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Experimental Study on Empty Fruit Bunch (EFB) Composite Subjected To Three Point Bending Using ANOVA Technique

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Abstract:

This study focuses on the evaluation of factor effect toobtain the optimum configuration on empty fruit bunch (EFB) composite for impact purposes performed by statistical analysis using light resin transfer molding (LRTM). Three factors considered in this study are resin pressure, EFB volume fraction and EFB composite thickness. There are three levels of factorial design and two factors that have been developed to relate between ultimate strength and young's modulus. Identification on the analysis of variance (ANOVA) was applied to achieve the most influential factors on responses and optimum configuration. All the three considered factors influence the composite performance although only two are considered as the most influential factors on the composite performance for impact purposes.
Keywords: *Optimum Configuration, EFB composite, Light Resin Transfer Molding (LRTM), Anova*

I. INTRODUCTION

Design development of composite materials in manufacturing technologies is one important advance in material history. Composite materials have been used in worldwide industries such as in aerospace, infrastructure and automotive industries [1]. Composite gives greater resistance to high temperature, corrosion, and oxidation, and is progressively replacing metals[2]. Furthermore, the layup optimum strength and stiffness can be customized for improved fatigue life with good design practice and reduced cost of detailed parts and fasteners [3]. Synthetic fibers, such as carbon and glass fiberwere most popular as it could deliver high strength and stiffness, however its availability is limited and its price too high when comparedto natural fibers that are made from animal, mineral and plant. There is a demand in natural fiber compositesas it offers low cost, low density, recyclability, biodegradability, renewability and, most importantly, is environmentally friendly [4]. Cost savings outweigh high composite performance, which can be achieved with natural fiber for many applications.

In Malaysia, the natural fiber in abundance is oil palm fiber, which is reportedly around 1.8 million tons annually and recommended in terms of availability and cost [5,6]. The extensive studies on oil palm fiber composite show its potential as an effective reinforcement in thermosetting materials [7]. One section of oil palm fiber is Empty fruit Bunch (EFB). The abundance of EFB has reached a level that severely threatens the environment as it is commonlyburnt, but due to air pollution, this method has been discouraged. Furthermore, EFB gives insights of fiber tensile strength and low strength but conservative elastic modulus (impact characteristics), which is useful for engineering applicationsunder moderate loading conditions [6].

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Several parts are manufactured in the automotive industry and it is facing difficulties to generate fuel efficiency, cost effective, competitive and environmentally friendly products [13]. It is reported that the best way to increase fuel efficiency is by using fiber reinforced composite materials in the car body [14]. For composite materials made from renewable materials, the greatest advantage to be gained is of it being environmental friendly [15].

There are many methods used to manufacture composites, one of it is resin transfer molding (RTM) which succeeds in producing high quality laminates from dry preforms, however the weakness of it is the uncontrollable resin pressure and the need to have one rigid surface to produce composites [8]. This affects the product quality and it is hard to handle the process. Vacuum Resin Transfer Molding (VARTM) is a low-cost closed molding process with the capability to produce complex parts, which consists of a rigid base mold and a semi-rigid counter mold [9]. The choice of manufacturing process must consider the composite design structure as it depends on the type of matrix and fibers, temperature required to design the part, duration to cure the matrix and cost effectiveness of the process [10]. Light resin transfer molding (LRTM) is one of the liquid composite molding techniques that is considered attractive to obtain good quality polymer composite products with complex shapes and features [11]. Furthermore, combination of EFB and polyester composite using LRTM gives lower propensity for internal void formation, higher dimensional stability, reproducibility and lower material wastage compared to other manufacturing processes [12]. Developments of LRTM become more capable, versatile, and with less cost per-part. Composites that use LRTM will increase the freedom of manufacturing design and give more control to meet local design requirements. Thus, the objective of this study is to obtain the optimum parameter using ANOVA technique to fabricate EFB composite for impact purposes.

II. EXPERIMENT AND METHODS

A. Materials

Dry empty fruit bunch (EFB) taken from Malaysian Palm Oil Board (MPOB). The raw fiber with random orientation was coated with polyester resinReversol P 9565 mixed with 1% methyl ethyl ketone peroxide (MEKP).

B. Fabrication of composite

The EFB composite was fabricated using LRTM with three different EFB volume fractions; 0.08, 0.09 and 0.10. The fiber was placed in the LRTM mold size 304.8mm x 304.8mm in random orientation. The mold was clamped and resin injected into the mold. After the resin has coated all the fiber, the resin injection was stopped and the EFBis cured at room temperature for approximately 3hours.

C. Design of experiment method

Design-Expert Software has been used to create full factorial design to gain EFB composite optimum configuration factors on flexural strength and flexural modulus. Full factorial design is to design the experiment with level number limited to two or more for each factor. Combination between levels is counted during the experiment and determines the factor effectson the response and interaction effects between different factors [16]. Selection on appropriate model, statistical approach used to decide which polynomial fits the equation with linear model, two-factor model interaction model (2FI), fully quadratic model, or cubic model under Design-Expert software to the responses and it displayed progress measurement during calculation. Most studies use linear models to assess the independent and dependent factors. Equation1 showed behavior on dependent variables (response) of linear model [17].

$$yi = \beta_o + \sum_{j=0}^{n} \beta_j X_{ij} + \varepsilon_i \qquad (1)$$

$\beta o$is for observations, βj is unknown constant, J is the factor, n is the number of observations and $\varepsilon i$is independent random variables. However for non-linear models it comes in equation 2 which is important and necessary to consider an experimental design that allows one to fit the experimental data on quadratic model.

$$y = \beta_o + \sum_{j=1}^{n} \beta_i X_i + \sum_{j=1}^{n} \beta_{ii} X_i^2 + \sum_{i=1}^{n} \sum_{i<j=2}^{n} \beta_{ij} X_i X_j (2)$$

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D. Empty fruit bunch (EFB)composite

Raw empty fruit bunch (EFB) has been coated with polyester to become EFB composite. It has been done by using light resin transfer molding (LRTM) which is one of the latest molding techniquewith cost effectiveness process proposed by many researchers in manufacturing process [20]. The EFB composite wascut using CNC milling according to its thickness of 6mm, 10mm and 12mm and then itsmechanical properties were evaluated using Instron 3367 flexural test machine with 1mm/min rate. Flexural test is to obtain EFB composite modulus of elasticity in bending and flexural stress.

III. RESULTS AND DISCUSSION

A. Analysis design of experiment on EFB composite

Analysis of variance (ANOVA) was conducted on the collected data to investigate the main effects of LRTM resin pressure (*A*), EFB volume fraction (*B*) and EFB composite thickness (*C*), with three level interaction effects on the young's modulus and ultimate strengthas shown in Table 2. These A, B, C factors have been used by studies of Isoldi in 2013 [18].About 27 configurations of EFB compositehas been generated on full factorial design method using three factors with three levels and experimental results shown in Table 3.

Table 2. Three factors and three levels

Factor	Code	Unit	Level 1	Level 2	Level 3
LRTM Resin Pressure	A	Bar	1	1.5	2
EFB Volume Fraction	B	Vf	0.08	0.09	0.10
EFB composite thickness	C	mm	6	10	12

Table 3. The experimental results obtained based on full factorial design

Run	A	B	C	Young modulus (Gpa)	Ultimate strength (Mpa)
1	1.5	0.09	6	2.965	35.261
2	2	0.09	6	3.155	19.548
3	2	0.10	12	2.034	23.261
4	2	0.09	10	2.698	15.688
5	1	0.09	12	0.416	23.911
6	2	0.08	12	2.071	24.101
7	2	0.08	6	2.447	19.733
8	1.5	0.09	10	1.097	19.289
9	1	0.08	10	3.056	39.821
10	1.5	0.09	12	3.276	15.989
11	1.5	0.08	10	4.593	24.249
12	1	0.10	12	5.321	21.254
13	2	0.10	6	4.247	23.175
14	1.5	0.10	10	3.590	15.300
15	1.5	0.08	12	2.962	15.810
16	1	0.10	6	5.031	41.371
17	1	0.09	6	1.559	35.085
18	1	0.10	10	2.999	30.431
19	1	0.08	6	4.688	38.972
20	1.5	0.09	12	2.843	15.531
21	2	0.08	10	1.743	24.800
22	1	0.09	10	3.399	29.190
23	1.5	0.10	6	4.878	26.003
24	1	0.08	12	2.224	35.239
25	2	0.09	12	0.435	20.810
26	1.5	0.08	6	2.481	14.093
27	2	0.10	10	0.892	21.520

B. Analysis of Young's Modulus

From the analysis, it was found that there are two factors interaction model to give the best young's modulus. Displays of high R-square values of 0.4635, predicted R-square of 0.0222 were not really close to adjusted R-square of 0.3025 as one might normally expect. Adequate precision measures the signal to noise ratio. Ratio greater than 4 is considered desirable. Ratio for young's modulus is 6.252 whichindicates an adequate signal and model used to navigate the space of design. Anova analysis results for young's modulus is shown in Table 4. The probablity (Prob>F) for each reponse has been examined to ensure it is below 0.05. If the value stated ranges bigger than 0.05 or between less than 0.1 it might be significant or if it bigger than 0.1 it can only become not significant. Young's modulus model stated 99% confidence level and P- value less than 0.0345 which shows this model as highly significant.AnalysisP-value has been done by Shin in 2015 in the ANOVA results [19].Based on P-value LRTM resin pressure (A), EFB volume fraction (B) and EFB composite thickness (C) composite initiate to have significant effect on young's modulus. The values were declaredas not significant when greater then 0.1000. Each factor have F-value to simplify the ratio of mean squared deviations to mean squared errors for larger F-value means highly significants for young modulus.In Table 4, B is the most significant because of thehigher F-value 4.06 rather than A and

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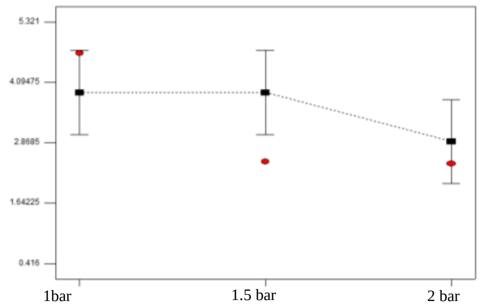
C which has F-value 2.31 and 2.27 respectively. Equation 3 showsthe two-factor interaction model for young's modulus.

$$\text{Young Modulus} = 2.86 + 0.33A_1 + 0.33A_2 + 0.063B_1 - 0.79B_2 + 0.64\,C_1 - 0.18C_2 \quad (3)$$

Table 4. Analysis of variance (ANOVA) young modulus

Source of data	Sum of square	Degree of freedom	Mean square	F-value	Prob> F	Comment
Model	22.9	6	3.72	2.88	0.035	significant
A	5.96	2	2.98	2.31	0.1253	
B	10.48	2	5.24	4.06	0.0331	
C	5.86	2	2.93	2.27	0.1294	

The main effect on young's modulus plot that has been influencedby A (resin pressure), B (EFB volume fraction) and C (EFB composite thickness). In figure 1 young modulus demonstrate to be decrease with increasing of resin pressure and the thickness of EFB composite. However, the value of young modulus increased with increasing of EFB volume fraction.



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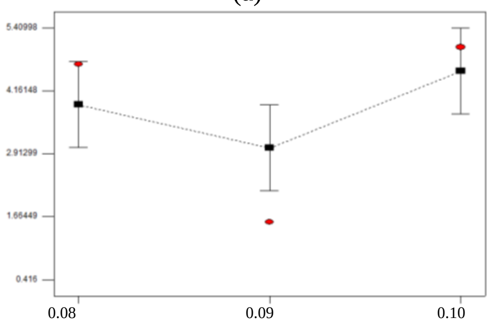

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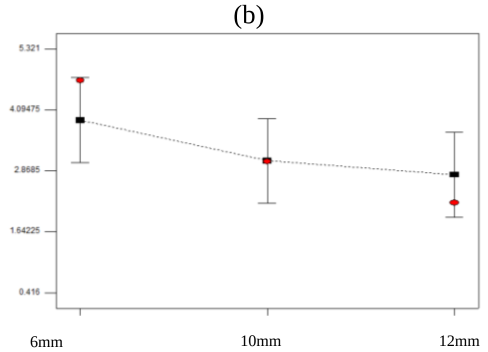

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Fig 1 a) Young Modulus vs LRTM resin pressure b) Young modulus vs EFB volume fraction c) Young modulus vs EFB composite thickness.

C. Analysis of Ultimate Strength.

Analysis of ultimate strength is similar to analysis of young's modulus which shows that two factors interaction (2FI) model is the best. R square values have been displayed as 0.9374, predicted R-square become 0.2867 which is far value form adjusted R-square 0.7965. This is because the standard derivation low is about 3.69. The adequate precision which is 9.154 gives good agreement to navigate the design as it actually indicates satisfactory value in terms of signal and model. Table 5 demonstrates the summary analysis on ultimate strength similar to the analysis ofKadir in 2016 [17]. Similar parameters which is LRTM resin pressure (A), EFB volume fraction (B) and EFB composite thickness (C) has been used in the analysis of young's modulus and the major effect is in ultimate strength with P-value 0.05. If the value ranges more than 0.05 or between less 0.1 it might be significant or if it bigger than 0.1 it can become not significant. LRTM resin pressure in ultimate strength showed most significant parameter with F-value 32.09, followed by EFB composite thickness (C) with F-value 6.76 and EFB volume fraction (B) with F-value 1.18. However interaction AB, AC and BC gives lower F-value in ultimate strengthparameters. Equation 4 is the proposal model for ultimate strength analysis.

$$\text{Ultimate strength} = 24.79 + 8.01A_1 - 4.62A_2 + 1.52B_1 - 0.98B_2 + 3.34\,C_1 - 0.32C_2 + 3.68A_1B_1 - 3.64A_2B_1 - 2.43A_1B_2 + 4.17\,A_2B_2 + 2.32\,A_1C_1 + 1.61\,A_2C_1 + 0.66\,A_1C_2 - 0.24\,A_2C_2 - 5.39\,B_1C_1 + 2.81\,B_2C_1 + 3.63\,B_1C_2 - 2.11\,B_2C_2 \quad (4)$$

Table 5. Analysis of variance (ANOVA) Ultimate Strength

Source of data	Sum of square	Degree of freedom	Mean square	F-value	Prob> F	Comment
Model	1630.52	18	90.58	6.65	0.0051	significant
A	873.96	2	436.98	32.09	0.0002	
B	32.04	2	16.02	1.18	0.3565	
C	183.99	2	91.99	6.76	0.0191	
AB	174.58	4	43.65	3.21	0.0755	
AC	161.16	4	40.29	2.96	0.0896	
BC	204.78	4	51.20	3.76	0.0525	

The main effect on young's modulus plot has been influencedby A (LRTM resin pressure), B (EFB volume fraction) and C. In figure 2 young's modulus decrease with increasing LRTM resin pressure and EFB composite thickness, different to the research by Manjunath in 2017 which observed that fracture toughness decreases when thickness increases[20]. However, the value of young's modulus increased

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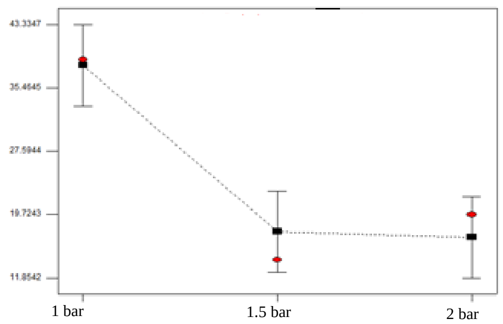
with increasing EFB volume fraction. Furthermore, the interaction of AB, AC and BC in figure 3 of young's modulus decrease with increasing resin pressure and thickness of EFB composite. However, the value of young's modulus increased with increasing of EFB volume fraction.



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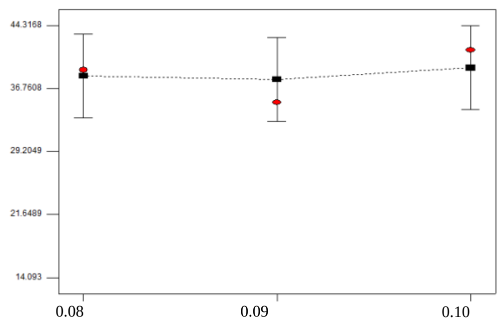

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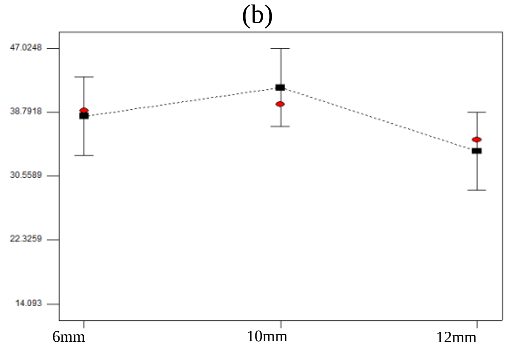

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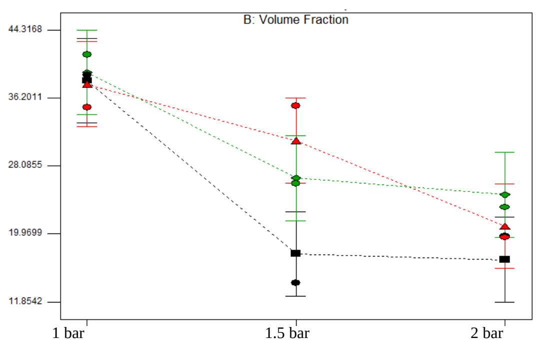
Fig. 2 a) Young Modulus vs LRTM resin pressure b) Young modulus vs EFB volume fraction c) Young modulus vs EFB composite thickness.



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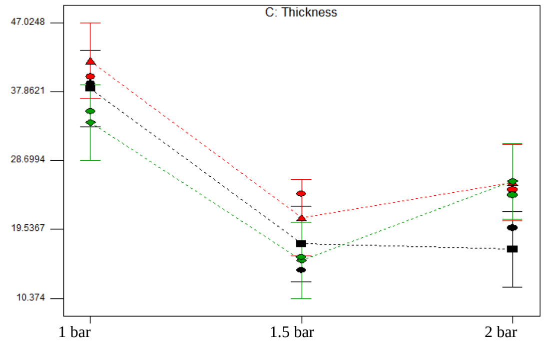

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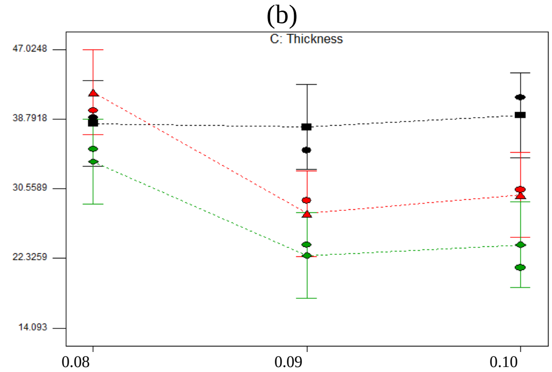

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Fig 3 shows the interaction graph AB, AC, BC a) Young Modulus vs LRTM resin pressure and EFB volume fraction b) Young modulus vs LRTM resin pressure and EFB composite thickness c) Young modulus vs EFB volume fraction and EFB composite thickness.

D. Optimization parameter of EFB composite

Based on the result LRTM resin pressure, EFB volume fraction and EFB composite thickness were found to havesignificant effect on the young's modulus and ultimate strength. Young's modulus and ultimate strength factors shows that decreasing it will increase the LRTM resin pressure and EFB composite thickness. EFB volume fraction appeared in the minimum point with the highest value of responses obtained however the LRTM resin pressure and EFB composite thickness appeared at the maximum point within the range of study. At the end of Anova analysis in Table 6 the results show the optimum configuration of the EFB composite on young's modulus and ultimate strength range of this study. The configuration is 1 bar LRTM resin pressure, 0.10 EFB volume fraction and 6mm EFB composite thickness. Furthermore this optimum configuration for all the samples has been evaluated through graph stress – strain analysis on the behavior of EFB composite. Stress (Mpa) increases until the peak and it starts to decrease with increasing strain (mm/mm). The graph in Figure 4a shows the highest stress on 1 bar resin pressure, which is agreed by Hutchinson in 2015 which stated using low resin pressure approximately less than 2 bar is able to

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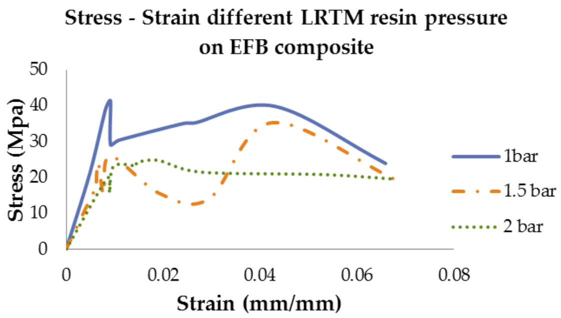
produce greater strength [21]. Furthermoregraph 4b shows that increasing volume fraction of EFB will increase its stress strength, and this is agreed by Karina et al in 2008 who mentioned in her studies that EFB composite with polyester will increase its stress strength if there is a high volume fraction of EFB in the composite [22]. Graph 4c stated the lower thickness will increase its strength, and this was agreed by Morales in 2010 who developed a plane part of 4 mm thickness with higher stress [23].

Table 6. Determine the Optimum Configuration Of EFB Composite

Run	Resin Pressure (bar)	Volume fraction	Thickness (mm)	Young Modulus, E	Ultimate Strength, σ	Desirable
1	1	0.10	6	4.55689	39.2694	0.883 Selected
2	1	0.08	6	3.88989	38.2873	0.793
3	1	0.08	10	3.06944	41.9774	0.736



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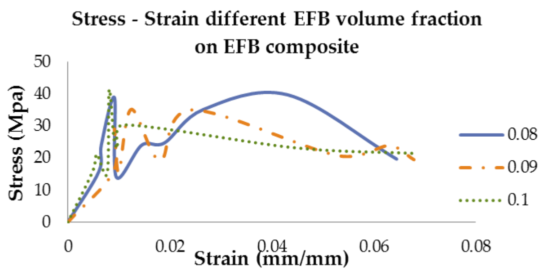

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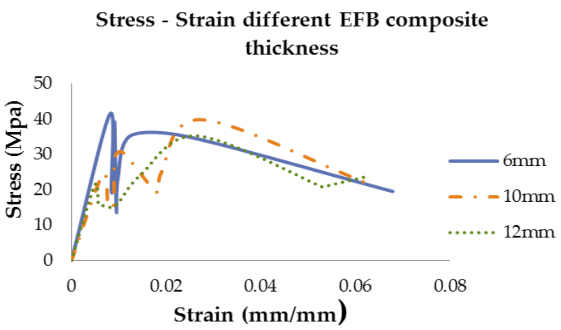

(c)

Fig 4 Graph stress – strain behavior on EFB composite parameter (a) LRTM resin pressure b) EFB volume fraction (c)EFB composite thickness

Verification on the young's modulus optimized value which is 1 bar LRTM resin pressure, 0.10 EFB volume fraction and 6mm EFB composite thickness show the first result of approximately 18.30% error. However,the second result which is 1 bar LRTM resin pressure, 0.08 EFB volume fraction and 6mm EFB composite thickness show about 19.13% error. Table 7 shows verification on the young's modulus.

Table 7. Verification optimized value for young modulus, E

Run	Resin Pressure (bar)	Volume fraction	Thickness (mm)	Model Value	Experiment Value	Error
1	1	0.10	6	4.55689	5.391	18.30%
2	1	0.08	6	3.88989	5.429	19.13%

Ultimate strength verification has been optimized which are 1 bar LRTM resin pressure, 0.10 EFB volume fraction and 6mm EFB composite thickness which show the first result of approximately 5.74% error. But the second result of 1 bar LRTM resin pressure, 0.08 EFB volume fraction and 6mm EFB composite thickness show about 5.42% error. The verification of ultimate strength is in Table 8.

Table 8. Verification of optimized value ultimate strength , σ

Run	Resin Pressure (bar)	Volume fraction	Thickness (mm)	Model Value	Experiment Value	Error
1	1	0.10	6	39.2694	41.524	5.74%
2	1	0.08	6	38.2873	40.363	5.42%

IV. CONCLUSION

This study is to apply valuable concept of experimental design methodology to achieve EFB composite optimum configuration using ANOVA technique. There is more to investigate the influencingfactors of LRTM resin pressure, EFB volume fraction and EFB composite thickness. Results expose that all factors actually deliver significant effect, however LRTM resin pressure and EFB composite thickness are the most influential ones on the EFB composite performance. The optimum configuration is 1 bar LRTM resin pressure, 0.10 EFB volume fraction and 6mm EFB thickness for EFB composite. It has been evaluated through its young's modulus and ultimate strength results achieved from three point bending test.

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