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Evaluation of Physical Properties of Composite Material Produced from Short Bamboo Fibre with Carbonized Bone Particles in an Epoxy Matrix

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Abstract

This study investigates the physical properties of a new composite material produced from short bamboo fibre and carbonized bone with epoxy as a binder for potential use as a lightweight engineering material. The water absorption and the thickness swelling properties of the composite were carried out. The optimum results from the composites produced had a composition of bamboo – carbonized bone – epoxy composition of 40%, 10% and 50% respectively. The optimum values of thickness swelling and water absorption were obtained as 0.067% and 3.52% respectively. The analyses of variance results showed that all the model terms were significant indicating that changes in the levels of bamboo, epoxy and bone powder will have a significant influence on the thickness swelling and water absorption of the composite material.

1. Introduction

The advantages of natural fibers, such as sisal, flax, hemp, jute, (as engineering materials), are the low costs, availability and environmental friendliness. The disadvantages however, are the quality variations, high moisture uptake and low thermal stability of the raw fibers. [1]
Holmes et al., [2][3] tested a novel bamboo-poplar epoxy laminate for wind turbine blades, and demonstrated that this material has high strength and stiffness, and can be used in wind blades instead of common composites. The high strength and durability of bamboo as well as its quick growth and broad availability make the bamboo to a very promising material for the wind energy applications.
It has been observed that natural fibre reinforced polymers are a potential environmentally friendly alternative for carbon fibre reinforced polymers or glass fibre reinforced polymers and that they could be a suitable replacement for these types of composites in some current applications. Moreover, bamboo has been observed to possess tensile and compressive strengths stronger than several types of wood and close to the strength of steel. Using this material keeps the high mechanical strength while serving as natural resource. This in turn helps in the reduction of energy consumption and pollution creation when building woven composites [4]. Some researchers have also investigated and ascertained the desirable effects of cow bone as reinforcement particles in composites [5][6].

Tests [7] were carried out to determine the water absorption and thickness swelling properties of the composite material produced from continuous bamboo fibre with carbonized bone particles in an epoxy matrix. The optimum values for water absorption and thickness swelling as 6.55% and 0.09% respectively.
Also, an evaluation of the mechanical properties of composite material produced from continuous bamboo fibre with carbonized bone particles in an epoxy matrix was done by [8]. The optimum values of modulus of rupture, modulus of elasticity, and tensile stress for the composite were obtained as 110.50 MPa, 13130.70 MPa, and 8448.41 MPa respectively.

This study evaluates the water absorption and thickness swelling properties of a composite material produced from short bamboo fibre with carbonized bone particles in an epoxy matrix for its suitability in deployment as a lightweight engineering material.

2. Materials and Methods

2.1. Material Collection and Pretreatment

Freshly harvested bamboo (bambusa vulgaris) was gotten from a wood shop in Benin City. The bamboo culms were cut at each node and processed into strips of size range 15-25 mm to ensure the bamboo was semi flat and not curved. The strips were soaked in 0.1 M sodium hydroxide solution for 72 hours in order to remove the lignin content of the bamboo [9]. The bamboo strips were thereafter rinsed with distilled water to neutrality, dried in air and later heated at 110 ^{o}C for two hours in an oven until they were dry. The Edwards Rolling Machine in the sheet metal lab at the Faculty of Engineering workshop in University of Benin was employed to press and splinter the bamboo. The fibres were obtained from these splintered bamboo manually. The diameter of the fibres ranged from 0.8 mm to 2.3 mm. The fibre strips were then cut to obtain short bamboo fibre (see Plate 1). The length of the short fibres ranged from 2.00 mm to 5.00 mm. Table 1 shows the average fibre diameter from a sample size of 20 fibres, along with their standard deviation.

Table 1: Dimensions of short bamboo fibres.

Minimum length	2.00 millimetres
Maximum length	5.00 millimetres
Average length	3.72 millimetres
Standard Deviation	1.0451 millimetres

Plate 1: A sample of the short fibres

Cow bone which was carbonized in a crucible furnace at about 550 ^{o}C for 45 min, was obtained at an animal feed processing factory in Benin City. The carbonized cow bone was crushed and grounded to powder. It was thereafter sieved to obtain a fine particle size distribution using a sieve size of 212 μm. Epoxy resin and catalyst which served as the matrix binder was obtained under the brand name of Epochem 105 Resin and Epochem 205 epoxy curing agent, from Epoxy Oilserv Nigeria Ltd, located in Port-Harcourt, Rivers State, Nigeria.

2.2. Composite Experimental Sample Formation and Testing

The experimental set up for producing the composite was planned using a three-variable simplex-lattice mixture experimental design with three variables serving as mixture components. This choice of the design was based on the fact that it has been established by numerous researchers as the best experimental design for production formulation in the field of engineering [10][11]. It is often employed whenever the components form a simplex region. Since the number of points may be equal to just the number needed to estimate the model, the simplex-lattice design was augmented to allow for detection of lack of fit. For this purpose, the overall centroid was added to the check blends (50-50 combinations of the center point and each vertex). Five replications of the design points was done in order to appropriately estimate the lack of fit from the pure error. This took the total number of experimental runs to 15 which was implemented in the Design Expert® software version 7.0.0, (Stat-ease, Inc. Minneapolis, USA). The Design Expert® software was used to develop the statistical models to relate the input factors to the chosen responses. The factors investigated in this study as well as their respective ranges are shown in Table 1. The relationship between the components of the mixture which also represent factors of the design is shown in Equations 1 and 2.

Table 2: Coded and actual levels of the factors for the composites

Factors	Unit	Symbols	Variable levels	
			Low level	High level
Bamboo fibre	%	X_1	40	45
Epoxy	%	X_2	45	50
Bone powder	%	X_3	10	15

$$0 \le X_i \le 100 \tag{1}$$

where, i = 1, 2, 3

$$X_1 + X_2 + X_3 = 100 \tag{2}$$

Equations 1 and 2 show that the components of the mixture formulation are not independent implying that changes in the levels of one component affect those of the others [12].

The test samples of the prepared short bamboo fibre, the carbonized bone particles, and the epoxy resin with the corresponding mixing ratio of the hardener (catalyst) were measured out respectively in weights using a digital electronic scale having an accuracy of 0.01g into a pan in batches according to the experimental design matrix. The epoxy and hardener were prepared according to the manufacturer’s specification. Each configuration was homogeneously mixed and put into the preformed wooden mould with dimensions based on ASTM D638 which had been previously rubbed with a petroleum jelly for the purpose of ease of extraction of the cured specimens. A pressure of about 80 kN was applied to the composite. It was allowed to cure at room temperature for 24 hours before extraction. The cured specimens were placed in distilled water for a period of 24 hours and thereafter their thickness swelling and water absorption properties were measured.

3. Results and Discussion

3.1. Analysis of Statistical Models

The statistical analysis of the chosen models was done by fitting the models to the experimental data as obtained from the mixture experimental design. The special cubic model was fitted to the experimental data for the responses (thickness swelling and water absorption). The fitting of the appropriate models to the respective experimental data was achieved through multiple regression analysis which culminated in the estimation of the unknown model parameters. Substitution of the estimated model parameters into the respective models produced the final models for predicting the responses. The final model equations representing these responses in terms of the input factors, bamboo fibre level (X1), epoxy level (X2) and bone powder level (X3) are presented thus.

$$\begin{aligned} Thickness\ swelling &= 95.21X_1 - 83.00X_2 - 605.39X_3 + 3.66X_1X_2 \\ &+ 16.65X_1X_3 + 15.31X_2X_3 - 0.38X_1X_2X_3 \end{aligned} \quad (3)$$

$$\begin{aligned} Water\ absorption &= 67.23X_1 + 59.23X_2 + 525.10X_3 - 2.55X_1X_2 \\ &- 13.51X_1X_3 - 12.72X_2X_3 + 0.30X_1X_2X_3 \end{aligned} \quad (4)$$

Equations 3 and 4 were used to predict the thickness swelling and the water absorption for the composite. The results are shown in Tables 3 and 4. For all the results obtained for all the responses under investigation, it was observed that the model predicted results were very similar to the experimental results. This is an indication of the validity of the statistical models developed to predict the responses.

Table 3: Experimental and RSM predicted results for thickness swelling

Run	Actual values of factors			Response (%)	
	Bamboo (%)	Epoxy (%)	Bone powder (%)	Actual Experiment	RSM Predicted
1	40.00	45.00	15.00	0.17	0.17
2	45.00	45.00	10.00	0.17	0.17
3	41.70	46.70	11.70	0.12	0.12
4	40.80	45.80	13.30	0.10	0.10
5	40.00	50.00	10.00	0.07	0.07
6	43.30	45.80	10.80	0.15	0.15
7	42.50	47.50	10.00	0.13	0.14
8	42.50	47.50	10.00	0.14	0.14
9	45.00	45.00	10.00	0.17	0.17
10	42.50	45.00	12.50	0.12	0.11
11	40.00	47.50	12.50	0.00	0.00
12	40.00	45.00	15.00	0.18	0.17
13	40.80	48.30	10.80	0.07	0.08
14	42.50	45.00	12.50	0.11	0.11
15	40.00	50.00	10.00	0.06	0.07

Table 4: Experimental and RSM predicted results for water absorption

Run	Actual values of factors			Response (%)	
	Bamboo (%)	Epoxy (%)	Bone powder (%)	Actual Experiment	RSM Predicted
1	40.00	45.00	15.00	5.60	5.60
2	45.00	45.00	10.00	9.10	9.10
3	41.70	46.70	11.70	8.30	8.30
4	40.80	45.80	13.30	7.20	7.20
5	40.00	50.00	10.00	3.60	3.50
6	43.30	45.80	10.80	8.70	8.70
7	42.50	47.50	10.00	7.20	7.20
8	42.50	47.50	10.00	7.20	7.20
9	45.00	45.00	10.00	9.10	9.10
10	42.50	45.00	12.50	7.40	7.40
11	40.00	47.50	12.50	5.90	5.90
12	40.00	45.00	15.00	5.60	5.60
13	40.80	48.30	10.80	6.40	6.40
14	42.50	45.00	12.50	7.40	7.40
15	40.00	50.00	10.00	3.50	3.50

3.2. Analysis of Variance of Models

The statistical significance and fit of the models developed were assessed using analysis of variance (ANOVA). The results are shown in Tables 5 and 6. The ANOVA results for thickness swelling and water absorption for the composite are respectively shown in Tables 5 and 6. Significance of the model terms are considered acceptable to if they have a p value less than 0.05. This is usually interpreted to mean that changes in the values of the factor represented by that model term will have a significant effect on the response under consideration [13]. Conversely, model terms with p values greater than 0.05 are not considered significant and this means that that factor does not significantly influence the response under consideration. The results indicates that the models developed to predict the thickness swelling and water absorption were all significant. This can be seen from the fact that the model p value in all cases was very much less than 0.05 ($p < 0.0001$). This implies that the models were adequate for predicting their corresponding responses. The lack of fit of the models developed to predict the thickness swelling and water absorption was not significant. The level of fit indicates the degree of agreement between the experimental observations and the model predictions [14].

Table 5: ANOVA results for model representing thickness swelling

Source	Sum of Squares	Degree of freedom	Mean square	F value	p value
Model	0.0340	6	5.69E-03	248.3000	< 0.0001
Linear mixture	0.0170	2	8.63E-03	376.2100	< 0.0001
X_1X_2	4.53E-04	1	4.53E-04	19.7800	0.0021
X_1X_3	4.36E-03	1	4.36E-03	190.2300	< 0.0001
X_2X_3	0.0120	1	0.012	529.2500	< 0.0001
$X_1X_2X_3$	2.24E-03	1	2.24E-03	97.8300	< 0.0001
Residual	1.83E-04	8	2.29E-05		
Lack of fit	7.91E-06	3	2.64E-06	0.0750	0.9708
Pure error	1.76E-04	5	3.51E-05		
Cor total	0.0340	14			

Table 6: ANOVA results for model representing water absorption

Source	Sum of Squares	Degree of freedom	Mean square	F value	p value
Model	42.9200	6	7.1500	4816.880000	< 0.0001
Linear mixture	35.3400	2	17.6700	11896.620000	< 0.0001
X_1X_2	1.0600	1	1.0600	715.5100	< 0.0001
X_1X_3	1.17E-03	1	1.17E-03	0.7900	0.4010
X_2X_3	1.4500	1	1.4500	978.0700	< 0.0001
$X_1X_2X_3$	1.3000	1	1.3000	875.1900	< 0.0001
Residual	0.0120	8	1.49E-03		
Lack of fit	5.75E-04	3	1.92E-04	0.0850	0.9654
Pure error	0.0110	5	2.26E-03		
Cor total	42.9300	14			

Another parameter which was further used to assess the fit of the models developed was the goodness of fit. The goodness of fit parameters such as coefficient of determination (R^2), adjusted coefficient of determination (adjusted R^2), predicted coefficient of determination (predicted R^2), coefficient of variation, standard deviation, adequate precision were adopted to further assess the fit of the models for predicting the responses. The results are shown in Table 7. The R^2 value was greater than 0.99 for the models considered. The R^2 value is used to assess the level of fit between a model and experimental results. As can be seen from the results presented in Table 7, the models were characterised by high R^2 values indicating very good fit between the experimental observations and model predictions. The adjusted R^2 value was another important parameter used to assess the fit of the models. There should be an excellent agreement between the R^2 value and the adjusted R^2 value for a good fit. The value of standard deviation was small compared to the mean of the observations, an indication that there was very little deviation between the individual experimental results compared to the mean value. This is a further confirmation of the very good fit of the model to the experimental results. The coefficient of variation (CV) was small for all the models considered.

Table 7: Goodness of fit statistics for response models.

Parameter	Thickness swelling	Water absorption
R^2	0.9947	0.9997
Adjusted R^2	0.9907	0.9995
Mean	0.1200	6.8000
Standard deviation	0.0048	0.0390
CV	4.0600	0.5700
Adeq. Precision	53.3200	211.6200

3.3. Model Diagnostics

In other to assess the accuracy and indeed the adequacy for the intended purpose, diagnosis of the models developed to predict the responses for the composite also carried out. The normal probability plots for the models representing the thickness swelling and water absorption for the composite produced are shown in Figures 1 and 2. From the results obtained, the residuals of the models did follow a normal distribution as seen from the fact that the points clustered around the straight line.

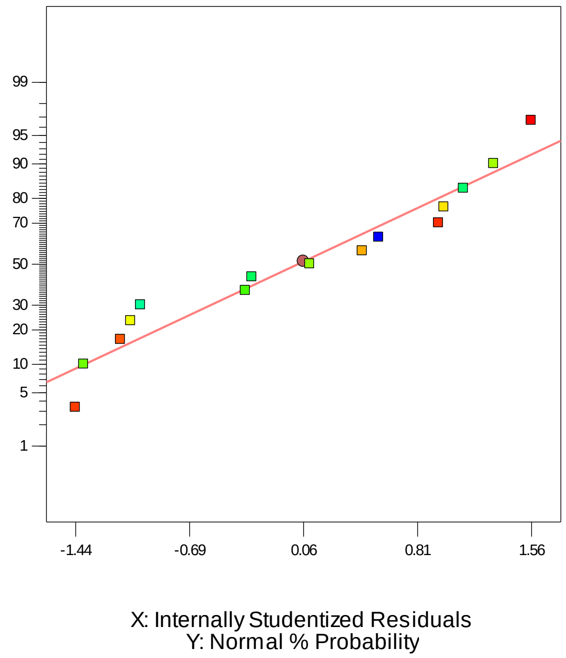

Figure 1: Normal probability plot for model representing thickness swelling.

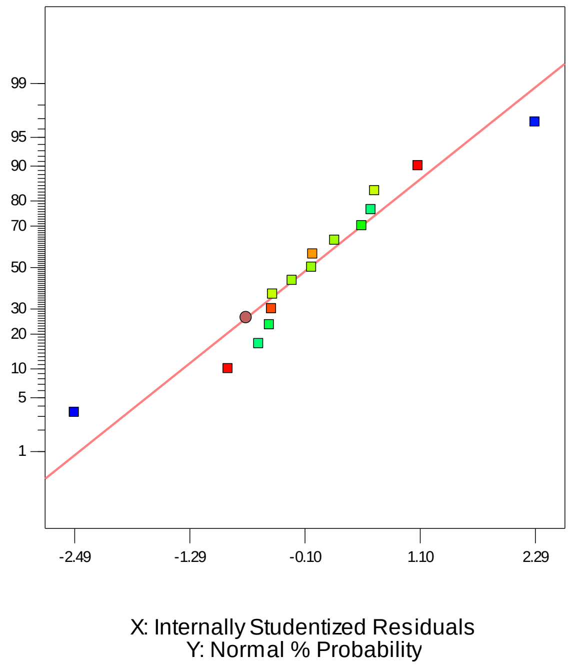

Figure 2: Normal probability plot for model representing water absorption.

3.4. Validation of RSM Model Results

The models results were validated by comparing their values with those obtained from the actual experiments. This was done in the form of parity plots which shows the comparison. Figures 3 and 4 show the parity plots for the models representing the two responses for the composite. Figures 3 and 4, reveals that there was significant fit between the experimental results and the model predictions because all the points clustered around the 45^o diagonal line.

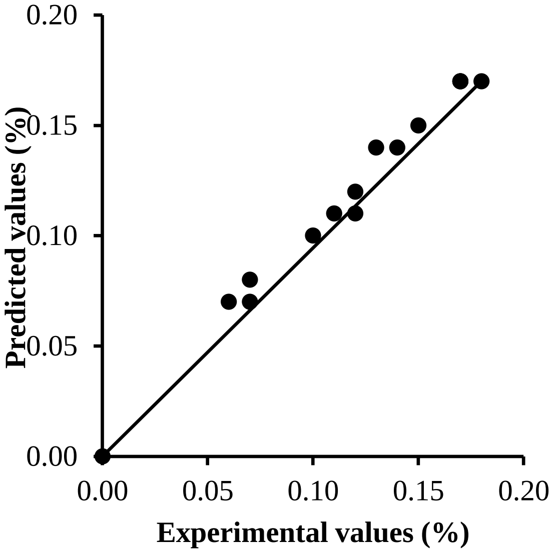

Figure 3: Parity plot for model representing thickness swelling.

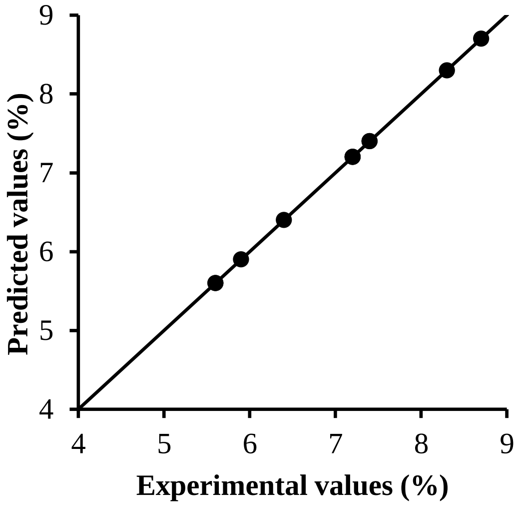

Figure 4: Parity plot for model representing water absorption.

3.5. Optimisation of Input Factors and Responses

The responses and the corresponding input factors were optimised using numerical optimisation. The thickness swelling and water absorption were both minimized. This is because they needed to be minimized for better productivity. After evaluating the model graphs and the solutions suggested by the numerical optimisation package, the optimum conditions were chosen as the one with the highest desirability value. Table 8 shows the optimisation results. This optimal point was chosen with the highest desirability of 0.968. The optimum values of thickness swelling and water absorption for the composite for the wind turbine blades produced from the short bamboo fibre were obtained as 0.067% and 3.52% respectively. The corresponding values of bamboo, epoxy and bone powder were 40%, 50% and 10% respectively.

Table 8: Optimisation results.

Variable	Value
Bamboo	40%
Epoxy	50%
Bone powder	10%
Minimum thickness swelling	0.067%
Minimum water absorption	3.52%
Desirability	0.968

3.6. Comparison with previous works

In a previous work [15], it could be seen that the water uptake of epoxy/glass fiber composites, was about 1.1% after subjected to water absorption compared to this work at 3.35%.

4. Conclusion

In this study, the physical properties of a composite produced from short bamboo fibre and carbonized bone particles in an epoxy matrix for the potential use for small scale horizontal axis wind turbine blades, was investigated. The following conclusions were drawn:

i. A new hybrid composite material produced from short bamboo fibre with carbonized cow bone using epoxy as a binder for potential use as a lightweight engineering material has been formulated.
ii. The optimum values of thickness swelling and water absorption for the composite produced from the short bamboo fibre were obtained as 0.067% and 3.52% respectively with corresponding values of bamboo, epoxy and bone powder of 40%, 50% and 10% respectively.
iii. ANOVA results shows that the model terms were significant indicating that changes in the levels of bamboo, epoxy and bone powder will have a significant influence on the physical properties of the new lightweight engineering material produced from the short bamboo fibres.

5. Conflict of Interest

There is no conflict of interest associated with this work.

References

[1] Kalagi, G.; Patil, R.; Nayak, N. Natural Fiber Reinforced Polymer Composite Materials for Wind Turbine Blade Applications. Int. J. Sci. Dev. Res. 2016, 1, 28–37.

[2] Holmes, J.W.; Sørensen, B.F.; Brøndsted, P. Reliability of Wind Turbine Blades: An Overview of Materials Testing. In Proceedings of the Wind Power Shanghai 2007, Shanghai, China, 1–3 November 2007.

[3] Holmes, J.W.; Brøndsted, P.; Sørensen, B.F.; Jiang, Z.H.; Sun, Z.H.; Chen, X.H. Development of a Bamboo-Based Composite as a Sustainable Green Material for Wind Turbine Blades. J. Wind Eng. 2009, 33, 197–210. [CrossRef]

[4] Gutu, T. (2013). A Study on the Mechanical Strength Properties of Bamboo to Enhance Its Diversification on Its Utilization. International Journal of Innovative Technology and Exploring Engineering, 2(5), pp. 314-319

[5] Asuke, F, Aigbodion, V.S., Adulwahab, M., Fayomi, O.S.I., Popoola, A.P.I., Nwoyi, C.I. and Garba, B. (2012). Effects of bone particle on the properties and microstructure of polypropylene/bone ash particulate composites. Results in Physics, 2, pp. 135 – 141

[6] Adewole, T. and Oladele, I., (2015). Effect of Cow Bone Ash Particle Size Distribution on the Mechanical Properties of Cow Bone Ash-Reinforced Polyester Composites. Chemistry and Materials Research, 7(3), pp. 40 - 46

[7] Ikpoza, E. and Akpobi, J.A. (2021), Composite Produced from Continuous Bamboo Fibre with Carbonized Bone Particles in An Epoxy Matrix: Evaluation of Physical Properties, NIPES Journal of Science and Technology Research, Vol. 3(1), pp.188 - 201

[8] Ikpoza, E. and Akpobi, J.A. (2021), Evaluation of Mechanical Properties of Composite Material Produced from Continuous Bamboo Fibre with Carbonized Bone Particles in an Epoxy Matrix, Nigerian Research Journal of Engineering and Environmental Sciences, Vol. 6(1), pp. 22-31

[9] Deshpande, A., Bhaskar Rao, M. and Lakshmana Rao, C. (2000). Extraction of bamboo fibers and their use as reinforcement in polymeric composites. Journal of Applied Polymer Science, 76(1), pp. 83-92.

[10] Zen, M., Izzati, N., Abd Gani, S. S., Shamsudin, R. and Fard Masoumi, H. R. (2015). The use of D-optimal mixture design in optimizing development of okara tablet formulation as a dietary supplement. The Scientific World Journal, 2015. pp. 1-7.

[11] Abutu, J., Lawal, S.A., Ndaiman, M.B., Lafia-Araga, R.A., Adedipe, O. and Choudhury, I.A. (2018). Study on mechanical properties of fly ash impregnated glass fiber reinforced polymer composites using mixture design analysis. Engineering Science and Technology, an International Journal, 21, pp. 787-797.

[12] Hirata, M., Takayama, K. and Nagai, T. (1992). Formulation optimization of sustained-release tablet of chlorpheniramine maleate by means of extreme vertices design and simultaneous optimization technique. Chemical and pharmaceutical bulletin, 40(3), pp. 741-746.

[13] Beg, Q. K., Saxena, R. K. and Gupta, R. (2002). Kinetic constants determination for an alkaline protease from Bacillus mojavensis using response surface methodology. Biotechnology and Bioengineering, 78, pp. 289–295

[14] Montgomery, D.C. (2005). Design and Analysis of experiments, 6th ed., New York: John Wiley & Sons, Inc.

[15] Chow, W. S. (2007), Water absorption of epoxy/glass fiber/organo-montmorillonite nanocomposites, eXPRESS Polymer Letters Vol.1, No.2 (2007) 104–108