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# Process Parameter Interaction Study for Epoxy/Kenaf Composites Preparation via Two-Level Full Factorial Approach

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**ABSTRACT**

This study was conducted to understand the interaction involved between the process parameters of the solution mixing for the preparation of epoxy/kenaf composites via two-level full factorial approach. There are three (3) independent variables which are the kenaf fibre loadings (-5.00 wt.%; +35.00 wt.%), stirring period (-10.00 mins; +50.00 mins) and the stirring speed (-100 *rpm*; +700 *rpm*), involved in this work. A set of $2^3$ full factorial design with three replications at a center point and no block was applied to yield a total of 11 set of experiments. The DesignExpert 6.0.8 statistical software has optimized the resulted tensile strength (TS) response as dependent variable of prepared epoxy/kenaf composites. It was found that the optimum processing parameter are at 100 *rpm* of stirring speed, 10 mins of the stirring period and about 5.00 wt.% of the kenaf fiber loading, with the highest coeficient of determination $R^2$ value of 99.9%. Fracture surface morphological observation via SEM has been performed to correlate further the interaction between the processing variables toward an optimum resulted TS response. In overall, this study has significance to facilitate manual processing of natural fiber based epoxy composite started at the early integration between the kenaf fiber as reinforcement phase and epoxy as the matrix phase, using a high speed mechanical stirrer apparatus.

***Keywords:***
Full Factorial, Interaction Study, Kenaf Fiber, Epoxy, Solution Mixing, High Speed Mechanical Stirrer, Optimization

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## 1. Introduction

Initially, the mechanical mixing by high speed stirring method has widely used in every common thermoset based polymer composites preparation, in order to control the dispersion of filler within

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the matrix phase [1-2]. This method allows for the formation of higher velocities and strong turbulence within the solution mixture, that desirable for efficient filler segregation in the matrix system [3]. However, according to Sallem et al. (2017), the stirring was an important experimental variable that has not been enough explored, particularly for the case of natural fiber based reinforced thermoset polymer composites [4]. Up till now, limited or no available optimization work has been done to establish the mechanical stirring processing parameter relationship and their interaction to the resulted composite properties. In composite development, it was very critical to optimize the processing parameters involved for optimum resulted performances as for future reference and design guideline. Hence, in this study, the high speed mechanical mixing stirrer apparatus was utilized for solution mixing between the kenaf fiber and epoxy matrix for epoxy/kenaf composites preparation. The interaction between the independent processing variables of high speed mechanical stirring process into the dependent resulted tensile strength response was established in this work. The tensile strength has been selected as a main response because the fracture mechanism due to the tensile test was generally portrayed the overall strength performance down to the macromolecular level.

The natural fiber is drawing considerable attention as an alternative replacement for synthetic filler of composite applications, due to their cost efficiency, sustainability and comparable performances. Among various type of natural fibers for composite applications, kenaf was selected in this study because of convenient and abundant availability in Malaysia than other types of natural fibers [5]. Kenaf has considered as tropical climate crop with profuse usability. However, this fiber possessed low tolerance to heat and moisture [6]. It also requires precise surface modification via chemical treatment to enhance the resulted matrix-filler interphase and interface interaction. In addition, due to the sustainability issue in material revolution, natural fiber like kenaf has always been selected, as a way forward to promote the utilization of green materials for many demanding engineering applications.

Epoxy possessed various attractive characteristics of high adhesion to many substrate, good chemical, corrosion and electrical resistance properties. However, epoxy is easily flammable and relatively poor resistance to crack initiation, higher brittleness and notch sensitivity, which limits their usage for many applications [7]. Hence, in many recent works, researchers are trying to improve an epoxy resin performance by incorporating it with thermoplastic fillers, rubber agents, diluents and nanoparticles as well as natural fibers [8]. In this study, kenaf natural fiber was incorporated with the epoxy through an optimized solution mixing method, to produce the epoxy/kenaf composites.

The kenaf reinforced epoxy composites tends to show variability in terms of their resulted properties, depending on the type of kenaf fibre, fibre orientation, fibre content, fibre form, fibre length, processing method, sample dimension, and the type of blending formulations [9, 10]. There are several concerns that must be emphasized when dealing with natural fibre kenaf as the reinforcement in composite research. Naturally, natural fibres are consisted of large amount of hydroxyl group. This functional group made natural plant based fibre polar and exhibits hydrophilic properties. Therefore, kenaf fibres wall possesses major limitations in respect to moisture, ultraviolet radiation, environmentally fungal and thermal sensitivity. The hydrophilic characteristics of kenaf fibres could cause poor fibre-matrix adhesion due to presence of hydroxyl and polar groups in their surfaces [11]. Since an epoxy matrix is hydrophobic in nature, when these two dissimilar phases are mixed together they had resulted into poor wettability, non-uniform fibre dispersion and inferior fibre-matrix interfacial interaction. Later, the resulted composite is poor in term of their mechanical performance [12, 13].

Hence, this study took the initiative to optimize the preparation of kenaf/epoxy composites by using the statistical experimental approach, utilizing the two-level full factorial statistical design. By performing this method, the interaction between factors towards the response studied was established. Through conventional experimental approach of one factor at a time, this interaction study between independent factors and dependent response are made impossible [14, 15].

## 2. Methodology
### *2.1 Materials*

In this study, the kenaf/epoxy composites were made from kenaf (*hibiscus cannabinus*) fiber as reinforcement phase and epoxy resin as the matrix phase. All chemicals are used as purchased without further purification steps. Thermoset epoxy resin consists of liquid epoxy part (CP360A) and hardener part (CP360B) was supplied by Terrra Techno Engineering (Malaysia) Sdn.Bhd. In specific, this epoxy grade possessed the pot life of 3 hrs, cure time of 7 hrs in total, and the final hardness achieved at 24 hrs. The weight ratio of epoxy into hardener was maintained at 2:1 of formulation ratio for all the prepared epoxy/kenaf composites.

Raw kenaf fiber was supplied by Lembaga Kenaf & Tembakau Negara (LKTN). The kenaf core fibre was milled with a rotary mill machine into chopped kenaf powder. The kenaf fibre was then sieved by using the vibratory sieve shaker (Fritsch, Analysette 3) at 90 µm mesh size range. As to confirm the size of grinded kenaf, the scanning electron microscope (SEM) observation was performed by using the Zeiss Evo 50 SEM, which operated at 5.00 kV of the accelerating voltage. Prior to that, the kenaf fiber was dried in a drying oven at the temperature of 80°C within 100 mins. Later, the dried kenaf powder was adhered on the carbon tape that was mounted on an aluminum stub for gold-palladium thin coating, using a sputter coater model SC7620 brand Quarom to eliminate the possibility of charging effects during the observation, which prone to reduce the quality of SEM images.

### *2.2 Epoxy/Kenaf Composite Samples Preparation via DOE Approach: Experimental Planning and Testing*

For epoxy/kenaf composites samples preparation, pre-experimental planning was designed by using a statistical software namely as Design Expert® Software (Statistics Made Easy, version 6.0.8 Portable, Stat-Ease, Minneapolis, US.). A two-level full factorial design of experiment was utilized in this study. A $2^3$ full factorial design for three independent variables, with three replications at centre point and no blocks were implemented to yield a total of 11 sets of experiments. The independent variables of kenaf fibre loading *(A),* stirring time *(B),* and stirring speed *(C)*, with a range of 5-35 wt. %, 10-50 mins and 100-700 *rpm*, respectively, were applied. The selected range of each independent variable are basically determined from the trial and error experiment and the processing equipment limitation. The levels of independent variables are represented in the following Table 1. The factorial designs of experiments for all the parametric combinations are listed in Table 2. The dependent variables tested in this study has focussed particularly on the tensile strength property, coded as $R_1$ response.

For the preparation of epoxy/kenaf composites in accordance to the Table 2 strategy, the kenaf powder was mixed into epoxy resin by using the mechanical overhead stirrer at a speed of 100 *rpm* for 10 mins of stirring duration. Then, the mixtures were put in a vacuum oven for 15 mins duration at a pressure of 0.04 MPa and temperature of 27°C for degasification purpose. The degasification process was crucial in order to remove entrapped air and moisture during the composite fabrication. Hardener agent CP360B was then poured into the mixture with ratio of 100:50 (epoxy: hardener) and continue stirred for another 15 mins at a constant speed of 100 *rpm*.

Next, the after-stirred mixture was then placed in a vacuum oven for five mins with similar previous condition. Lastly, the mixture was poured into silicon rubber mould and cured for 120 mins at 110°C in a drying oven. Later, all specimens were post-cured at ambient temperature for a week prior of conditioning stage, sample cutting and subsequent performance testing. The following Figure 1 has summarized an overall process flow involved in the preparation of epoxy/kenaf composites.

**Table 1**
The level of variables chosen for experimental run

| Kenaf Fibre Loading (A, wt. %) | Stirring time (B, mins) | Stirring speed (C, rpm) |
|---|---|---|
| 5 (-1) | 10 (-1) | 100 (-1) |
| 20 (0) | 30 (0) | 400 (0) |
| 35 (+1) | 50 (+1) | 700 (+1) |

For mechanical tensile test, the Universal Testing Machine (UTM) from an Instron 5969 that equipped with a maximum of 50 kN load cell was used. Tensile testing was conducted in conformity to ASTM D3039-14 with a crosshead rate of 2.00 mm/min and the testing was performed at a constant temperature of 25 °C and humidity level at 50 %. At this stage, the combination of the best stirring parameter of stirring period and stirring speed with an optimum kenaf fibre loading was determined from the statistical analysis on the basis of the best resulted tensile strength response.

**Table 2**
Sample formulation of epoxy/kenaf composite by *Design Expert-6.0.8*

| **Experiment Number** | **Factor A: Kenaf fibre loadings (wt. %)** | **Factor B: Stirring time (mins)** | **Factor C: Stirring speed (rpm)** |
|---|---|---|---|
| 1 | 5 | 10 | 100 |
| 2 | 35 | 10 | 100 |
| 3 | 5 | 50 | 100 |
| 4 | 35 | 50 | 100 |
| 5 | 5 | 10 | 700 |
| 6 | 35 | 10 | 700 |
| 7 | 5 | 50 | 700 |
| 8 | 35 | 50 | 700 |
| 9 | 20 | 30 | 400 |
| 10 | 20 | 30 | 400 |
| 11 | 20 | 30 | 400 |

*2.3 Fractured Surfaces Morphological Observation of Epoxy/Kenaf Composites*

For tensile fractured surface morphological observation, the scanning electron microscope (SEM), model Zeiss Evo50 was utilized. The observation using SEM was performed at 5.00 kV of an accelerating voltage. The fractured surface of selected epoxy/kenaf composite was cut and mounted on an aluminium stub with carbon tape prior of palladium-gold coating to eliminate the electrostatic charging effects. From the SEM observation, the fracture surfaces morphological feature of fibre-matrix interface and fracture mode were evaluated further.

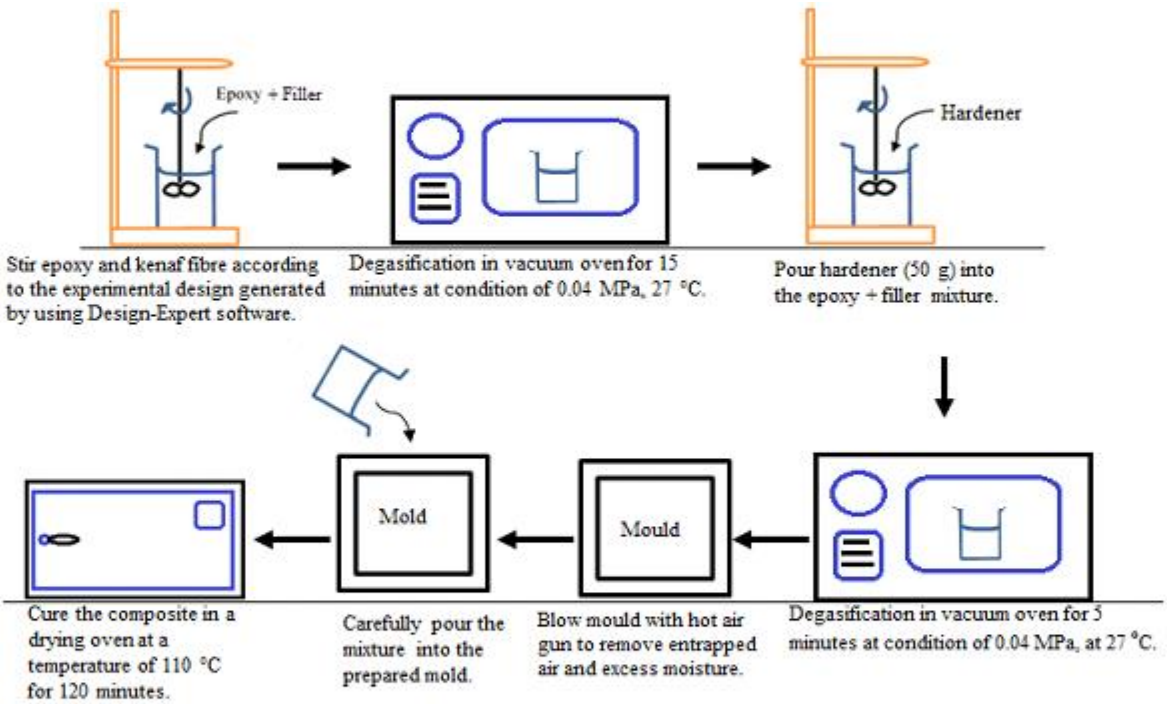



**Fig. 1.** Schematic diagram for epoxy/kenaf composites preparation steps

## 3. Results

### *3.1 Characterization on Kenaf Natural Fiber Size and Shape using SEM Observation*

The following Figure 2 depicts the SEM observation for grinded kenaf fiber at 100x of magnification. About nine measurements were randomly taken for kenaf fiber length size. The mean value was calculated for averaged result, which about 90.83 µm. The kenaf fiber sizes were particularly varied within ~90.00 µm in accordance to the sieve size used and there are inhomogeneity in their shape and geometrical feature. The inconsistency in the surface texture and shape of kenaf fiber has basically important in influencing the filler-matrix interaction of epoxy/kenaf composites.

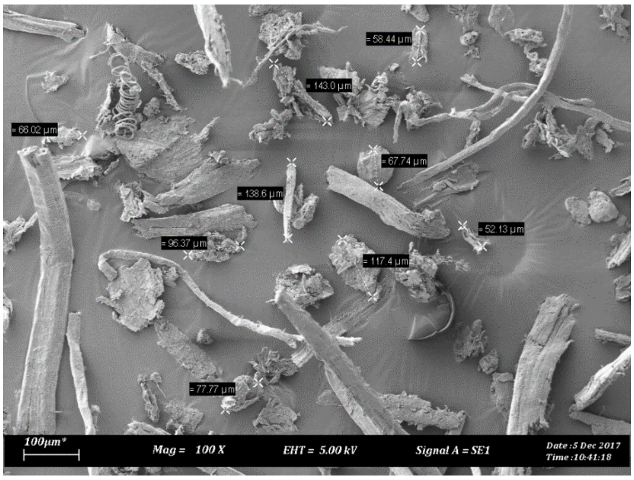



**Fig. 2.** SEM micrographs of raw grinded kenaf fibre (mag: 100x)

### 3.2 Tensile Strength Analysis of Epoxy/Kenaf Composites

Table 3 has tabulated about eleven (11) set of experimental design with different parametric combination of kenaf loading (A), stirring time (B) and stirring speed (C), for epoxy/kenaf composites preparation by using a $2^3$ two-level full factorial design strategies. The experimental design was generated from the Design-Expert 6.0.8 software. The experimental design was analysed by focusing to only one response, which was tensile strength of produced epoxy/kenaf composites. The real values of coded factor are listed in the following Table 4. The negative one (-1) is denoted for the minimum range, zero (0) is indicated as centre point and positive one (+1) is for the maximum range of each parameter.

**Table 3**
Parametric combination for epoxy/kenaf composites preparation by using $2^3$ two-level full factorial design strategies

| Experiment | Kenaf Fibre Loading [A], wt. % | Stirring time [B], mins | Stirring speed [C], *rpm* |
|---|---|---|---|
| 1 | -1 | -1 | -1 |
| 2 | +1 | -1 | -1 |
| 3 | -1 | +1 | -1 |
| 4 | +1 | +1 | -1 |
| 5 | -1 | -1 | +1 |
| 6 | +1 | -1 | +1 |
| 7 | -1 | +1 | +1 |
| 8 | +1 | +1 | +1 |
| 9 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 |

**Table 4**
Selected level of variables for epoxy/kenaf composites preparation

| Kenaf fibre loading (wt. %) | Stirring time (mins) | Stirring speed (*rpm*) |
|---|---|---|
| 5 (-1) | 10 (-1) | 100 (-1) |
| 20 (0) | 30 (0) | 400 (0) |
| 35 (+1) | 50 (+1) | 700 (+1) |

The results were averaged from five (5) tested samples of each respective experimental design at different parametric combination. The results had revealed that, at the highest kenaf content of 35 wt. %, extended duration of stirring time at 50 mins and at maximum stirring speed of 700 *rpm*, the tensile strength respond had decreased, dramatically. This event has proven by the experiment 2, 6 and 8. Meanwhile, the tensile strength for experiment 4 was about 22.118 MPa which considerably higher as compared than the highest tensile response from experiment 1 which was 27.257 MPa. The result shows that, at higher kenaf content in epoxy matrix requires longer stirring period and must be stirred at lower stirring speed, to produce a better tensile strength performance. Ghosh et al. (2015) have proved that the higher stirring speed might cause degradation of epoxy matrix due to high heat generation especially, at the region of mechanical stirrer blade, which diminished the strength of the resulted epoxy/kenaf composites [16]. In contrast, researchers has found that at increased rotational speed, the agglomerated particle can be dispersed well [2, 17]. This could be the best reason to explain the tensile strength improvement for samples that produced at higher stirring speed of mechanical stirring mixer.

Half normal plot of tensile strength response generated from two-level full factorial design of experimental approach was depicted in the following Figure 3. From the effects (factorials) result, it can be seen that factor A (kenaf fibre loadings), B (stirring time) and C (stirring speed) as well as the interaction term between BC, AC, ABC and AB were positioned away from the straight line, indicating the significant terms of this experiment. The farther the individual term or interaction term from the half normal plot, the higher the contribution of the term or interaction term towards the response studied. Next, all model terms were chosen to be analysed through analysis of variance (ANOVA) test.

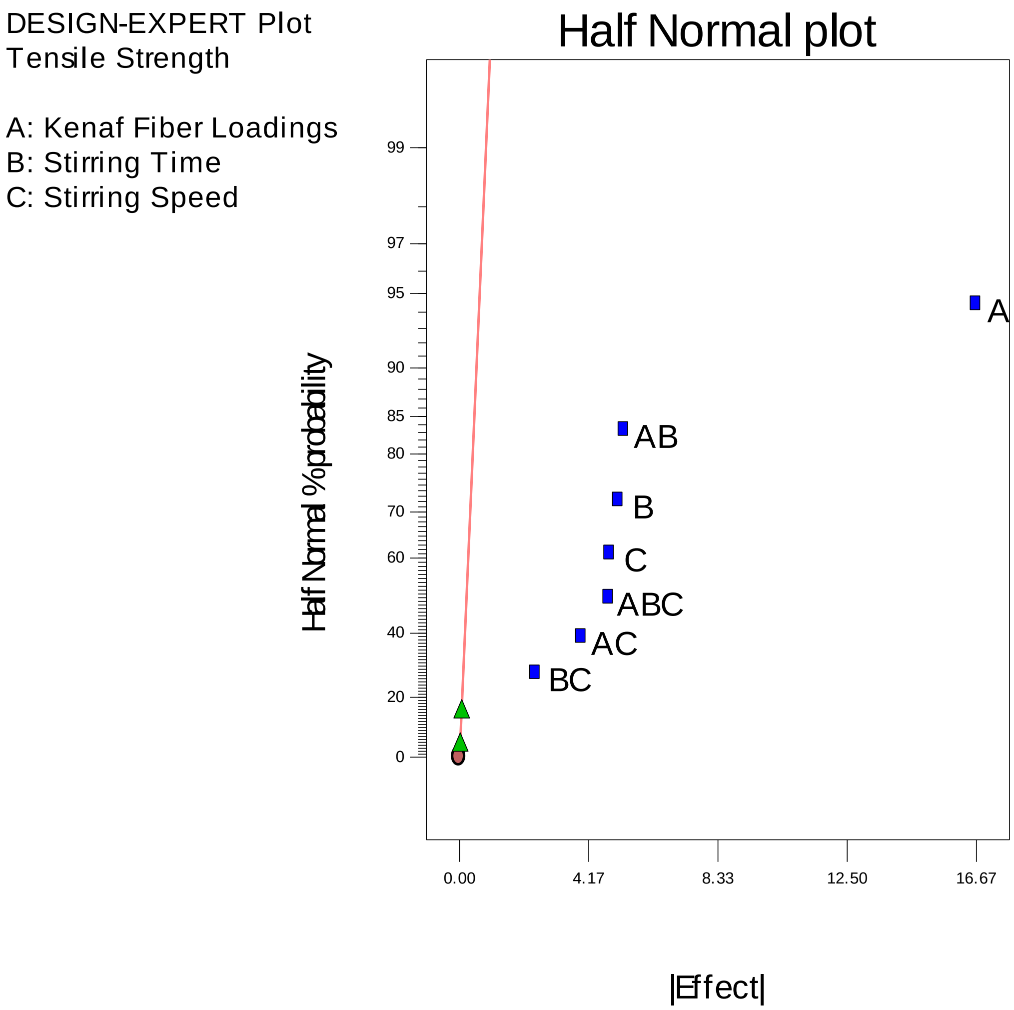



**Fig.3.** Half normal plot of epoxy/kenaf composite tensile strength response

Figure 4 represents a residual versus predicted plot of tensile strength response. Montgomery (2013), has stated that if the regression model was correct and the assumptions has fully satisfied, the residuals should be non-structured and not related to other factors including the predicted response [18]. As in plotted residuals versus predicted in Figure 4, there are no unusual structure was noticed. This plot was appeared satisfactory and had no problem with the validity of performed experimental works.

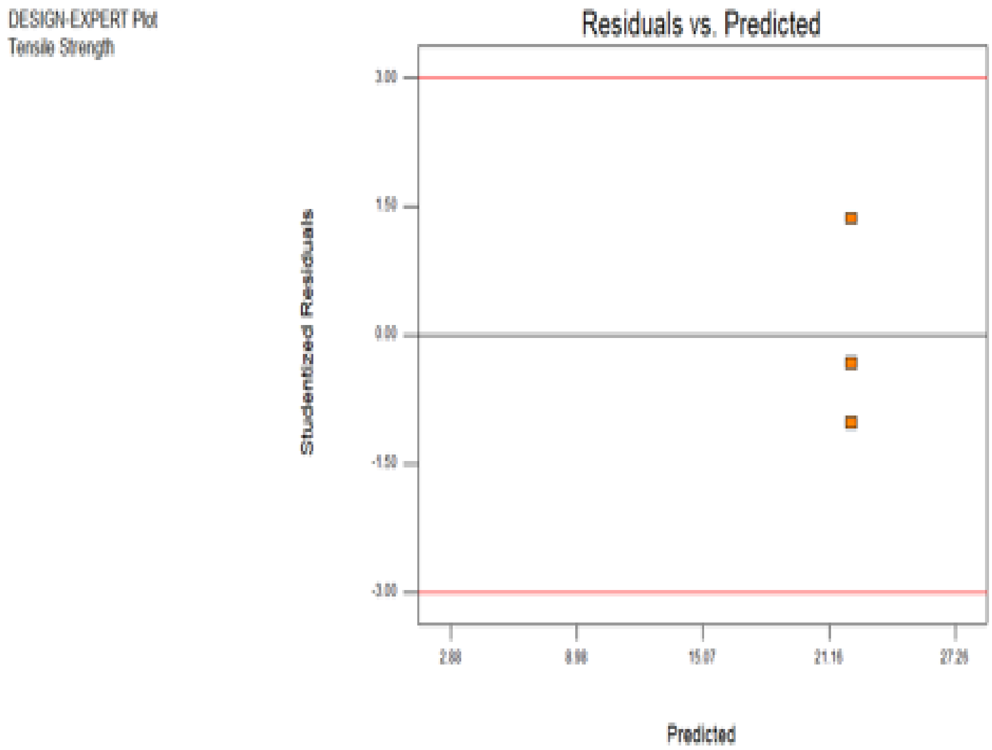



**Fig. 4.** Plot of residuals versus predicted tensile strength response for epoxy/kenaf composite

The details on effects list of all model and interaction terms were listed as in Table 5. From the effects list, it was noticed that the highest percentage of contribution on tensile strength response was contributed by the kenaf loading (factor A) of variable parameter. This result has revealed that the factor A was the most significance factor with 64.78 % of contribution on the studied response with 555.56 of sum of squares (SS). Factor B and C shows lower contribution on the response with only about 6.14% and 5.49%, respectively. The individual factor A and C as well as interacted factor between AC, BC and ABC had exhibited a negative Studentized effects. This event suggests that a decreasing pattern of A and/or C from the higher level to lower level will increase the tensile strength response.

**Table 5**
The effect list of model terms for epoxy/kenaf composite

| Term | Studentized Effects | Sum of Squares | % Contribution |
|---|---|---|---|
| A | -16.67 | 555.56 | 64.78 |
| B | 5.13 | 52.67 | 6.14 |
| C | -4.85 | 47.08 | 5.49 |
| AB | 5.31 | 56.46 | 6.58 |
| AC | -3.94 | 31.04 | 3.62 |
| BC | -2.46 | 12.07 | 1.41 |
| ABC | -4.82 | 46.55 | 5.43 |

The following Eq. 1 shows the linear equation that has been developed by Design Expert Software, to relate the input variable parameters interaction to the tensile strength response of the tested epoxy/kenaf composite. The regression equation for the response was coded as *R1*, obtained after the analysis of variance gives the tensile strength (MPa) as a function of different variables of; kenaf loading (A, wt. %), stirring time (B, minutes) and stirring speed (C, *rpm*). The regression model was consisted of one offset, three interacted terms and four linear correlations. The final equation *(R1)* in terms of coded factors were presented as in Equation 1. The regression coefficient values in Equation 1 are calculated from the mentioned software and the values were listed in the following Table 6.

$$\text{Tensile Strength (MPa)}, R1 = +17.19 - 8.33{*}A + 2.57{*}B - 2.43{*}C + 2.66{*}A{*}B - 1.97{*}A{*}C - 1.23{*}B{*}C - 2.41{*}A{*}B{*}C \quad (1)$$

**Table 6**
Regression coefficient calculated from the model *(R1)*

| Variables | From Equation (4.1) | Coefficient |
|---|---|---|
| $X_o$ | $X_o$ | 17.19 |
| $X_1$ | $X_1A$ | -8.33 |
| $X_2$ | $X_2B$ | 2.57 |
| $X_3$ | $X_3C$ | -2.43 |
| $X_{12}$ | $X_{12}A{*}B$ | 2.66 |
| $X_{13}$ | $X_{13}A{*}C$ | -1.97 |
| $X_{23}$ | $X_{23}B{*}C$ | -1.23 |
| $X_{123}$ | $X_{123}A{*}B{*}C$ | -2.41 |

**Table 7**
ANOVA of experimental data for epoxy/kenaf composites

| Source of variation | Sum of Squares | DF | Mean Square | $F_o$ | P-Value |
|---|---|---|---|---|---|
| Model | 801.42 | 7 | 114.49 | 543.70 | 0.0018 |
| A | 555.56 | 1 | 555.56 | 2638.34 | 0.0004 |
| B | 52.67 | 1 | 52.67 | 250.13 | 0.0040 |
| C | 47.08 | 1 | 47.08 | 223.58 | 0.0044 |
| AB | 56.46 | 1 | 56.46 | 268.13 | 0.0037 |
| AC | 31.04 | 1 | 31.04 | 147.39 | 0.0067 |
| BC | 12.07 | 1 | 12.07 | 57.33 | 0.0170 |
| ABC | 46.55 | 1 | 46.55 | 221.05 | 0.0045 |
| Curvature | 55.73 | 1 | 55.73 | 264.64 | 0.0038 |
| Error | 0.42 | 2 | 0.21 | | |
| Total | 857.57 | 10 | | | |

**Table 8**
Statistical model summary of the tensile strength response for epoxy/kenaf composites (Screening experiment)

| Statistical Results | Value |
|---|---|
| Standard deviation | 0.46 |
| *R*-Squared | 0.9995 |
| Adjusted *R*-Squared | 0.9976 |
| Adequate Precision | 58.724 |

Analysis of Variance (ANOVA) was conducted to predict the statistical significance of process parameters and it helps to determine the effect of input parameter on the output response [19]. In this case, it was used to determine the significance effect and contribution of each variables factor on the tensile strength response of the tested epoxy/kenaf composites. A single factor or interacted factors with high importance will show a higher percentage of contribution in relation to other factors in study. This occurance has indicated that the paramater gives higher effect toward the response studied.

The following Table 7 has presented the results of statistical ANOVA for the tensile strength response (R1) of epoxy/kenaf composites. Model *F*-value ($F_o$) of 543.70 implied that the model was significant. There were only 0.18% of chance that the model *F*-Value could occur due to noise. Prob > *F* or *P-values* that were less than 0.05 indicate that the model terms were significant in which model terms A, B, C, AB, AC, BC and ABC are all significant. Curvature *F*-value of 264.64 has implied that there was significant curvature (measured by difference between average of the center points and average of the factorial points) in design space. There was only 0.38% of possibility that the Curvature F-value could occur due to noise. There is no Lack-of-Fit value in this study. This result has implied that the experiment was perfectly conducted without any suggested error by the DOE software.

Three-dimensional response surface contour plot was utilized to interpret and evaluate the produced statistical model as depicted in Figure 5 (a) and (b). The surface plot of the tensile strength response was based on the regresses of kenaf loading (A, wt. %), stirring period (B, mins) and stirring speed (C, *rpm*). The interaction of two factors through response surface plot has helped to understand and to locate the optimum level between of the results. From the response surface plot, the tensile strength response value was escalated to the highest of 27.257 MPa at decrease of kenaf content (factor A). These facts were proven in Figure 5 (a), as the tensile response increased remarkably with less content of kenaf fibre added into produced epoxy based composites. Conversely, there was opposite correlation existed between the stirring periods (factor B) and stirring speed (factor C). The independent factors were corresponded to decrease the tensile strength response, substantially with the increase of either one of the factors. At 100 *rpm* of stirring speed, the longer the stirring period, the tensile strength has dramatically decreased. At 10 mins of stirring time, the faster the stirring speed, the tensile strength was also sharply declined. The tensile strength has increased substantially as factor B and factor C rise up in sync to the maximum range.

Optimization strategy that are recommended by the DOE software were tabulated in the following Table 9, whereas the optimum recommendations were presented in the following Table 4.10. Referring to Table 4.9, the factors were optimized as follows: kenaf loading (factor A) = 5 wt. %; stirring time (factor B) = 10 mins, and; stirring speed (factor C) = 100 rpm, with suggested optimized result of 27.2569 MPa. The goal of this optimization was fixed into “is in range” for all independent variable factors and “is maximum” for the tensile strength dependent response. Meanwhile in Table 10, there are about nine possible optimization suggestion were recommended with higher desirability of the corresponding tensile strength response. First recommendation with desirability of one (unity) was selected for further validation test, which represents as the most desirable solution for maximum tensile strength response. The selected solution were 5 wt. %, 10 mins and 100 rpm for kenaf loading, stirring time and stirring speed, respectively. The desirability result has approached unity value of one which denoted that all analysed factors are fully significant and should not be neglected. Other recommendation solutions also can be employed to acquire the similar result with less desirability value and presence of residual. In this study, the first solution that has been suggested by the software was further used for validation purpose.

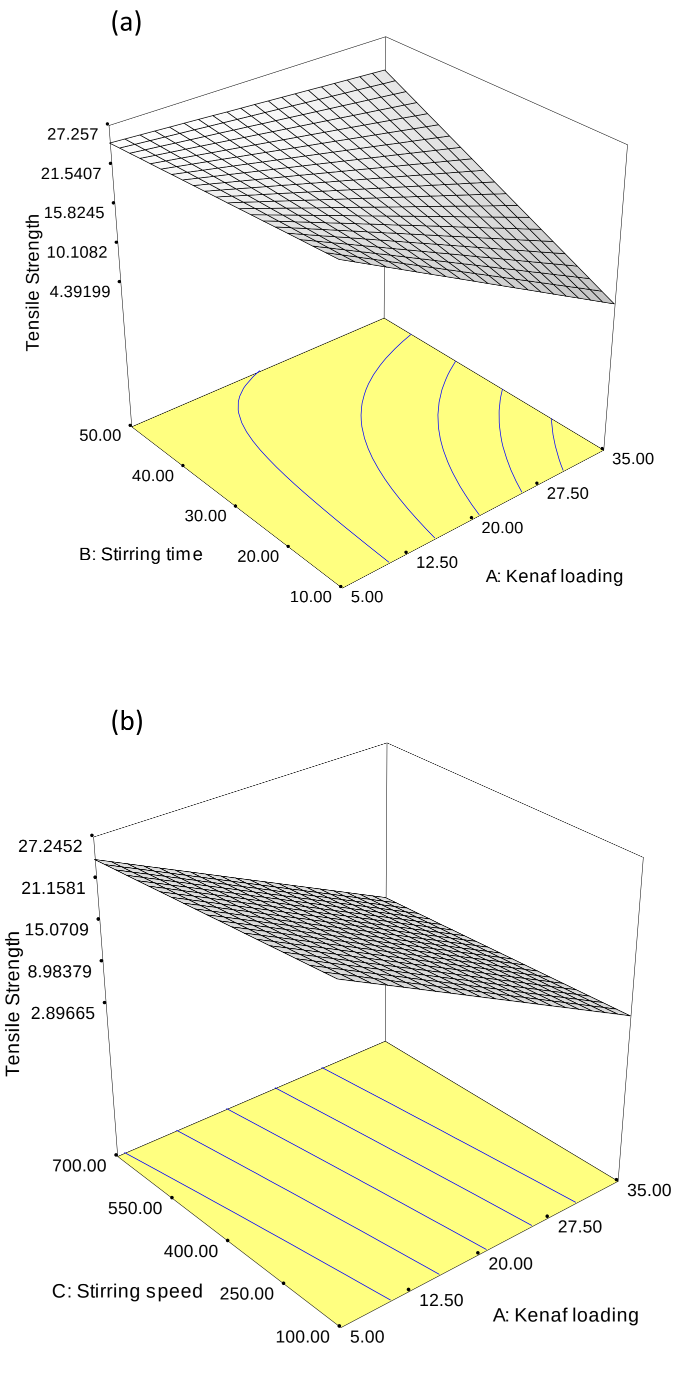



**Fig. 5.** Response surface plots of tensile strength response of epoxy/kenaf composites with (a) AB interaction; and (b) AC interactions

**Table 9**
Optimization results of RSM on epoxy/kenaf composites

| Parameter | Units | Goal | Level | | Optimization Result |
|---|---|---|---|---|---|
| | | | Lower | Upper | |
| Kenaf loading | wt. % | is in range | 5 | 35 | 5 |
| Stirring time | minutes | is in range | 10 | 50 | 10 |
| Stirring speed | rpm | is in range | 100 | 700 | 100 |
| TS | MPa | maximize | 2.882 | 27.257 | 27.2569 |

**Table 10**
Optimization recommendation of epoxy/kenaf composites solution

| Number | Kenaf loading | Stirring time | Stirring speed | Tensile strength | Desirability | |
|---|---|---|---|---|---|---|
| 1 | 5.00 | 10.00 | 100.00 | 27.2569 | 1.000 | Selected |
| 2 | 5.00 | 10.00 | 116.79 | 27.1652 | 0.996 | |
| 3 | 5.00 | 10.00 | 133.41 | 27.0743 | 0.993 | |
| 4 | 5.27 | 10.00 | 100.00 | 27.0503 | 0.992 | |
| 5 | 5.00 | 13.31 | 100.01 | 27.0459 | 0.991 | |
| 6 | 5.00 | 42.63 | 699.99 | 25.7604 | 0.939 | |
| 7 | 5.00 | 34.00 | 100.01 | 25.7276 | 0.937 | |
| 8 | 5.00 | 34.83 | 388.47 | 25.5108 | 0.928 | |
| 9 | 5.00 | 13.87 | 531.14 | 24.9827 | 0.907 | |

Figure 6 represents the optimization result for Epoxy/Kenaf composite in ramps graphical view whereas Figure 7 shows the desirability result of Epoxy/Kenaf composite in histogram view. Referring to Figure 4.6, the ramps showed that the optimal factor settings were at the lowest range for kenaf loading, stirring time and stirring speed whereby the tensile strength response was at the highest range (shown by the red bullet). The histogram in the following Figure 7 shows the desirability for each factor and the tensile strength response, individually. The bottom histogram bar shows the combined desirability of all factors for the tensile strength response. The combination of all factors with the recommended solution of 5.00 wt. % of kenaf loading, 10 mins of stirring time and 100 *rpm* of the stirring speed, are able to generate the desirability of one or unity value which indicate a perfect interaction between the involved factors.

Fractured micrographs in Figure 8 (a–b) depicts the SEM observation of fractured surface morphologies of Epoxy/Kenaf composite that are utilized to evaluate the fracture characteristic, due to tensile loading at different magnifications of 35X and 100X, respectively. As can be seen in Figure 8 (a) – (b), there are evident presence of rough fractured surface area, porosity, cracked matrix, fibre and matrix breakage and fibre pull-out, through the observed morphologies. The matrix surface of epoxy resin was extremely disrupted due to tensile loading, whereby good interaction between epoxy matrix and kenaf fibre, provide major cause of such fracture characteristics. This is the indication of ductile mode of failure characteristic for typical composites bodies. The addition of fibrous kenaf fibre as single reinforcement within brittle epoxy matrix have contributed to the optimum performance of prepared epoxy/kenaf composite and such imperfection likes fibre pull-out, fibre breakage, roughed fractured surfaces and etc. are appeared to indicate the ductile fracture mode behaviour. This situation provide a positive indication on the successful selection of processing parameter of high-speed mechanical stirring operation and material factor through an optimization effort using DOE in producing the epoxy/kenaf composites. Ductile mode of failure has proven that the brittle nature of epoxy materials could be successfully modified through some innovative ways of composite development and systematic optimization.

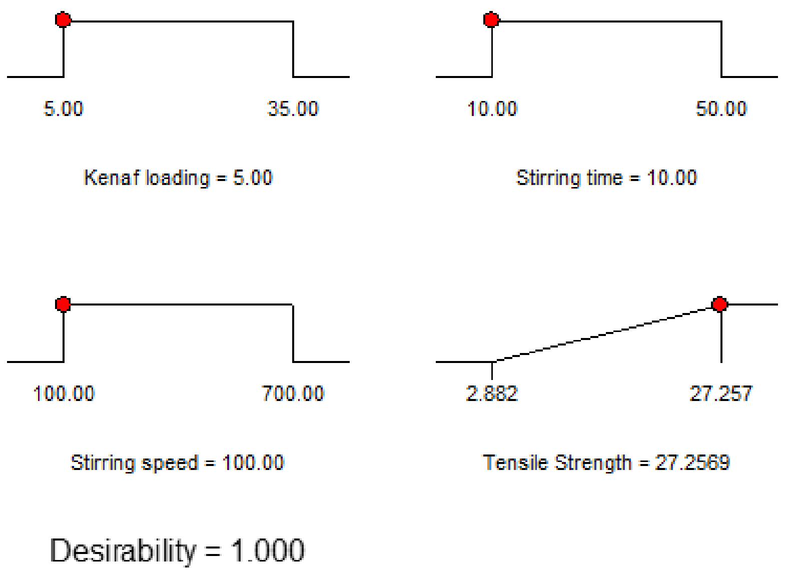



**Fig. 6.** Optimization result of Epoxy/Kenaf composite in ramps graphical view

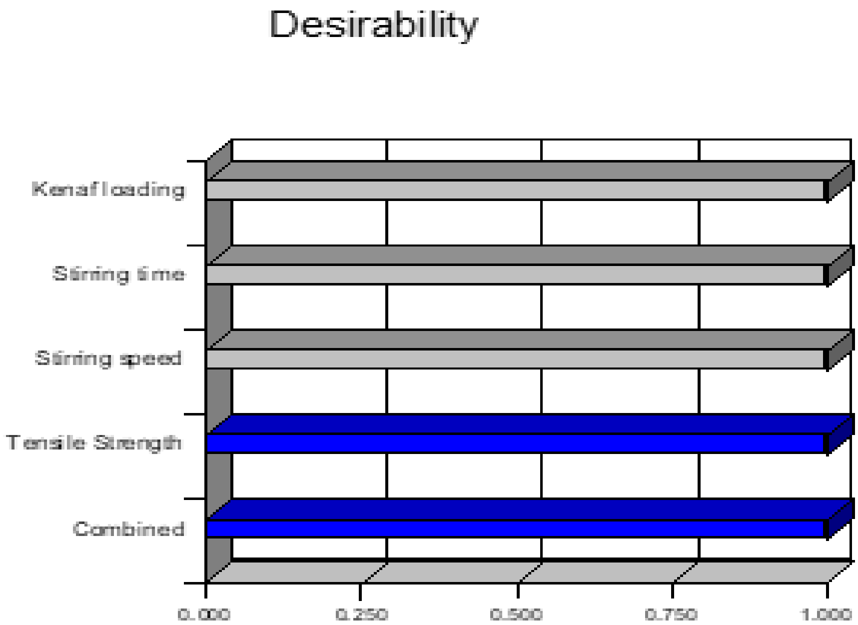
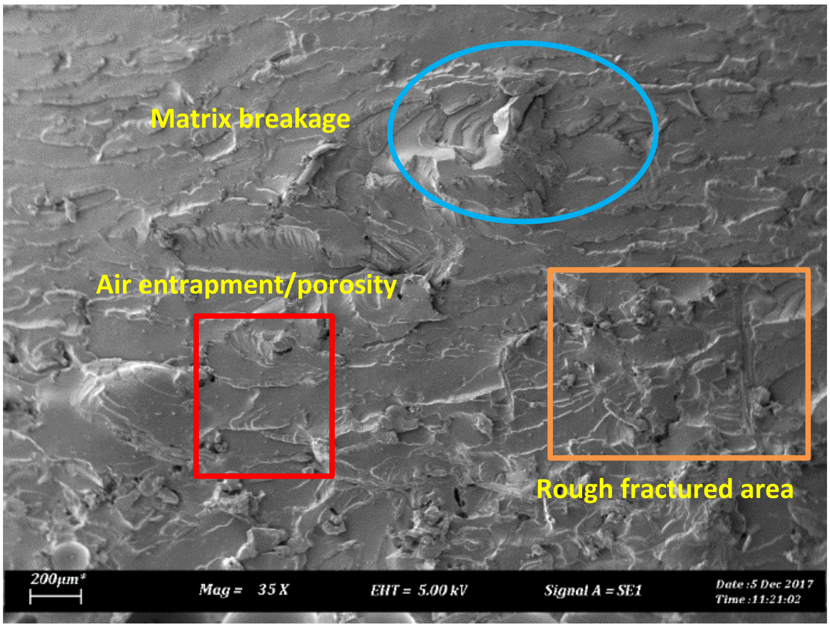
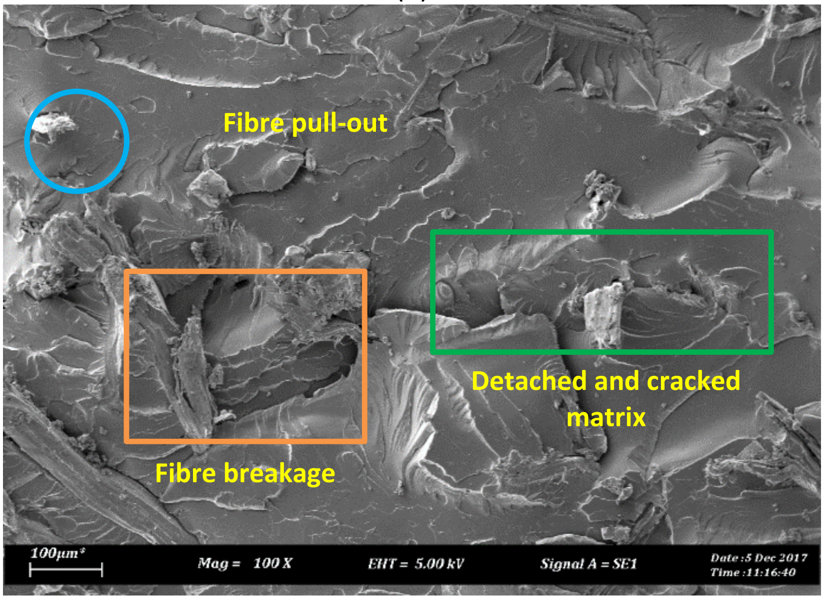



**Fig.** 7. Optimization result of Epoxy/Kenaf composite in histogram graphical view




(a)




(b)

**Fig. 8.** SEM observation of epoxy/kenaf composite (control sample) at (a) 35X of magnification and; (b) 100X of magnifications

## 4. Conclusions

As for conclusions, the optimum processing parameter and kenaf fibre loading for epoxy/kenaf composite system prepared by the solution casting and high-speed mechanical stirring method has been successfully determined by two-level full factorial statistical design approach. The tensile strength property was referred as a main response for optimization purpose. The best combination of interacted factors (kenaf loading: 5 wt. %; stirring time: 10 mins; stirring speed: 100 *rpm*) were determined in this work in ensuring the best possible performance (tensile strength) of the resulted epoxy/kenaf composites system. Moreover, the value of $R^2$ was approaching into one (1.00) which was highly adequate to represent the proposed linear regression model in predicting the optimum interacted parameters for the tensile strength response of epoxy/kenaf composite. As for future work, it is suggested to include the chemical surface modification into kenaf fiber as one of the variable parameter, to understand further the correlation between filler surface modification and processing parameter to the response studied.

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