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Physical Properties of Abaca (*Musa textilis nee*) Fibre Reinforced High Impact Polystyrene (HIPS) Composites

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ABSTRACT

The physical properties by natural fibre have a great importance, specifically in the structural of natural fibre which reinforces matrix. Response surface methodology with Box-Behnken (BB) design of experiment was utilized to study water absorption and melt flow index (MFI) of abaca fibre reinforced high impact polystyrene (HIPS) composites. The design utilizes fraction of weight abaca fibre, maleic anhydride (MAH), and impact modifier to develop models for characteristic behaviours of water absorption and MFI of composites. Abaca fibre reinforced high impact polystyrene (HIPS) composites were produced with different fibre loadings (30, 40, and 50 wt%), different compositions of coupling agent, maleic anhydried (MAH) (1, 2, and 3 wt%) and different compositions of impact modifier (4, 5, 6 wt%). The individual optimum of water absorption was found when loading abaca fibre close to 34.61 wt%, maleic anhydride 1 wt%, and impact modifier 4.01 wt%. The individual optimum of melt flow index dealt with loading abaca fibre 36.71 wt%, maleic anhydride 3 wt% and impact modifier 4.02 wt%. Meanwhile, the optimum condition for water absorption of abaca fibre reinforced HIPS composites was followed by a decreasing trend of the value of melt flow index.

Keywords: Water absorption, Melt Flow Index, Box-Behnken, abaca fibre

INTRODUCTION

Studies on the use natural fibre reinforced composites are emerging in polymer science. Natural fibres such as jute, kenaf, pineapple leaf, abaca, sisal, bamboo have been investigated for use in polymer composites (Bogoeva-Gaceva *et al*., 2007). However, there are several disadvantages of the natural fibre composites as demonstrated by their properties. Generally, thermal and mechanical degradation during processing of natural fibre reinforced polymer composites can make them undesirable for certain applications. As far as compatibility between natural fibre and polymer is concerned, the main problem is the poor interfacial adhesion between the hydrophobic polymer matrix and hydrophilic natural fibre (Espert *et al*., 2004; Majid *et al*., 2008).

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Abaca is also known as Manila hemp. It is a *Musasea* family plant native to Asia and planted in humid areas including in the Philippines and East of Indonesia. Abaca fibres are extensively used to produce ropes, woven fabrics, tea bags, etc. Abaca fibre reinforced polymer composites have been investigated by Shibata *et al*. (2002; 2003), Ochi (2006) and Teramoto *et al*. (2004), in which they focused on using thermosetting matrices, especially polyesters. A study carried out on abaca fibre reinforced thermoplastic, specifically polypropylene, has been reported by Bledzki *et al*. (2007). In the recent innovative application, abaca fibres are used in under floor protection for passenger cars made by Daimler Chrysler (Bledzki *et al*., 2006). The application is a new combination of polypropylene (PP) thermoplastic embedded with abaca fibres and it was patented by Daimler Chrysler's researchers, and the manufacturing process (compression moulding process) has been initiated by Rieter Automotive.

All polymer composites absorb moisture in humid atmosphere and when immersed in water. The effect of water absorption leads to the degradation of fibre matrix interfacial region resulting in undesirable effects on the mechanical properties and dimensional stability of the composites (Lu *et al*., (2004) as well as Gassan & Bledzki (1997). It is important to study the water absorption behaviour in detail so as to estimate the amount of water absorbed and the effects on the durability of natural fibre composites.

Generally, the addition of natural fibre to polymer composites restricts molecular motion in the matrix and causes the lowering of melt flow index (MFI) values. Meanwhile, an increase in the MFI value indicates a better molecular motion between polymer chains.

This paper reports work related to the water absorption behaviour and MFI of abaca fibre reinforced HIPS composites. The study uses response surface methodology with Box-Behnken (BB) design of experiment. The research concerned with the interaction between effect and optimization, based on the composition of fractions of with abaca fibre, maleic anhydride (MAH) as a coupling agent and styrene butadiene styrene (SBS) as an impact modifier of composites.

EXPERIMENTAL DESIGN

Materials

Abaca is a type of banana plant that is native to the Philippines. It is also grown in moderately humid area in Indonesia. The abaca fibres used in this study were obtained from Pekalongan, Central Java, Indonesia, which were produced by Ridaka Hand Craft. The matrix used for this study was High Impact Polystyrene (HIPS) Idemitsu PS HT 50, a product of Petrochemical (M) Sdn. Bhd, Sungai Besi, Malaysia. It has a density and a melt index of 1.04 g/cm^3 and 4.0 g/10 min, respectively. The coupling agent used in this study was maleic anhydride (MAH) - (polystyrene-block-poly(ethylene-ran-butylene)-block-polystyrene-graft-maleic anhydride), a product of Sigma Aldrich Inc., Germany. The supplier was Sigma Aldrich Malaysia (M) Sdn. Bhd, Petaling Jaya, Selangor, Malaysia. Impact modifier was a styrene butadiene styrene (SBS) copolymer rubber (Cyclo resin). Meanwhile, the cylindrical granules of cyclo resin were produced by multiversum, Germany and supplied by PT. Wahana Makmur Kencana, Jakarta, Indonesia.

Sample Preparation

The abaca fibres were dried under the sun between 27 and 30ºC for four days. The dry abaca fibres were cut into 2–3 mm by means of an electronic cutting machine. The matrix, high impact polystyrene (HIPS), maleic anhydride (MAH), Cyclo resin, and abaca fibres were prepared based on the design of experiment and they were classified into three levels (namely, high [+], intermediate [0], and low [-]). The abaca fibre reinforced high impact polystyrene (HIPS) composites were produced with different abaca fibre loadings (30, 40, and 50 wt%) compared with high impact polystyrene. The compositions of the coupling agent, maelic anhydried (MAH) (1, 2, and 3 wt%) and different compositions of impact modifier (4, 5, 6, wt%) were designed according to the performance of matrix composites. The processing of the abaca fibre reinforced HIPS composites was accomplished using a rolling machine (see *Fig. 1*). The working temperature of the rolling machine was kept approximately 200ºC. The composites were produced in the rolling machine by manually placing the matrix and fibres in the rolling machine at a very slow rate. The speed of the first cylinder was on 6.6 m/min (meter/minutes) and the second cylinder was on 10.5 m/min. The process was continued until all the materials were well-mixed. The composites produced were brown in colour, following the natural colour of abaca fibres. Sheets of abaca fibre reinforced HIPS composites produced had an average thickness of approximately 1 mm.

Fig. 1: The production of abaca fibre reinforced HIPS composites using a rolling machine

The composite materials produced were then crushed and pressed to the thicknesses of 1, 2, and 3 mm using a hot pressing machine.

MEASUREMENTS

Water Absorption

The water absorption tests of the abaca fibre reinforced HIPS composites were carried out according to ASTM D 570. The composites were dried at 80°C for 24 h in a vacuum oven and in the room temperature; the specimens of the composites were weighed to the nearest 0.1 mg. They were immersed in water in a water beaker at 30°C for 24 h. Weight gains were recorded by periodic removal of the specimens from the water and weighed on a balance with a precision of 0.1 mg. The composites were calculated by weight difference between the samples which were immersed in water and the dry samples. The percentage gain at any time t (M_t) as a result of moisture absorption was determined using Equation (1):

$$M_t = \frac{W_w - W_d}{W_d} \text{ x } 100\% \quad (1)$$

where W_d and W_w denote the weight of dry material (the initial weight of materials prior to exposure to the water absorption) and the weight of materials after exposure to water absorption, respectively.

Melt Flow Index Test

The melt flow index is a measure of the ease of flow of the melt of a thermoplastic polymer. It is defined as the weight of polymer (in grams) flowing in 10 minutes through a capillary of specific diameter and length by a pressure applied via prescribed alternative gravimetric weights at alternative prescribed temperatures. Approximately 7 grams of the material were loaded into the barrel of the melt flow apparatus. The melt flow index was performed according to ASTM D 1238, in a melt flow indexer, and the temperature of 200ºC. The weight of 5 kg was applied to a plunger and the molten material was forced trough the die. The extruders within the duration of 10 minutes, being several extrudates, were cut before weighing.

Design of the Experiments

The response surface methodology was used to divide the samples into three levels. This research uses the Box-Behnken design to analyze the physical properties of the abaca fibres reinforced HIPS composites, whereas the water absorption and melt flow indexes identified were strongly affected by the three factors chosen for this study designated as X_1 (abaca fibres), X_2 (maleic anhydride (MAH)) and X_3 (impact modifier (IM)) and also prescribed into three levels, coded +1, 0, −1 for high, intermediate and low value, respectively. They are described in Table 1. The three test variables were coded according to equation 2 below:

$$X_i = \frac{X_i - Xo}{\Delta X}; \text{ i = 1, 2, 3} \quad (2)$$

Where is the coded value of an independent variable, X_i is the actual value of an independent variable, X_0 is the actual value of an independent variable at the centre point, and ΔX is the change value of an independent variable. The Box-Behnken design consists of a set of points lying at the midpoint of each edge and the replicated centre point of the multidimensional cube. All the experiments were performed in triplicates and the averages of the physical property yields were taken as responses.

TABLE 1
Levels and codes of the variables for the Box-Behnken design

Variables	Symbol		Coded levels		
	Uncoded	Coded	-1	0	+1
Abaca	X_1	X_1	30	40	50
MAH	X_2	X_2	1	2	3
IM	X_3	X_3	4	5	6

For predicting the optimum point, a second-order polynomial model was fitted to correlate the relationship between the independent variables and responses (physical property yield). For the three factors, equation (3) is as follows:

$$Y = \beta_0 + \beta_1\chi_1 + \beta_2\chi_2 + \beta_3\chi_3 + \beta_{11}\chi_1^2 + \beta_{22}\chi_2^2 + \beta_{33}\chi_3^2 + \beta_{12}\chi_1\chi_2 + \beta_{13}\chi_1\chi_3 + \beta_{23}\chi_2\chi_3 + \varepsilon$$

where Y is the predicted response, β_o is model constant, x_1 ; x_2 and x_3 are independent variables, β_1; β_2 β_3 and are linear coefficients, β_{12}, β_{13}, and β_{23} are cross-product coefficients, and β_{11}, β_{22}, and β_{33} are the quadratic coefficients. The quality of the fit of the polynomial model equation was expressed by the coefficient of determination R^2.

RESULTS AND DISCUSSION

The Physical Properties of Abaca Fibre Reinforced with HIPS Composites

The experimental results for the water absorption and melt flow index (increasing % of mass) at different contents of abaca fibre, coupling agent of maleic anhydride (MAH) and impact modifier (SBS) (IM) are the responses which were measured at three levels of three factors in the abaca fibre reinforced HIPS composites. A three-coded level Box-Behnken design was used to analyze the responses. The abaca fibres, MAH and IM were independent variables changed in order to predict the responses (physical properties) of abaca fibre reinforced HIPS composites. The optimum responses and the interaction effect of each independent variable were carried out based on the design of the experiment given in Table 2. In this study, the Box-Behnken experimental design was used to determine the relationship between the responses of water absorption and melt flow index (MFI) of the abaca reinforced HIPS composites for three different variables with three levels.

To ensure a good model (equation 3) of the physical properties of the abaca fibre reinforced HIPS composites, test for significance of the regression model, test for significance on individual model coefficients and test for lack-of-fit must be performed. The ANOVA analysis was used to perform the tests for this particular analysis. Tables 3 and 4 summarize the test performance of the ANOVA analysis for the physical properties of the abaca fibre reinforced HIPS composites.

TABLE 2
The Box-Behnken design with the actual values for three weight fractions and three levels for the physical responses of the abaca fibre reinforced HIPS composites

Run	X_1	X_2	X_3	Y_1	Y_2
	A:Abaca	B:MAH	C:IM	Water Absorption	Melt Flow Index (MFI)
	wt %	wt %	wt %	%	gr/10 min
1	50	1	5	3.518	0.886
2	30	1	5	2.638	0.708
3	40	2	5	3.576	0.688
4	40	1	4	3.086	0.762
5	30	2	6	5.588	0.747
6	40	2	5	3.186	0.656
7	40	2	5	3.176	0.656
8	50	2	6	4.492	0.098
9	30	3	5	2.745	1.514
10	40	2	5	3.156	0.658
11	40	2	5	3.176	0.658
12	40	3	6	3.279	0.820
13	50	3	5	3.821	0.112
14	30	2	4	2.623	0.780
15	40	3	4	3.029	0.769
16	50	2	4	5.819	0.096
17	40	1	6	3.875	0.730

TABLE 3
ANOVA table (partial sum of squares) for quadratic model (response: water absorption)

Source	Sum of Squares	DF	Mean Square	F - Value	Prop> F	
Model	13.508	9	1.501	32.968	< 0.0001	*significant*
A	2.056	1	2.056	45.160	0.0003	
B	0.007	1	0.007	0.161	0.7001	
C	0.896	1	0.896	19.689	0.003	
A^2	1.619	1	1.619	35.564	0.0006	
B^2	2.024	1	2.024	44.454	0.0003	
C^2	2.411	1	2.411	52.968	0.0002	
AB	0.010	1	0.010	0.211	0.6602	
AC	4.605	1	4.605	101.146	< 0.0001	
BC	0.072	1	0.072	1.591	0.2476	
Residual	0.319	7	0.046			
Lack of Fit	0.189	3	0.063	1.933	0.2659	*not significant*
Pure Error	0.130	4	0.033			
Cor Total	13.827	16				
Std. Dev.	0.213		R-Squared	0.9770		
Mean	3.575		Adj R-Squared	0.9473		
			Pred R-Squared	0.7671		
			Adeq Precision	20.0519		

In Tables 3 and 4, the value of "Prob>*F*" is less than 0.05 for the model. It will indicate that the model is significant. The condition deals with desirable that indicating the terms in the model of abaca reinforced HIPS composites has a significant effect on the response (physical properties). The ratio of abaca fibre (A), coupling agent MAH (B), two level interaction of abaca fibre (A^2), Maleic Anhydride (B^2) and Impact Modifier (C^2), as well as the abaca fibre to impact modifier ratios (AC) are significant terms for the response of water absorption of abaca fibre reinforced HIPS composite. Then, other model terms can be said to be insignificant. In a similar manner, the responses of the melt flow index (Table 4), based on each value of "Prob>*F*", ratios of abaca fibre (A), a two level interaction of abaca fibre (A^2), Maleic Anhydride (B^2) and Impact Modifier (C^2), as well as the abaca fibre to Maleic Anhydride ratios (AB) are significant terms for the response of melt flow index of the abaca fibre reinforced HIPS composite. The ANOVA analysis indicates that the responses of the physical properties of abaca fibre reinforced HIPS composites are in a linear relationship between the main effects of abaca fibre wt% and impact modifier wt% (water absorption). Besides, between the main effects of the abaca fibre wt% and maleic anhydride wt% (melt flow index). The quadratic relationship of the factors of abaca fibre wt%, maleic anhydride wt%, and Impact Modifier wt% resulted in melt flow index (MFI).

As indicated by equation 1 and based on the ANOVA analysis, the final mathematical equations are based on the coded factors given in equations 2 and 3. The models were obtained after the analysis of variance and they gave the levels of weight percentages of the abaca fibres, maleic anhydride (MAH) and impact modifier (IM) using the Design-expert software.

The equation of water absorption (2):

$$y = 3.25 + 0.51X_1 - 0.03X_2 + 0.33X_3 + 0.62X_1^2 - 0.69X_2^2 + 0.76X_3^2 + 0.049X_1X_2 - 1.07X_1X_3 - 1.13X_2X_3$$

The equation of melt flow index (3):

$$y = 0.66 - 0.32X_1 + 0.016X_2 - 0.0015X_3 - 0.099X_1^2 + 0.24X_2^2 - 0.13X_3^2 - 0.40X_1X_2 + 0.0086X_1X_3 + 0.021X_2X_3$$

This model can be used to predict the physical properties of the abaca fibre reinforced HIPS composites within the limits of the experiment. *Figs. 2* and *3* respectively show the relationship between the actual (experiments) and the predicted values of the abaca fibre reinforced HIPS composites for their physical properties responses. It is seen in *Figs. 2* and *3* that the developed models are adequate because the residuals for the prediction of each response are minimum, since the residuals tend to be close to the diagonal line. The R^2 value for water absorption is 0.9770 and the Melt Flow Index is 0.9983 which desirable. All the predicted R^2 of the physical properties of the abaca reinforced HIPS composites are in agreement with the adjusted R^2 (Tables 3 and 4). The adequate precision value of the physical properties of the abaca fibre reinforced HIPS composites are well above 4.

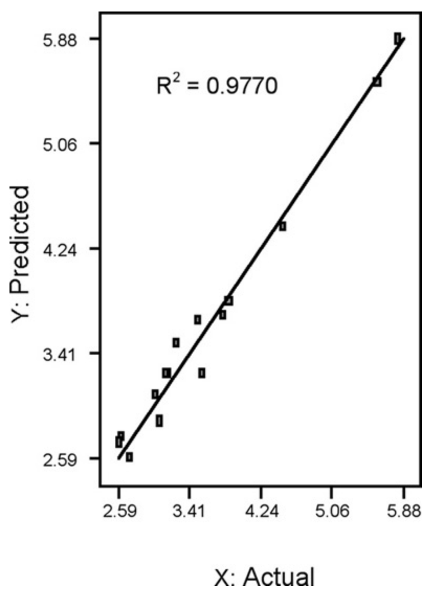

Fig. 2: Relation between experimental and predicted water absorption (%)

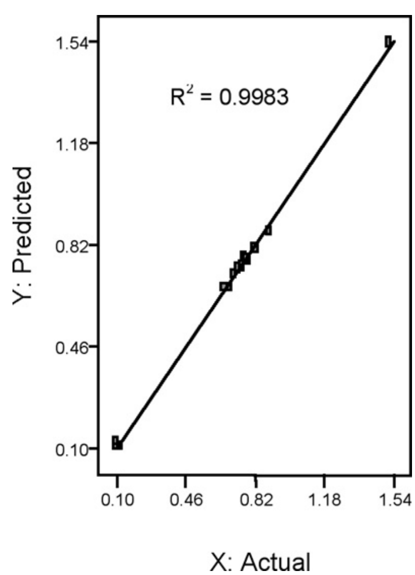

Fig. 3: Relation between experimental and predicted Melt Flow Index (g/10min)

TABLE 4
ANOVA table (partial sum of squares) for quadratic model (response: melt flow index - MFI)

Source	Sum of Squares	DF	Mean Square	F - value	Prob > F	
Model	1.789	9	0.199	448.963	< 0.0001	*significant*
A	0.817	1	0.817	1846.337	< 0.0001	
B	0.002	1	0.002	4.699	0.0668	
C	0.000	1	0.000	0.041	0.8459	
A^2	0.041	1	0.041	93.416	< 0.0001	
B^2	0.244	1	0.244	552.013	< 0.0001	
C^2	0.075	1	0.075	170.417	< 0.0001	
AB	0.624	1	0.624	1409.918	< 0.0001	
AC	0.000	1	0.000	0.692	0.433	
BC	0.002	1	0.002	3.891	0.0892	
Residual	0.003	7	0.000			
Lack of Fit	0.002	3	0.001	4.013	0.1064	*not significant*
Pure Error	0.001	4	0.000			
Cor Total	1.792	16				
Std. Dev.	0.021		R-Squared	0.9983		
Mean	0.667		Adj R-Squared	0.9960		
			Pred R-Squared	0.9786		
			Adeq Precision	88.7669		

Table 5 summarizes the coefficients regression for the responses variables in the experimental design written in equations 3 and 4. The response functions representing water absorption and melt flow index properties are expressed as a function of loading abaca fibre wt% (β_1), maleic anhydride (MAH) wt% (β_2), and impact modifier wt% ($\beta 3$). Table 5 also shows the statistical significance of each effect of the abaca fibre reinforced HIPS composites.

The results of the study carried out on the physical properties show that they are strongly affected by the independent variables selected. It was also observed that the main effects of X_1 and X_3, represent the effects of the abaca fibre and impact modifier to be correlated with the function of water absorption of the abaca fibre reinforced HIPS composites. Table 3 shows the values of "*Prob > F*" for the abaca fibre β_1 (0.0003) and the impact modifier β_3 (0.003) less than 0.05, whereas Table 5 reveals that X_1 is a positive value and X_3 is a negative value. These conditions describe that the effect of abaca fibres has affected for the maximum response and the impact modifier has the minimum response to the performance of water absorption of the abaca fibre reinforced HIPS composites. The negative coefficients (*see* Table 5), where β_{23} = -0.1346 for all the independent variables (β_{23}; *Prob>F* = <0.0001) indicate very little effect on water absorption. In this case, the interaction between the abaca fibre and impact modifier is well correlated with water absorption.

Using a similar approach, the main effect of the abaca fibre (β_1) is positive, so it has a strong effect on the melt flow index (MFI).

TABLE 5
Regression coefficients of approximate polynomials for response variables in the experimental design

Regression coefficients		Water absorption (WA)	Melt flow index (MFI)
Main effects	β_1	0.0813	0.1219
	β_2	3.2199	0.5288
	β_3	-2.6722	1.2605
Interaction effects			
	β_{12}	0.0049	-0.0395
	β_{13}	-0.1073	0.0009
	β_{23}	-0.1346	0.0208
R^2		0.9770	0.9983

Values of "Prob > F" less than 0.0500 indicate model terms are significant
R^2 : Determination coefficients obtained by ANOVA

Water Absorption of the Abaca Fibre Reinforced HIPS Composites

Water absorption of natural fibre composites is an important study. Most natural fibre composites absorb moisture as the cell wall polymers contain hydroxyl and other oxygenated groups that attract moisture through hydrogen bonding (Shanks, 2004). The hemicelluloses are mainly responsible for moisture absorption in the natural fibre, but the other non-crystalline cellulose, lignin, also plays a major role in this content. Generally, increasing the content of natural fibre in the composites increases the number of hydroxyl group, and consequently, it increases water absorption (Rahman *et al*., 2009). In this study, the water absorption of the abaca fibre reinforced HIPS composites, observed through the response surface method (Box-Behnken design), revealed the interactive effect of the level and fraction wt% of variables (abaca fibre, coupling agent (maleic anhydride), and impact modifier that made water absorption desirable.

The observation, which was based on Table 3 and *Figs. 4a* and *b*, evaluated showed that water absorption in the abaca fibre reinforced HIPS composites was influenced by the addition of the abaca fibre and impact modifier. The graph illustrates that together, the abaca fibre and impact modifier caused the changes in the water absorption of the composites. When the abaca fibre loading was close to 30 wt%, impact modifier 4.25 wt% and coupling agent (maleic anhydride) was fixed at 20 wt%, the water absorption of the composites became minimal. Thus, the interaction between the abaca fibre and impact modifier strongly affected water absorption in the composite specimen.

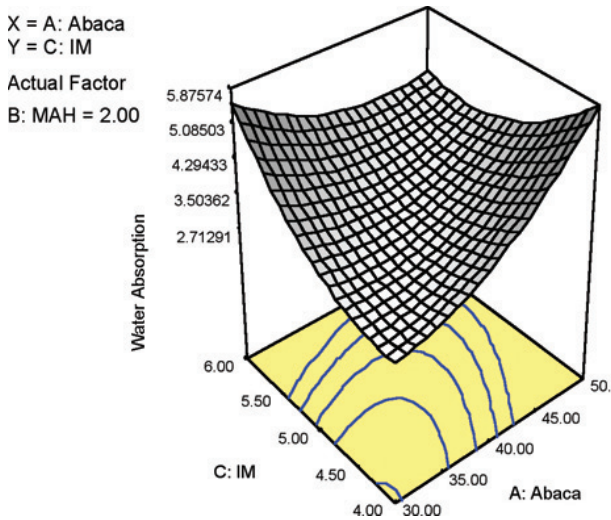

Fig. 4a: Response surface 3D plots showing the effect of the abaca fibres and impact modifier for water absorption (%)

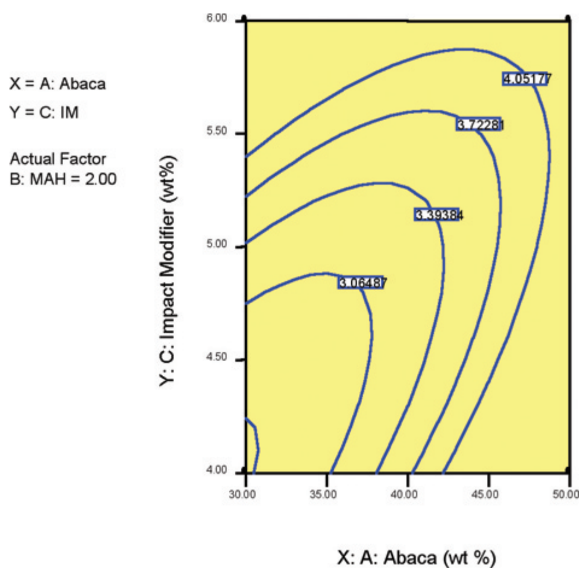

Fig. 4b: Response surface contour plots showing the effect of the abaca fibres and impact modifier for water absorption (%)

Melt Flow Index (MFI) of the Abaca Fibre Reinforced HIPS Composites

The melt flow index (MFI) is a measure of the ease of flow of the melt of a thermoplastic polymer. It provides a means of measuring flow of a melted material which can be used to differentiate grades or determine the extent of degradation of the plastic as a result of moulding. The MFI of the plastic materials is a point of a degraded material which generally flows more as a result of

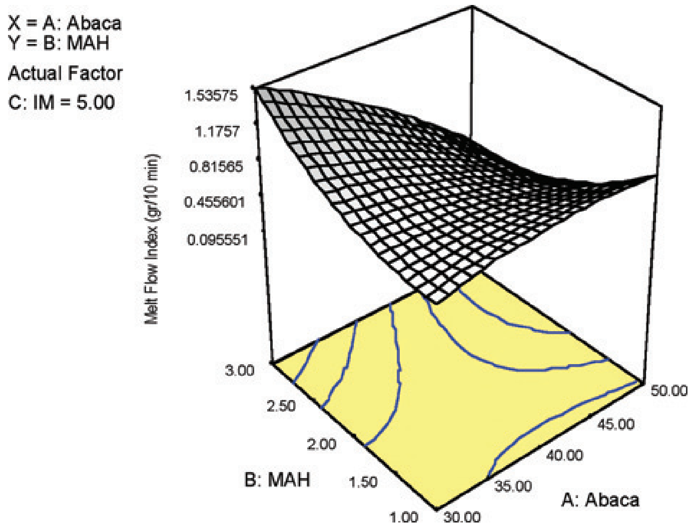

Fig. 5a: Response surface 3D plots showing the effect of the abaca fibres and Maleic Anhydride for the Melt Flow Index (g/10 min)

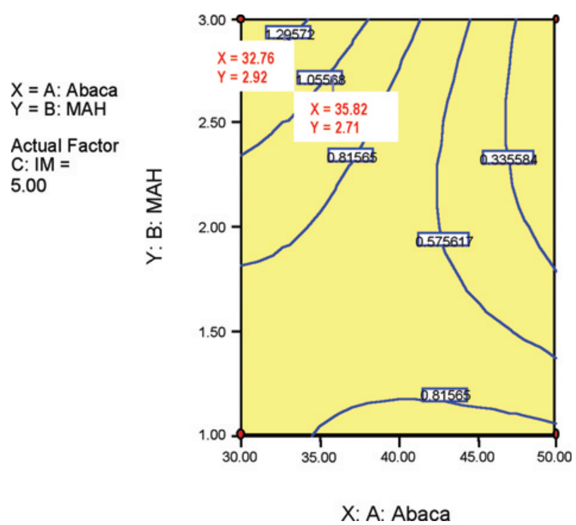

Fig. 5b: Response surface contour plots showing the effect of the abaca fibres and Maleic Anhydride for the Melt Flow Index (g/10 min)

reduced molecular weight, and can exhibit reduced physical properties. For polypropylene/wood fibre composites, the MFI of PP was found to be a key factor governing the mechanical properties (tensile and flexural strength) Kim *et al*. (2008).

Figs. 5a, b shows 3D and surface contour plots of the MFI of the abaca fibre reinforced HIPS composite that was designed using the response surface methodology. The interaction effects among the three factors, namely, the abaca fibre, maleic anhydride and impact modifier, are described by the saddle point graph. From the previous discussion on the ANOVA analysis (Table 4), the abaca fibre is as the main factor that affected the interaction between abaca fibre and maleic anhydride, as well as significantly influenced the melt flow index of composite. Normally, the addition of partitive restricts molecular motion in the matrix imposes resistance to flow and gives lower MFI. Meanwhile, an increase in MFI value indicates a better molecular motion between polymer chains. In this study, the interaction between maleic anhydride and abaca fibre improves the poor interfacial interaction between the hydrophilic abaca fibre and hydrophobic HIPS matrix. It is important to note that the impact modifier is fixed variable at 5 wt%. A possible reason for this phenomenon is that the abaca fibre and maleic anhydride exhibit antagonistic interaction, as shown in *Figs. 5a, b*. It can be concluded that the melt flow index in this case was governed by the abaca fibre and maleic anhydride. This research has enabled the loading of abaca fibre 32.76 wt%, maleic anhydride 2.92 wt% and impact modifier to be fixed at 5 wt% to give a value of MFI 1.295 g/10 min.

Optimization of the Experiments

Since the interactions were found to be present, the next step was to optimize these interactions to obtain the optimum physical properties and to deal with the minimum amount of the chemicals added. To achieve this, the Design Expert software was used and an optimization was carried out for optimizing both the physical properties and the amount of chemicals used. A compromised zone of the abaca fibre reinforced high impact polystyrene where all the experimental responses had been satisfying. This condition was dependent on the characteristics of the optimum individual values of water absorption and melt flow index (MFI). For example, a good value of the melt flow index (MFI) 0.992 g/10 min was compromised with 2.623% water absorption; this condition was dealt with the loading of abaca fibre 36.76 wt%, maelic anhydride 3 wt%, and impact modifier 4 wt%. These optimized properties were also based on the models shown in equations 3 and 4. After optimization, there are some solutions for the physical properties of the abaca fibre reinforced HIPS composites, as shown in Table 6. However, the performance of the physical properties of the abaca fibre reinforced HIPS composites did not show any linear relationship.

TABLE 6
Optimization experiments of physical properties prepared by Box-Behnken design

Number	Abaca wt%	MAH wt%	IM wt%	Water absorption	Melt flow Index g/10 min
1	36.75	3.00	4.00	2.623	0.992
2	40.36	3.00	6.00	3.470	0.782
3	38.18	3.00	4.00	3.459	0.770
4	43.64	1.00	6.00	3.451	0.751
5	43.78	1.02	6.00	2.596	1.001
6	34.44	1.00	4.00	2.989	0.811
7	35.63	1.00	4.00	3.092	0.765
8	35.76	1.00	4.00	2.231	0.713
9	40.57	3.00	4.87	3.862	0.690

MAH: Maeliic Anhydride, IM: Impact Modifier

The Box Behnken designed experiments in optimum composition within the range of the level plotted. The optimum conditions are the solution for the whole physical properties of the abaca fibre reinforced HIPS composites. In this study, the individual optimum of water absorption was a minimum value 2.231%, with the optimum level of abaca fibre 34.61 wt%, maleic anhydride 1 wt%, and impact modifier 4.01 wt%. The individual optimum value of the melt flow index (MFI) was on 1.001 g/ 10 min with deal on abaca fibre 36.71 wt%, Maleic Anhydride 3 wt%, and impact modifier 4.02 wt%.

CONCLUSION

The results obtained in this study have indicated that the enhancement of the physical properties by water absorption and Melt Flow Index of the abaca fibre reinforced HIPS composite is possible by changing the level of three-level fraction variables (abaca fibre, maleic anhydride, and impact modifier). The Box-Behnken design was reliable to explain the interaction effect of each variable which focused on finding the optimum physical yields of the abaca fibre reinforced HIPS composites. The optimum condition for the individual water absorption of the abaca fibre reinforced HIPS composites was following the decreasing tendency value of the Melt Flow Index. The characteristic of the composites (abaca fibre reinforced high impact polystyrene) designed might be produced based on the compromised zone with all the experimental responses satisfied.

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