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Full Factorial and Taguchi Design for the Impact Strength of Oil Palm Fiber Reinforced Composite: A Comparative Study

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Abstract

In this research, Taguchi Method is used for optimizing the quantity of the samples in investigating the properties of composite material. The objective of this study is investigating the validity of Taguchi method to optimize the sample quantity in the research on the impact strength of polymer matrix composite reinforced with oil palm fibers. The result was compared to the full factorial design. There were 3 Factors used in this work, i.e.: fiber contents/ percentage, Fiber length and chemical treatment. Every factor consists of three levels. The fiber contents were varied into 3 different percentages: 5%, 7% and 10%. The fiber lengths were also varied in three sizes: 5mm, 7mm and 10mm. The level of chemical used factors consist of Untreated, Treated and Coupling agent. NaOH is used here to treat the fiber while PPgMA (Polypropylene grafted Maleic Anhydride) is used here as The coupling agent. The analysis graph, from the two methods were obtained almost same graph. The analyze of multiple regression analysis also results similar regression equation, with the p-value of all independent variables also below 0.05 which indicated all independent variables are significant. Even There are little different in coefficient number of the two equation. But still too small. Taguchi method has succeeded in making research more efficient. The use of a small number of sample combinations is able to produce good analytical validity, equivalent to a full factorial method which is 3 times the number of combination samples.

Index Terms— Oil Palm fiber, Taguchi method, Factorial design, regression, significant.

Introduction

Research on the utilization of natural resource waste, including plant fibers such as coconut, cotton, hemp, oil palm, hemp, has recently been increasingly being carried out by researchers for various industrial purposes [1] or as bio-composites [2]. The low cost and their properties, e.g. fairly good mechanical properties, high specific strength, non abrasive, eco-friendly and biodegradability characteristics, make the Natural fibers are exploited as replacement of conventional fiber such as glass, aramid and carbon [3], although composites from synthetic materials are still being developed [4]. There are many types of Natural fibers have been investigated to be used as reinforcing or even just as a filler of composite materials [5][6][7][8][9] [10][11][12] explored the physical and mechanical properties of natural fibers filled polypropylene composites and Its recycle. Bamboo fiber have been investigated as reinforced epoxy sandwich structure composites [13].

There are many methods have been investigated to improve the mechanical properties of Natural fiber polymer matrix composites. One of the methods is by doing alkali treatment on fiber. The Alkali treated fiber greatly influences Mechanical properties of PLF/PP composite [14].

There are many applications in the automotive and plastic industries due to the strength of Oil Palm Biomass (OPB) based polymeric composites compared to pure polymers. Polymer matrix composites have some advantages i.e. rust resistance, lightweight, and generally have a high flexibility [15][16][17]. The needs of specific material properties have become varied caused by the wider application of composite material recently. Therefore the research related to the mechanical properties of the composite materials has also become more diverse and complicated. There are many samples should be prepared during investigation caused by many factors to be investigated. It is needed to use any approach to reduce the sample quantity without reducing the accuracy of the result.

Taguchi approach is an effective design of experiment (DOE) applications [18] which is a set of techniques based on statistical principal and utilizing an engineering knowledge [19]. Taguchi method provides an efficient Taguchi systematic and efficient Methodology for the design optimization of the cutting parameters with far less effect than would be required for most optimization techniques [20][20]. Methodology for the design optimization of the cutting parameters with far less effect than would be required for most optimization techniques [20]. Taguchi Method has become a powerful tool for improving the productivity during research and development [21]. The parametric design of the Taguchi Method provides a simple, systematic and efficient methodology for optimization of the cutting parameters [22]. Taguchi Method is a statistical approach to optimize the process parameter and improve the quality components that are manufactured [23]. Taguchi Method of parameter can perform with lesser number of experimentation as compared to that of full factorial and yield similar result [23][24].

The studies described above were using the Taguchi method in research on machining processes. The use of Taguchi method in studies related to the mechanical properties of composite materials is still rare. The aim of this study is to investigate the validity of Taguchi method compare to full Factorial design, in optimizing the sample quantity in the research on the impact strength of polymer matrix composite reinforced with oil palm fibers. There are 3 Factors used in this work, i.e.: fiber content/ percentage, fiber length and chemical used. NaOH is used here to treat the fiber and PPgMA (Polypropylene grafted Maleic Anhydride) is used here as The coupling agent.

Methodology

Design of Experiment (Full Factorial Design and Taguchi Method)

Design Experiments refer to the process of planning, designing and analysing the experiment so that valid and objective conclusion can be drawn effectively and efficiently [25].

Design of experiment (DOE) is a statistical technique introduced by Sir R. A. Fisher in England early 1920 which is used to study the effect of multiple variables simultaneously [18]. Fisher was able to lay out all combinations of the factors. This method is known as full factorial design.

In this research, three factors were considered, i.e.: fiber content, fiber length, and chemical use. All of each factors have three level considerations as follows:

1. Fiber contents: 10%, 7% and 5%
2. Fiber lengths: 10mm, 7mm and 5mm
3. Fiber Treatment: Untreated, Alkali Treated and Coupling Agent

Full factorial

A Full Factorial Experiment consists of an equal number of replicates of all possible combinations of the levels of the factors [26].

This research use full factorial design [18] which the total the combination number or the number test conditions [18] was calculated as follows:

$$\text{Total number of combinations} = (\text{number of levels})^{\text{number of factors}} \quad (1)$$

$$\text{Number of test } 3^3 = 27 \text{ different test conditions.}$$

Therefore, in this study 135 samples of specimens had to be prepared for testing because for each condition consist of 5 samples.The combination of samples is shown in Table 1.

Taguchi Method

Another approach is Taguchi Method. Dr. Taguchi developed a method to optimize the process engineering experimentation which is now known as Taguchi Method [27]. In this method, a set of orthogonal arrays is constructed to lay out the experimental condition [28]. The orthogonal arrays in Taguchi methods can be applied where there are a large number of design factors in experimental work [27]. By following this array, the experimental conclusion still valid, even the configuration to be studied was significantly reduced. The selection of the orthogonal array is the first step in designing the experiment. The smallest array was selected to do the job [18]. The next step which is very important in this method was the selection of the factor [19][27].

Taguchi method would also be used to analyze this experimental work. And the analysis result will be compared to the result of factorial design. All specimens and data needed in this method are included in the factorial design. The first step in this method, as have been explained above is the selection of the orthogonal array which is proper to the number of factor and level of this research. Since there are 3 levels on every factor in this research, the arrays should refer to 3^n series [19] e.g. L_9 (3^4), L_{18} (3^7), L_{27} (3^{13}). A research that have maximum 4 factors can use L_9 (3^4) array [18], so L_9 (3^4) array will enough to be used in this research. Based on this array, only 9 combinations of test numbers must be performed, each consisting of 5 samples, so that the total number of samples to be prepared are = 45 specimen samples. Compare this with a full factorial experiment which had to prepare 27 test combinations so that a total of 135 samples of specimens had to be prepared.

Table 1. *Full factorial design for 3 factors with consists of 3 levels for every factor.*

Specimen number	Fiber Contents (%)	Fibers length (mm)	Fiber Treatment
1	5	5	1
2	5	5	2
3	5	5	3
4	5	7	1
5	5	7	2
6	5	7	3
7	5	10	1
8	5	10	2
9	5	10	3
10	7	5	1
11	7	5	2
12	7	5	3
13	7	7	1
14	7	7	2
15	7	7	3
16	7	10	1
17	7	10	2
18	7	10	3
19	10	5	1
20	10	5	2
21	10	5	3
22	10	7	1
23	10	7	2
24	10	7	3
25	10	10	1
26	10	10	2
27	10	10	3

Note: Fiber treatment: 1 = Untreated, 2 = Alkali Treatment, 3= Coupling Agent

Using the Minitab application, the orthogonal array can also be directly selected by inputting all the factors and levels of this research so that the L9 orthogonal array is obtained as shown in table 2.

Table 2. *L_9 Orthogonal Arrays [18] [19]*

No.	Fiber Contents (%)	Fibers size (mm)	Fiber Treatment	Specimen Number from table 1
1	5	5	1	1
2	5	7	2	5
3	5	10	3	9
4	7	5	2	11
5	7	7	3	15
6	7	10	1	16
7	10	5	3	21
8	10	7	1	22
9	10	10	2	26

Materials and Methods

The chemicals and materials used in this research are the Oil Palm Fibers, Polypropylene (PP), Polypropylene Maleic Anhydride (PPgMA) and NaOH. The oil palm fiber used in this present work is obtained from Kian Hoe Plantation Berhad, Kluang, Johor Malaysia is the company where the oil palm fiber used in this research obtained. Whereas a commercially graded homo-polymer Polypropylene was used as the matrix material. PPgMA (Polypropylene grafted Maleic Anhydride) which used as a coupling agent in this research supplied by Shenzhen Jindaquan Technology Co. Ltd.

Fiber Preparation

Before used, the Oil palm fiber must be cleaned by washing it with plenty of water, then dried for 2 days in bright sunlight, until it can be ascertained that the fiber is very dry and can be processed for the next process.

Furthermore, the dried palm fiber was divided into 2 groups, which were prepared for 2 different processes, namely: untreated fiber and alkaline treated fiber. For untreated fiber, it can be directly used for the preparation of specimen materials. But for the alkali treatment, the fiber must be soaked in 97% water and 3% NaOH for 1.5 then washed with plenty of water and dried in an oven for 15 hours at 70°C

Flowchart of the research Methods

The flowchart of this research is shown in figure 1.

Figure 1 shows the schematic chart of this research. The fibers were prepared for two conditions during the fiber preparation, i.e., untreated and alkali treated fibers. After the treatment process, all fibers (Treated and Untreated) were cut into short fibers, i.e., 5, 7 and 10 mm. Each of these fibers were then mixed % using Brabender machine with polypropylene in three different contents, i.e., 5%, 7% and 10 During this mixing, the untreated fiber also used for coupling agent samples, which added 3% PPgMA. Totally, there are 3 classifications (3 Factors) of the specimen prepared, i.e., Untreated, treated and Coupling agent. The combination of samples prepared just follow full factorial design as shown in table 1, all combinations among fiber length, fiber contents and chemical used, should be prepared. All data needed in Taguchi analysis included in the full factorial design. All samples prepared based on ISO 179-1: 2001 standard [29]. Figure 2 shows the specimen dimension base on this standard The notch dimension (B Notch type) were made follow table 3.

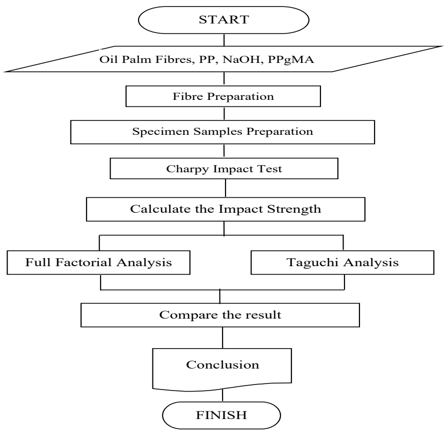

Figure 1. *Schematic of research*

Data analysis in this research was done by 2 methods, i.e., full factorial design and Taguchi method. The graph result of these two methods would be compared visually. The influence of the Three independent variables (fiber content, fiber length and treatment) to impact strength of the composite material sample also perform in regression models by forming a regression equation using 2 kinds data i.e., full factorial data and Taguchi method data. Then the result of the both of analysis will be compared to know whether the two methods give same result related to significancy of every independent variable. By setting the significance level 0.05, every variable in the regression equation would be classified as significant variable when the p-value lower than 0.05 [30].

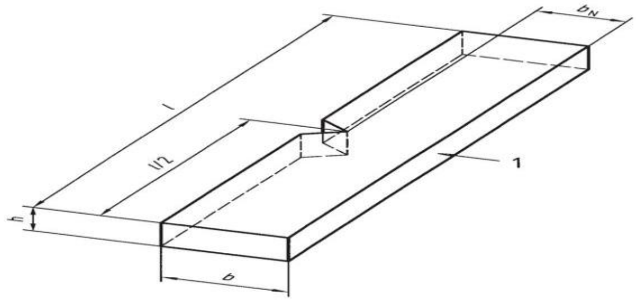

Figure 2. *The single-notched Carpy Impact specimen base on ISO 179-1: 2001[29]*

Table 3. *ISO 179-1: 2001; Method designations, specimen types, notch dimensions - materials not exhibiting interlaminar shear fracture [29]*

Dimensions in millimetres

Specimen type	Length[a] l	Width[a] b	Thickness[a] h	Span L
1	80 ± 2	10,0 ± 0,2	4,0 ± 0,2	$62^{+0,5}_{-0,0}$
2[b]	25h	10 or 15[c]	3[d]	20h
3[b]	11h or 13h			6h or 8h

[a] The specimen dimensions (thickness h, width b and length l) are defined according to $h \leq b < l$.
[b] Specimen types 2 and 3 shall be used only for materials described in 6.3.2.
[c] 10 mm for materials reinforced with a fine structure, 15 mm for those with a large stitch structure (see 6.3.2.2).
[d] Preferred thickness. If the specimen is cut from a sheet or a piece, h shall be equal to the thickness of the sheet or piece, up to 10,2 mm (see 6.3.1.2)

Charpy Impact Test

Charpy impact test was performed on all samples (treated, untreated fiber, and coupling agent composites). The equipment used is the Wolpert brand Charpy impact test, located at the Polymer Laboratory, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM). The maximum capacity of this equiment is 4 Joules. The impact energy data obtained are then used to calculate the Charpy impact strength [29] using the equation:

$$a_{cN} = \frac{E_c}{h \cdot b_N} \times 10^3 \qquad (2)$$

Where:
a_{cN} is the Charpy impact strength (kJ/m^2)
E_c is the corrected energy, in joules, absorbed by breaking the test specimen (J)
H is the thickness of the test specimen (mm)
b_N is the remaining width of the test specimen (mm)

Experimental Results

Charpy impact strength

The results of Charpy impact tests were impact energy of every specimen in joules. Furthermore, this data were used to calculate the impact strength in kJ/m^2 of them using equation 2, and the results are shown in the table 4, 5, and 6.

Table 4. *The Impact Strength of samples for Untreated fiber Polypropylenen composite (kJ/m^2)*

Fibre Contents (%)	5	5	5	7	7	7	10	10	10
Fibres length (mm)	5	7	10	5	7	10	5	7	10
1	5.00	6.67	5.00	5.00	5.00	6.67	5.00	5.83	6.67
2	4.17	5.00	5.00	5.00	5.42	6.67	5.83	7.50	7.92
3	5.00	5.83	4.58	5.00	6.25	5.83	5.83	5.83	6.67
4	3.33	4.17	5.00	5.83	5.83	6.67	6.67	5.83	7.50
5	4.17	5.42	8.33	6.67	6.67	6.25	5.83	7.50	5.83
Average	**4.333**	**5.417**	**5.583**	**5.500**	**5.833**	**6.417**	**5.833**	**6.500**	**6.917**

The Impact Strength of samples for Untreated fiber Polypropylenen composite (kJ/m^2) are shown in Table 4. The first row is the variation of fiber content, i.e.: 5%, 7% and 10%. while the second row is fiber length, namely 5mm, 7mm and 10mm. the first column contains numbers 1 to 5 is the samples number while the other column is the value of the impact strength of each combination of fiber content and fiber length.

Table 5. *The Impact Strength of samples for Alkali treated fiber Polypropylenen composite (kJ/m^2)*

Fibre Contents (%)	5	5	5	7	7	7	10	10	10
Fibres length (mm)	5	7	10	5	7	10	5	7	10
1	4.17	5.00	5.42	5.00	5.00	6.67	6.25	6.67	7.50
2	5.00	6.67	5.00	5.00	6.25	7.92	5.83	6.67	6.67
3	6.25	5.00	5.42	6.67	5.42	7.50	5.00	5.83	7.50
4	5.00	5.83	5.83	5.00	5.00	5.00	5.83	7.50	7.50
5	6.25	5.42	7.50	5.83	6.67	6.67	5.42	5.42	5.83
Average	**5.333**	**5.583**	**5.833**	**5.500**	**5.667**	**6.750**	**5.667**	**6.417**	**7.000**

Table 6. *The Impact Strength of samples for Coupling agent Polypropylenen composite (kJ/m^2)*

Fibre Contents (%)	5	5	5	7	7	7	10	10	10
Fibres length (mm)	5	7	10	5	7	10	5	7	10
1	7.92	7.08	7.92	6.67	7.08	8.33	9.17	9.17	9.17
2	7.50	7.50	8.33	7.50	7.50	8.33	5.83	6.67	9.17
3	6.67	6.67	7.50	7.50	7.92	9.17	7.92	7.50	9.17
4	5.83	5.83	5.42	7.08	9.17	9.58	10.42	10.00	9.17
5	7.50	8.33	9.58	9.17	7.50	7.92	7.50	8.33	10.00
Average	**7.083**	**7.083**	**7.750**	**7.583**	**7.833**	**8.667**	**7.833**	**8.333**	**9.333**

Table 5 and 6 are same with the Table 4 but The fiber of the samples in Table 5 are alkali treated fiber while samples of Table 6 were made by added coupling agent.

Table 7. *Average Impact Strength for every combination of sample base on Full factorial design*

Specimen number	Fibre Contents (%)	Fibres Length (mm)	Chemical Treatment	Impact strength (kJ/m2)
1	5	5	1	5.333
2	5	5	2	5.333
3	5	5	3	6.750
4	5	7	1	5.417
5	5	7	2	5.583
6	5	7	3	7.083
7	5	10	1	5.583
8	5	10	2	5.833
9	5	10	3	8.083
10	7	5	1	5.500
11	7	5	2	5.500
12	7	5	3	7.583
13	7	7	1	5.833
14	7	7	2	5.667
15	7	7	3	7.417
16	7	10	1	6.167
17	7	10	2	6.750
18	7	10	3	8.417
19	10	5	1	5.833
20	10	5	2	5.500
21	10	5	3	8.167
22	10	7	1	6.167
23	10	7	2	6.417
24	10	7	3	8.333
25	10	10	1	6.917
26	10	10	2	7.000
27	10	10	3	9.333

Note: 1= Untreated, 2= Alkali Treatment, 3= Coupling Agent

The impact strength analysis of the specimen in this research is done by two methods, i.e. full factorial design and Taguchi method. The recapitulation of average impact strength of every combination of samples from table 4, 5 and 6 are shown in table 7 for full factorial design which consists of 27 combinations.

Table 8 *Charpy impact test results base on Taguchi method (to be analysed using Minitab application)*

Fibre content (%)	Fibre Length (mm)	Impact Strength (kJ/m^2)		
		Untreated	Alkali Treated	Coupling Agent
5	5	5.333	-	-
	7	-	5.583	-
	10	-	-	8.083
7	5	-	5.500	-
	7	-	-	7.417
	10	6.167	-	-
10	5	-	-	8.167
	7	6.167	-	-
	10	-	7.000	-

Table 8 shows the recapitulation of the the data for Taguchi method base on L9 orthogonal arrays which consists of 9 combinations

These data are inputted into Minitab application to be analysed. The analysis result was plotted as demonstrated in figure 3 and 4.

Figure 3 and Figure 4 shows the influence of fiber content, fiber length and treatment to the impact strength of polypropylene matrix composite reinforced with oil palm fiber using Taguchi analysis and Full factorial respectively. Those figures demonstrated almost same graph. This graph proves that there is a similarity result between Taguchi analysis and Full factorial analysis. The two graphs show the influence of fiber content, fiber length and treatment to the impact strength of polypropylene matrix composite reinforced with oil palm fiber. One of the simplest ways to know the significance effect of the three independent variables, i. e. fiber contents, fiber length and fiber treatment to the impact strength were by observing the slope of the relationship graph of these variables to the impact strength. The greater the gradient of the graph signed the more significant effect of the variables on the impact strength of the composite material.

The figure demonstrated that by increasing the fiber content of the composite material specimens, the average values of impact strength were also increased. The highest average impact strength was obtained by specimen with 10 % fiber content.

The fiber length also gives almost the same effect with fiber contents to the impact strength of a composite material specimen. From 3 levels of fiber length, i .e.: 5mm, 7mm and 10mm, the highest average impact strength was obtained by specimen with 10 mm fiber length.

The chemical treatment also gives a positive effect on the impact strength of the specimen. Especially for PPgMA, give dramatically increase in impact strength of the specimen while the alkali treatment to the fiber didn't give a significant effect to the impact strength of specimens.

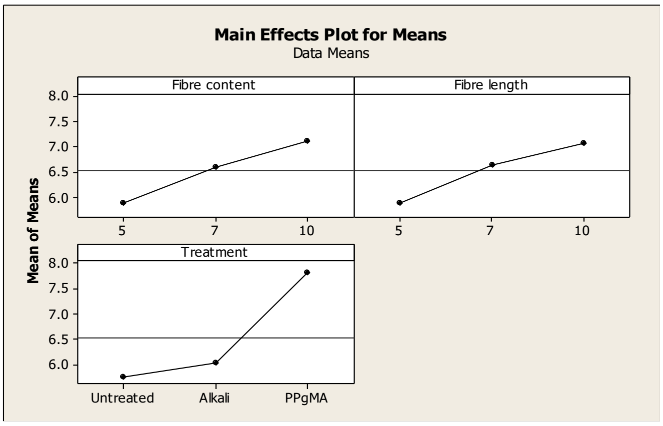

Figure 3 Taguchi *analysis graph of Charpy Impact strength using Minitab application.*

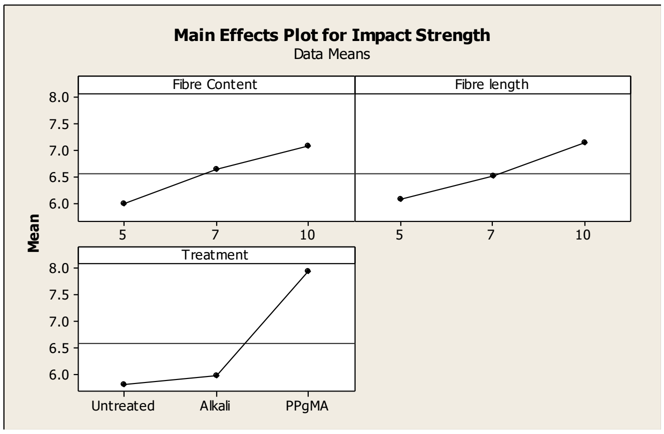

Figure 4 *Full Factorial analysis graph of Charpy Impact strength using Minitab application.*

The most accurate method to know the significance effect of the fiber contents, fiber length and chemical treatment is done by making the multiple linear regression equation of the 3 independent variables to the impact strength using Minitab application.

The result of the multiple linear regression is as follows:

Using Taguchi analyses data
The regression equation is
Impact Strength = 2.09 + 0.239 Fiber Content + 0.226 Fiber Length
+ 1.03 Treatment

Predictor	Coef	SE Coef	T	P	VIF
Constant	2.0900	0.9510	2.20	0.079	
Fiber Content	0.23905	0.08751	2.73	0.041	1.000
Fiber Length	0.22595	0.08751	2.58	0.049	1.000
Treatment	1.0277	0.2202	4.67	0.005	1.000

Using Full Factorial data
The regression equation is
Impact Strength = 2.39 + 0.213 Fiber content + 0.212 Fiber length
+ 1.06 Treatment

Predictor	Coef	SE Coef	T	P	VIF
Constant	2.3904	0.5322	4.49	0.000	
Fiber content	0.21323	0.04897	4.35	0.000	1.000
Fiber length	0.21250	0.04897	4.34	0.000	1.000
Treatment	1.0648	0.1232	8.64	0.000	1.000

By setting the significance level 0.05, every variable in the regression equation would be classified as significant variable when the p-value lower than 0.05. The result above is shown for all of dependent variable (fiber content, fiber length and Treatment), obtain the p-value < 0.05 even using Taguchi or full factorial. This indicates that base on Taguchi also full factorial, all independent variables, i. e. fiber content, fiber length and Treatment have significant effect on the impact strength of the specimen. Even a small difference of these two methods found in the coefficient of the linear regression model. The comparison of the linear regression of those two methods are as follows:

Table 9 *linear regression equation comparison between Taguchi and Full Factorial*

Item	Taguchi method	Full Factorial
Linear regression model	IS = 2.09 + 0.239 FC + 0.226 FL +1.03 T	IS = 2.39 + 0.213 FC + 0.212 FL +1.06 T
Constant	2.09	2.39
Fiber Content Coefficient	0.239	0.213
Fiber Length Coefficient	0.226	0.212
Treatment Coefficient	1.03	1.06

Note: IS = Impact Strength
FC = Fiber content
FL = Fiber Length
T = Treatment

Conclusion

The effect of fiber content, fiber length, and Chemical treatment on the impact strength of oil palm fiber polymer matrix composite has been investigated. The test result was analysed by 2 methods, i.e.: Taguchi method and Full factorial method with the aim of comparing the result of the analysis of both methods. The number of sample combinations in the Taguchi method is 9 (to follow L9 orthogonal array). While 27 samples combination are used in full factorial method. From the analysis graph, the two methods obtain almost same graph. Multiple regression analysis also results similar regression equation the p-value of all independent variables also below 0.05 which indicated all independent variables are significant. Even There are little different in coefficient number of the two equation. But still too small. Thus, this study has proven that the Taguchi method has succeeded in making research more efficient. The use of 9 samples combination using the Taguchi method is able to produce good analytic validity, equivalent to the full factorial method with 27 combination samples in this research.

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