilization can be optimized.
ii. The parameter settings of barrel temperature and holding pressure must be set to optimum levels to perform the good quality of the product while injection pressure is less significant for the recycled composition.
iii. The defects such as short mold, sink mark and flashing can be avoided through proper setting of parameters during injection molding.
iv. Mixture of 100% recycled PP is recommended as best composition materials if mechanical properties of product produced is ignored. Besides, it also can save the cost.

After the overall review of the study approach, it is recommended that there are several things can be noted for purposes of modification and improvement of this research into a greater achievement. The recommendations as follows:
i. Mechanical testing should be performed in order to investigate the mechanical performance of meter cluster products.
ii. Part inspection standard (PIS) is necessary to check the tolerances and specification of product dimensions.

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