Investigation of Control Factors for Water Absorption of Natural Fiber Reinforced Composite

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Abstract

Environmental friendly products and materials are very much important for the sustainability of human being in this earth. For this reason, researchers are focusing on it. As synthetic fiber has a negative impact on environment, these are being replaced by the natural fiber in the reinforcement of composites. In this study, corn cob particles and palmyra fruit fiber are used as reinforcement in epoxy based composite. As a fabrication technique hand lay-up method is used. Weight percentage of resin and hardener in composite, weight percentage ratio of resin and hardener, weight percentage ratio of corn cob particles and palmyra fruit fiber, and also thickness of the composite were taken as control factors for the fabrication of the composites. Experiments were designed according to Taguchi L9 orthogonal array. Then the water absorption characteristic was observed for different experiments. Optimum control factors were chosen using Taguchi analysis. Also different statistical analysis was done for finding the effect of the control parameters on water absorption property of the natural fiber reinforced composite.

Keywords: Natural composites, Water Absorption, Taguchi L9 orthogonal design of experiments.

1. Introduction

At present, the focus of researcher's attention is centered to the improvement of natural fiber reinforced composite (NFC) to meet the demand of new era utilizing the superior advantages of natural fibers over artificial ones. Natural fiber reinforced composites (NFC) are gaining wider consideration in current years in various applications including structural, automobile, roof and wall panel, container, protective vest, etc. As a fabricated material, the characteristics of NFC can be controlled to meet certain demands. Wider variation in properties and characteristics is a major challenge to work with NFC. Different parameters such as the category of fibers, ecological condition where the plant fibers are grown, and fiber treatment methods influence the characteristics of NFC to a large extent. Natural fiber composites, with their exclusive and wide range of variability in characteristics, can alter the use of synthetic fiber composites in the way of searching new alternative engineered material (Ticoalu et al., 2010). Natural fiber reinforced composite is a composite material that contains a polymer matrix (resin and hardener) embedded with high-strength natural fibers such as coir, jute, sponge gourd, sisal, banana, kenaf, cotton, hemp, corn cob, palmyra fruit fiber etc. In a new engineered composite, natural fibers have been accepted as good potential reinforcements (Kabir et al., 2012).

There are plenty of natural fibers that are tried to make a composite such as bast fibers (jute, hemp, kenaf), seed fibers (cotton, sponge gourd, coir), leaf fibers (banana, sisal, agave, pineapple), grass and reed fibers (wheat, corn, rice), and core fibers (jute, hemp, kenaf) as well as all other kinds (wood and roots), dried Palmyra fiber and Bagasse (Mohammed et al., 2015). (Venkateswarlu et al. 2016), (Bullibabu et al. 2018), Sailesh & Shanjeevi (2013). Taguchi method was used to develop DOE by various researchers for optimizing different input parameters involved in mechanical behavior as well as process parameters, production and machining methods (Grcaeraj & Venkatachalam, 2015), (Poostforush et al., 2013), (Fei et al. 2013), (Esmizadeh et al., 2011), (Sailesh & Shanjeevi (2013), Vankantia&Gantab (2014) (Uysal et al., 2012), (Mehat & Kamaruddin 2011), (Yusuf et al., 2019). Both the Taguchi method and Analysis of Variance (ANOVA) can be used to explore the effects of different parameters to find out the optimal combination and the percentages of the contribution of each parameter.

2. Materials and Methods

2.1Materials

In this study, natural fibers (corn cob particles and palmyra fruit fiber) were used for reinforcement in the composite. Corn cob and palmyra fruit fibers are collected from the local area of Nawabganj, Dinajpur, Bangladesh. Caustic Soda (NaOH) is used for the treatment of natural fibers. Caustic Soda is collected from a Chemical store of Saidpur. Thermoset polymers are widely used to fabricate NFC. Epoxy resins, one of the thermosetting resins, have outstanding mechanical and chemical characteristics, thermal and corrosion resistance. The epoxy resin (Araldite AW 106) and hardener (Hardener HV 953 IN) were used as the matrix of this composite. The hardener is applied to provide more strength and enhance the interfacial adhesion. Both epoxy resin and hardener were collected from the local market of Khulna.

2.2 Experimental Design

The minimization of percentage of water absorption is the objective function described in this study. The selection of control factors is a key stage in the design of experiments. Four factors i.e., weight percentage ratio of resin and hardener (A), weight percentage of resin and hardener in composite (B), weight % ratio of corn cob particle and Palmyra fruit fiber in composite (C), and thickness of composite in mm (D), each at three levels is considered in this study. Using a L9 (3^4) orthogonal design, the influence of four variables was investigated where 9 experiments are sufficient to optimize the parameters. Table 1 shows the levels and control factors.

Table 1: Levels of control factors used in the experiment.

Control factors	Levels		
	1	2	3
Weight % ratio of resin and hardener, A	2:1	5:2	3:1
Weight percentage of resin and hardener in composite, B (%)	90	88	86
Weight % ratio of corn cob particle and Palmyra fruit fiber, C	9:2	5:1	11:2
Thickness of composite in mm, D	7	10	12

2.3 Composite Fabrication Procedure

The hand lay-up process, a simple and easy technique for manufacturing composites, is used to fabricate composite. First, three molds were prepared. The dimensions of the molds were 300 × 150 × 7 mm^3, 300 × 150 × 10 mm^3 and 300 × 150 × 12 mm^3 which were made from wood. Then, rapping polythene were placed on the molds surface for easy removal of composite. The mass of resin, hardener, and chemically treated fibers were measured. The resin was mixed with the hardener properly at a specified proportion according to the composition of different samples. After mixing, the mixer of epoxy resin with natural fibers was then poured into the mold. A hand roller and brush were employed to evenly distribute the resin throughout the fibers and decrease voids in the fiber structure. Finally, a glass covering was placed over the fibers and resin, and load was applied over the glass sheet to remove any air gaps. It was then left for 48 hours to solidify. After the composite material has completely solidified, it is taken from the mold and the rough edges are cleanly trimmed. After that, NFC samples were exposed to regular air to cure them. To obtain specimens for various mechanical tests, the manufactured NFCs were sliced using a Jig saw machine.

3. Results and Discussion

3.1 Percentage of Water Absorption

The water absorption tests of corn cob particle and palmyra fruit fiber reinforced epoxy composites were done as per ASTM D5229M-12 (ASTM, 2012) by immersion in distilled water (rain water) at room temperature. The specimens were taken out periodically and after wiping out the water from the surface of the specimen weighted immediately using a precise balance machine to find out the content of water absorbed. The specimens were weighed regularly at 24, 48 and 72 hours.

Table 2 shows the design of the experiment by using Taguchi L9 orthogonal array with the % of water absorption values of these composites. Experiment no. 7 gives the minimum % of water absorption value (3.39%), where wt% ratio of resin & hardener, wt% of resin & hardener in composite, wt% ratio of corn cob particle and palmyra fruit fiber in composite, and thickness of composite in mm are 2.00, 86, 5.5, and 10 respectively. On the other hand, experiment no. 4 reveals the maximum % of water absorption value (12.55%), where wt% ratio of resin & hardener, wt% of resin & hardener in composite, wt% ratio of corn cob particle and palmyra fruit fiber in composite, and thickness of composite in mm are 2.00, 88, 5, and 12 respectively. Percentage of water absorption results of the various experiments are compared in figure 1.

Table 2: Experimental output for mean of water absorption at various levels of control parameters.

Expt. No.	Wt % ratio of resin and hardener	Wt % of resin and hardener in composite (%)	Wt % ratio of corn cob particle and Palmyra fruit fiber in composite	Thickness of composite in mm	% of Water absorption			
					Specimen 1 (24 hrs)	Specimen 2 (48 hrs)	Specimen 3 (72 hrs)	Mean
1	2:1	90	9:2	7	5	6.57	6.94	6.17
2	5:2	90	5:1	10	4.15	6.35	6.84	5.78
3	3:1	90	11:2	12	7.69	9.15	10.15	9.00
4	2:1	88	5:1	12	10.03	10.46	17.15	12.55
5	5:2	88	11:2	7	4.56	6.20	13.18	7.98
6	3:1	88	9:2	10	8.26	9.71	10.45	9.47
7	2:1	86	11:2	10	2.29	2.62	5.26	3.39
8	5:2	86	9:2	12	8.12	8.26	12.73	9.70
9	3:1	86	5:1	7	3.52	6.34	11.54	7.13

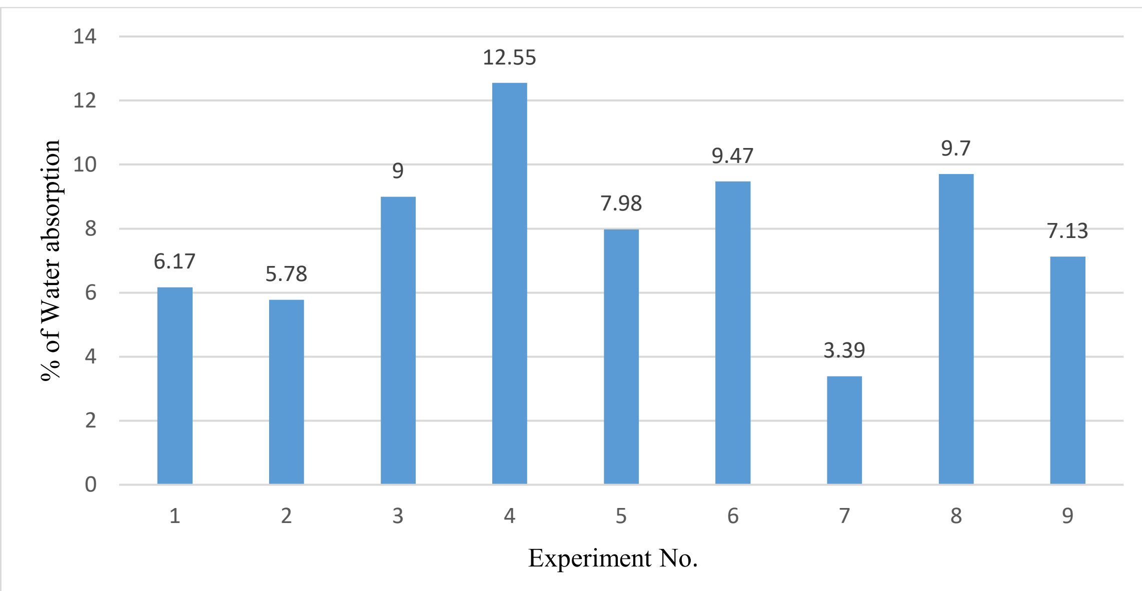

Fig. 1: Comparison of percentage of water absorption at different experiments

3.2 Taguchi Analysis

The "smaller is better" approach is used in this method as the minimization of percentage of water absorption is the main goal of thesis work. The response table for mean of percentage of water absorption at different levels of control parameters is shown in table 3.

From table 3 and figure 2, it is seen that the lowest response appears in thickness of the composite. It is clearly seen from the graph that the thickness must be kept very close to 10 mm for keeping the percentage of water absorption of the natural reinforced composite lower. Second favorable option for maintaining the percentage of water absorption lower is weight percentage of resin and hardener in the composite. Minimum response was measured for 86 weight percentage of resin and hardener, and 88 weight percentage resin and hardener gave a maximum response for percentage of water absorption. So increased weight percentage of corn cob particle and palmyra fruit fiber in composite decrease the percentage of water absorption.

Table 3: Response table for mean of flexural strength at different levels of control parameters

Level	Weight % ratio of resin and hardener, A	Weight % of resin and hardener in composite, B (%)	Weight % ratio of corn cob particle and Palmyra fruit fiber in composite, C	Thickness of composite in mm, D
1	**7.37**	**6.74**	8.45	7.09
2	7.82	10.00	8.49	**6.21**
3	8.53	6.98	**6.79**	10.42
Delta	1.16	3.26	1.70	4.20
Rank	4	2	3	1

Third favorable option for decreasing percentage of water absorption is weight percentage ratio of corn cob particles and palmyra fruit fiber. As the weight percentage ratio of corn cob particles and palmyra fruit fiber increases, the percentage of water absorption of composite decreases. It also shows that increase in the amount of corn cob particles in the composite decrease the percentage of water absorption. A minimum response of percentage of water absorption was found for 5.5 weight percentage ratio of corn cob particles and palmyra fruit fiber. Weight percentage ratio of resin and hardener is the last important factor for decreasing the percentage of water absorption of the natural fiber reinforced composite. By decreasing weight percentage ratio of resin and hardener, response for the percentage of water absorption is linearly decreased. The result is better for the ratio of 2.

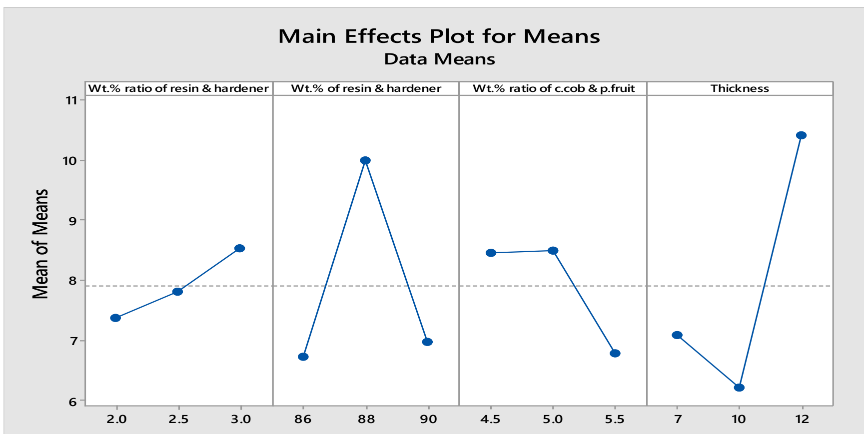

Fig. 2: Main effect plots for mean values of percentage of water absorption

3.3 Confirmation Test

The Taguchi experimental design revealed that the best combination of parameters is A(2.0), B(86%), C(5.5), and D(10). The following equation is used to compute the estimated maximum flexural strength:

Water absorption (Predicted) = A(2.0) + B(86) + C(5.5) + D(10) – 3Y = 7.37 + 6.74+ 6.79+ 6.21 – 3(7.91) =3.38 %

The average mean values of water absorption at their optimum levels are A, B, C, and D, respectively, while the overall mean is Y. A(2.0), B(86), C(5.5), D(10) is the best combination of control parameters for minimum percentage of water absorption. As a result of the foregoing combination, three new specimens were created to justify the anticipated percentage of water absorption. Water absorption (Experimental) = 3.94 %. Percentage of error (%) = 16.57.

3.4 Analysis of Variance

The thickness of reinforced composite is the main contributor to the percentage of water absorption of the reinforced composite, according to table 4, which is a one-way ANOVA table. The maximum percentage of contribution is 45.77. For numerator 1 and denominator 4, the critical value $F_{critical}$ =7.71 is obtained from the F-distribution table. The projected F-value for the aforementioned maximum percentage of contribution is 1.40, which is lower than the critical F-value of 7.71. Also P-value is 0.302 or 30.2% which is greater than 5% which implies the high probability of accepting the assumptions statistically.

Table 4: ANOVA analysis for percentage of water absorption at 95% Confidence Level

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage of contribution
Wt % ratio of resin and hardener, A	1	2.03	2.03	0.22	0.666	7.05
Wt % of resin and hardener in composite, B (%)	1	0.089	0.089	0.01	0.927	0.31
Wt % ratio of corn cob particle and Palmyra fruit fiber in composite, C	1	4.117	4.117	0.44	0.544	14.29
Thickness of composite in mm, D	1	13.185	13.185	1.40	0.302	45.77
Error	4	37.543	9.386			32.58
Total	8	56.964	28.807			100

Similarly, weight percentage of resin and hardener in composite shows the minimum level of contribution which value is 0.31. The predicted F-value in this case is 0.01, which is less than the critical threshold of 7.71. Also P-value is 0.927 or 92.7% which is larger than 5% which implies that the probability of accepting the assumptions is statistically high. The combined impact of unaccounted control factors contributes to a 32.58% inaccuracy in this study.

3.5 Contour Plots

The maximum and minimum projected reactions of the process are determined using a Contour Plot. Contour plots are particularly beneficial when a maximum or minimum response is anticipated within or near the data range as a contour area. Contour plots are extremely useful for investigating the combined effects of several control parameters on output characteristics.

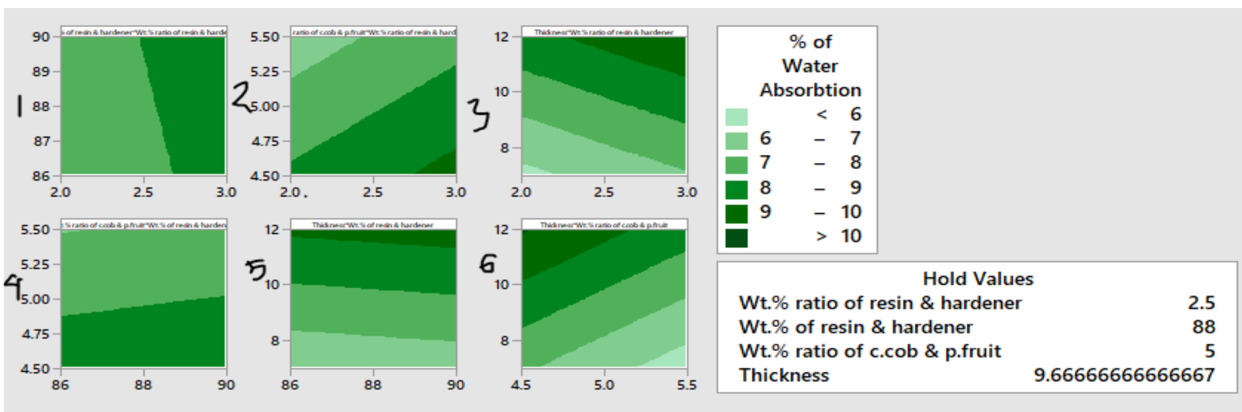

Fig. 3: Contour plots of impact strength

Figure 3 represents the contour plots for percentage of water absorption of the natural fiber reinforced composite. In 1st contour plot, if the value of weight percentage of resin and hardener increases with the increase in weight percentage ratio of resin and hardener in composite, then it shows improved contour surface with higher percentage of water absorption. From 2nd contour plot it is found that percentage of water percentage decreases with the increase of weight percentage ratio of corn cob particle and palmyra fruit fiber. From 3rd contour plots, decreasing values of weight percentage ratio of thickness of the composite reduce percentage of water absorption. From 4th contour plot, higher values of weight percentage ratio of corn cob particle and palmyra fruit fiber along with smaller weight percentage of resin and hardener show minimum results in percentage of water absorption. In 5th contour plot, percentage of water absorption decreases with decreasing values of weight percentage of resin and hardener along with lower thickness of the composite. In 6th contour plot, increasing value of weight percentage ratio of corn cob particle and palmyra fruit fiber along with lower thickness decreases the percentage of water absorption of the natural fiber reinforced composite.

4. Conclusion

From the above results and discussions, the following conclusions are taken:

- Percentage of water absorption behavior of these composites were investigated where combinations of control factors in each sample was designed by Taguchi method.
- It was explored from the Taguchi analysis that the combination of Weight percentage ratio of resin & hardener: 2:1, Weight percentage of resin & hardener in composite: 86%, Weight percentage ratio of corn

cob particle and palmyra fruit fiber: 5.5:1, and thickness of the composite: 10 conditions was the optimal setting for obtaining minimum percentage of water absorption.

- Confirmation experiments were carried out with the optimal settings on three different specimens. The average percentage of water absorption was 3.94% which were in goodagreement with the predicted responses and have a deviation of 16.57%.
- Percentage of contribution of various control factors was investigated through ANOVA analysis and it was found that thickness has the highest contribution on percentage of water absorption.
- The interaction effects of various combinations between two control factors over percentage of water absorption behavior are represented graphically by contour plots.

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Biography

Md. FirozKabir received the B.Sc. Engg degree with distinction in Industrial and Production Engineering from Rajshahi University of Engineering and Technology, Rajshahi, Bangladesh, in 2016. He is currently pursuing his M.Sc. Engg with distinction in Industrial and Production Engineering at Rajshahi University of Engineering and Technology, Rajshahi, Bangladesh. Since 2019, he has been employed as Lecturer in the department of Industrial and Production Engineering, Bangladesh Army University of Science and Technology. His research areas of interest include operations research and optimizations, Machine Tools and Machining, Composite materials, Solid waste management.

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