The optimisation of fabrication process for various chemically treated kenaf fibres in epoxy matrix composites

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Abstract. The fabrication process is crucial since it determines the overall performance of the bio-composites. This study draws from the drawbacks of the natural fibre reinforced composites that are high voids content, low in surface interaction as well as low-stress distribution property especially using a simple mould-press process. The study explores the correlation between various fabrication processes of thermoset matrix towards the composites density, voids content, tensile and morphological properties. The study was carried out by mould pressed only 10 percent (%) filled composites by varying its curing temperatures, moulds type, fibres size and fibres chemical treatments afflicted. The results showed that 50˚C of curing temperature, in plunger mould-type, using 0.25 mm mesh size fibre are the optimised parameters. The coated 1:6 composite showing the optimum properties since it improves 6.5% density, 99.95% voids content, 38.1% water uptake and 33.2-50.6% of tensile properties. The suitable processing parameters and high coating penetration might contribute to the total improvement of the coated fibre composites properties. Since it influences the fibres compact-ability that leads to low voids formation as analysed on its fractured surfaces. In summary, a better understanding of the materials characteristic and fabrication processes are needed to obtain the optimum bio-composites performance.

1. Introduction

The prevalent usage of natural fibres as a reinforcing filler in various applications nowadays become a trend for the industrialist to introduce a ‘green’ element in their products. The benefits that are easily in availability and low tooling cost not just prolong to the manufacturer but, to the human and mother-nature as well since it less toxic and easily to decomposed [1]. But, the question remains on the low in properties of natural-based products since the fibres naturally have variability in physical and chemical aspects that affect its mechanical and morphological properties.

Therefore, the natural-based material and processing must be optimised to get an improved property to replace the available man-made materials. Recently, the biocomposites fabricator tend to manipulate the various processing parameters to achieve the said goal. However, by far, less research conducted on the combination of the parameters that referred to curing temperatures, mixing method, fibre size, type of mould and fibre surface treatment by considering the nature of the matrix and the...
fibre used. In this study, the epoxy thermosetting resin is used as the matrix of the composite since it recognised able to reduce its viscosity before its gel time.

This study also explores the effect of the heated mixing process between fibre and epoxy to its surface interaction. Since, in theory, the process able to make the matrix to become lower in viscosity and the important aspect, it enables to efficiently wet-out the surface of the natural fibre that naturally incompatible. The importance of the viscosity thinning is, it will improve the surface contact to make the matrix penetrated onto the delicate surfaces of the fibre. An improved matrices surface contact is crucial since it will determine the effectiveness of the stress transfer that cannot be achieved by a composite system that has low surface interaction.

It is also expected that, when the surface interaction is high, the fibre compaction inside the composite system also improved. Therefore, this study focuses on all the processing parameters that cover on material and composite fabrication aspects and only for thermoset matrix in the simple mould-press process. In an effort to optimise the fibre-filled biocomposites to perform at its best properties to replace the costly and harmful synthetic materials.

2. Methodology

2.1. Materials

The raw kenaf natural fibre was obtained by the Kenaf and Tobacco Board. The received fibre was in the continuous form (more than 30 cm in length). The epoxy resin (CP362A) and hardener (CP362B) were manufactured by Oriental Option Sdn. Bhd. The physical, mechanical and chemical characteristics of kenaf fibre and epoxy resin and hardener are tabulated in table 1 and 2 respectively. Acetone was supplied by Classic Chemicals Sdn. Bhd. with 95% purity and 58.08 g/mol of the molecular weight.

### Table 1. The physical and mechanical properties of Kenaf bast fibres.

| Fibrous Material | Density (g/cm³ fibres) | Lengths (mm) | Diameter (μm) | Length/diameter | Tensile Properties |
|------------------|------------------------|--------------|---------------|-----------------|--------------------|
|                  | Fibres | Bundle | Range | Average | Range | Average | Ratio | Average and Spec. Strength (MPa) | Average and Spec. Modulus (GPa) |
| Kenaf (bast)     | -      | 1.2    | 1.4-11 | 2.6     | 12-36 | 21       | 124   | 295-930 & 246-993 | 22-60 & 18-50 |

Source: Physical and mechanical properties of commercially important lignocellulosic fibre and of E-glass fibre [2]

### Table 2. The physical characteristics of CP 362 epoxy resin.

| Part                | Chemical Type    | Viscosity (cps) | Colour | Gel Time | Post Cure | Final Viscosity (cps) |
|---------------------|------------------|-----------------|--------|----------|-----------|-----------------------|
| Epoxy (CP 635A)     | Epoxy DGEBA      | 13 000          | Transparent | 35 Minutes (25°C) | 9.5 Hours (25°C) | 8500                 |
| Hardener (CP 362B)  | Modified Polyamine | 400              | Transparent |           |           |                       |

Source: All Purpose Epoxy [3]
2.2. Fibre Treatment Process
Before the coating treatment, the Kenaf fibres were combed prior conditioned at 24 °C for 48 hours. The coating solutions were prepared by diluting the epoxy solution with acetone at 1:4, 1:5 and 1:6 w/w epoxy to acetone ratios. The fibres were immersed instantly after prepared using 3:7 fibre to coating ratio in room temperature. The processes were conducted in a controlled condition to prevent evaporation of acetone. After 5 minutes of soaking process, the fibres were tossed and individually separated to promote a single fibre coating during the curing process at 80 °C for 24 hours in an air circulated oven.

The untreated and sodium hydroxide (NaOH)/ aminosilane (APS) treated fibre batches become reference 1 and 2 samples respectively. Prior treatments, the fibres were combed and cleansed using water and dried. For the first treatment, the fibres were immersed in 6 w/v % of NaOH-water solution with 7:3 immersion ratio at 25 °C. The fibres were washed and dried at 70 °C at 96 hours. The fibres were treated again with 1 (v/v %) of APS, 95 (v/v %) of ethanol, 4 (%) water for 30 minutes and air-dried for 1 hour.

2.3. Pulverisation Process
All fibres were cut using a pulveriser machine (Fritsch Power Cutting Mill PULVERISSETTE 15) passing thru 5.0 mm, 1.0 mm, 0.5 mm until 0.25 mm pulverise mesh sizes aperture in consecutively. The fibre was added gradually and collected in the receiver bowl. Only, the 5.0 mm and 0.25 mm sizes of pulverised fibres were used in this study.

2.4. Fabrication Process
The details of the process flow of tests and analyses were illustrated in figure 1 and 2. The summary of the analysis parameters was tabulated in table 3. All the composite samples were pressed at 1200 psi using HP-25T press machine for 2 hours and post-cured at 50 °C for 24 hours using an air circulated oven.
The 50 °C of curing temperature was selected.

The 5-Minutes of mixing time between epoxy and hardener was selected.

The 5 mm fibres size was chosen to be optimised.

The plunger-type mould and 0.25 mm fibre size were selected.

The mixing method 1 was chosen.

The composites were fabricated at 50 °C, in 5 minutes, using mixing method 1, plunger-mould type and 0.25 mm fibre size.

**Figure 1.** Process flow chart for test and analysis.

**Figure 2.** Illustrations of mixing (a) method 1 and (b) method 2.
Table 3. The overall fabrication parameters in all analyses.

| Analysis | Fibre Loading (wt%) | Composites Curing Temperatures (°C) | Matrices mixing time (mins) | Fibre Sizes (mm) | Mould Types | Mixing Methods | Fibre Treatments |
|----------|---------------------|-------------------------------------|-----------------------------|------------------|-------------|----------------|-----------------|
| 1        | Nil.                | 24 to 90                            | 5                           | Nil.             | Flat        | Nil.           | Untreated        |
| 2        | 10                  | 24 and 50                           | 5 to 30                     | 0.25             | Flat        | 2              | Untreated        |
| 3        | 10                  | 24                                  | 5                            | 5.0, hybrid\(^a\) and 0.25 | Flat        | 2              | Untreated        |
| 4        | 10                  | 24                                  | 5                            | 5.0              | Flat and Plunger | 2              | Untreated        |
| 5        | 10                  | 50                                  | 5                            | 0.25             | Flat        | 1 and 2        | Untreated Treated and untreated |
| 6        | 10                  | 50                                  | 5                            | 0.25             | Plunger     | 1              | Untreated        |

\(^a\)Hybrid fibre size is 5% for each 5-mm and 0.25-mm fibre sizes.

2.5. Testing and Characterisation

All the samples were tested for density, water absorption and tensile test. The fractured surface of tensile tested samples was further analysed using a polarised optical microscope.

2.5.1. Density Test.

The density test was referred to ASTM C29/C29M-09 [4] that used deionised water as an immersion medium using Shimadzu UX 450S densitometer. Minimum of five (5) samples with dimension 2 cm length by 2 cm width with 0.3 cm thickness were used. The samples density was obtained by measuring the samples dry weight and its volume by placing onto the upper and lower pan respectively.

2.5.2. Voids Content Test.

The voids content was obtained from the difference between the theoretical density and experimental density as done by Fiore, et al. [5]. The theoretical density can be calculated from equation (1).

\[
\rho_t = \left(\rho_m \times M_f\right) + \left(\rho_f \times F_f\right)
\]  

(1)

Where, \(\rho_m\) (unit: g/cm\(^3\)) is the epoxy density, and \(M_f\) (unit: %) is the fraction of epoxy matrix. Whereas, \(\rho_f\) (unit: g/cm\(^3\)) is the density of the Kenaf fibres, and \(F_f\) (unit: %) is the fraction of Kenaf fibres in a solid composite system (no voids formation). The percentage of voids content can be seen in equation (2).

\[
U_v = \frac{\rho_t \times \rho_f}{\rho_t} \times 100\%
\]  

(2)

Where, \(U_v\) (unit: cm\(^3\)) is the volume of void content, \(\rho_t\) (unit: cm\(^3\)) is the samples theoretical densities, and \(\rho_f\) (unit: cm\(^3\)) is the samples experimental density [6].
2.5.3. **Water Absorption Test.**
The test was referred to ASTM D570-98 [7] of 24 hours of water uptake. Minimum of five (5) samples with dimension 2 cm length by 2 cm width with 0.3 cm thickness were cut and immersed in the testing cup containing deionised water. The weighing process was conducted until a plateau reading obtained. The percentage of water uptake was calculated as in equation (3).

$$\text{Water absorption (\%) = } \left( \frac{W_f - W_0}{W_0} \right) \times 100\% \quad (3)$$

Where, $W_f$ is the sample mass (unit: gram) after 24 hours immersion, $W_0$ is sample mass (unit: gram) before the test immersion.

2.5.4. **Tensile Test.**
The tensile test was conducted using the Shimadzu AG-X4205 universal testing machine based on ASTM D3039/3039M-08 [8]. Five (5) samples with a dimension of 15 cm in length x 2 cm in width x 0.3 cm thickness were tested at a crosshead speed of 5 mm/min with 8 cm gauge length. The tensile stress, strain and modulus were calculated as in equation (4) to (6).

$$\text{Tensile stress, } \sigma_T \left( \frac{N}{mm^2} \right) = \frac{F}{A} \quad (4)$$

Where, $F$ (unit: N) is the force that applied to the sample in the axial direction and $A$ (unit: mm$^2$) is the cross-sectional area of the sample.

$$\text{Tensile strain, } \epsilon_T (\%) = \left( \frac{L_f - L_i}{L_i} \right) \times 100 \quad (5)$$

Where, $L_f$ (unit: mm) is the samples length after deformation and $L_i$ (unit: mm) is the initial length of the sample.

$$\text{Tensile modulus, } E_T \left( \frac{N}{mm^2} \right) = \frac{\sigma}{\epsilon} \quad (6)$$

Where, $E_T$ is the tensile modulus, $\sigma$ is the tensile stress and $\epsilon$ is the tensile strain.

2.5.5. **Characterisation of Composites Morphology.**
The fractured surface of the tensile tested sample was analysed using darkfield in reflected light. The voids formation inside the composite system were analysed using brightfield in transmitted light via polarised optical microscope Olympus BX 51 as referred to ASTM F728-81(1997)e1 [9].

3. **Result and Discussions**

3.1. **Analysis 1 (Curing temperature of pristine epoxy)**
Figure 2 shows the tensile properties of pristine epoxies that fabricated at various curing temperatures. For the tensile stress as in figure 3 (a) and (b), the epoxy that cured at 24 °C temperature recorded the lowest tensile stress and modulus properties. It might be due to the presence of voids inside its system. The high viscous epoxy might reduce the mobility of bubbles to escape from its system thus creating more voids once harden and reduce its tensile stress. In addition, due to the low-stress transfer as the result of high voids formation, the 24 °C sample has low resistance to break and lowering its tensile modulus.
Figure 3. The tensile (a) stress and (b) modulus of pristine epoxies that cured at 24, 40, 50, 60, 70, 80 and 90 °C moulding temperatures.

By comparing the tensile stress and modulus pattern, an increasing trend was observed and reduced slightly at 90 °C sample. It might be due to the effect of high curing temperature on the voids mobility to efficiently aerate out from the 90 °C sample matrix. Since the high curing temperature accelerates the epoxy molecule to create faster 3-Dimensional links thus reduce the fabrication time that needed for voids escape out from the matrix system. Thus, this drops slightly the stress and modulus for 90 °C sample. But, for the 50 °C sample, it shows the highest tensile stress and modulus compare to the other samples. It might be because it is an ideal temperature for voids to efficiently escape out from its system thus contribute to an increment of its tensile stress and modulus properties.

3.2. Analysis 2 (Matrices mixing time)
Figure 4 shows the comparison of optical micrographs on the surface and inside the 10 wt% of the fibre reinforced composites. For 24 °C samples, as the mixing time increasing, the amount of voids also increased. The voids formation might be affected by the workable time of the epoxy matrix. As the mixing time increased, more air being whipped into the matrix thus, reducing the chance of voids to effectively escape-out from the matrix system. In addition, the size of the voids is also getting smaller as the mixing time increased since the increasing number of voids restrict their movement out from the matrix.
| Time (min) | Composite fabricated at 24 °C | Composite fabricated at 50 °C |
|-----------|-----------------------------|-------------------------------|
|           | Surface                     | Inside                        | Surface                     | Inside                        |
| 5         | ![Image](image1)             | ![Image](image2)             | ![Image](image3)             | ![Image](image4)             |
| 10        | ![Image](image5)             | ![Image](image6)             | ![Image](image7)             | ![Image](image8)             |
| 15        | ![Image](image9)             | ![Image](image10)            | ![Image](image11)            | ![Image](image12)            |
| 20        | ![Image](image13)            | ![Image](image14)            | ![Image](image15)            | ![Image](image16)            |
| 25        | ![Image](image17)            | ![Image](image18)            | ![Image](image19)            | ![Image](image20)            |
| 30        | ![Image](image21)            | ![Image](image22)            | ![Image](image23)            | ![Image](image24)            |

Not Available.

Note: At 25 to 30 minutes of mixing time range, the mixtures were hardened.

**Figure 4.** The polarised optical micrographs comparison between voids formation on the surface and inside the 10 wt% filled untreated fibres in the epoxy matrix composite. Fabricated at 24 °C and 50 °C curing temperatures. Captured via bright and darkfield in reflected and transmitted light at 5x magnification.

For samples the 50 °C samples, the same pattern was observed since more voids formed on and inside the matrices system as its mixing time increases. However, it noticed that the formation of the voids is less than the 24 °C samples. It might be due to the effect of heat that applied to the mixture since it results in the reduction of viscosity of the mixtures thus promote to the voids release from its system. For the 50 °C workable time, by heat application, it shortens to 20 minutes compare to the 24 °C sample.

The heat might accelerate the reaction time for the formation of 3-D links in the composite system and reducing its ‘pot life’. Therefore, by comparing between mixtures, 50 °C sample at 5 minutes of mixing time appeared to has a better morphological property as it observed having low in voids formation as compared to the other samples. It might be as the effect of the optimum mixing time that
slowly permeates out the from the composite system compare to the 10, 15 and 20 mixing time. Figure 5 shows the fractured surface of 24 and 50 °C samples.

| Untreated fibre fabricated using 24 °C temperature | Untreated fibre fabricated using 50 °C temperature |
|---------------------------------------------------|--------------------------------------------------|
| (a)                                               | (b)                                             |
| Agglomerated pull-out fibres                      | Wide stress streaks                             |
| (c)                                               | (d)                                             |
| Undetached fibres                                | Small stress streaks                            |

**Figure 5.** The fractured surfaces of the tensile tested samples that fabricated at 24 °C and 50 °C.

By comparing the condition of the fibres, the 24 °C sample (Figure 5 (a)) appeared to have fibre pull-out which indicated that low fibre-matrix interaction in the sample. The fibre also agglomerated since it showed that 24 °C sample unable to disperse well in the matrix system. Vice versa for 50 °C sample (Figure 5 (c)) that shows few untreated fibres that undetached and well dispersed throughout the region. The good distribution of stress also can be seen as the 50 °C sample have smaller stress streaks compared to the 24 °C sample as shown in Figure 5 (b) and (d).

### 3.3. Analysis 3 (Fibre size)

Table 4 shows the physical and mechanical properties of composites using various sizes of untreated fibre. As expected, the 10F5.0 sample recorded the lowest properties compared to the other samples. It might be due to the effect of fibres length since the long fibres might tend to agglomerate thus it inclined to create intratow voids on the unwetted fibre surfaces. Thus, it reduces its physical and mechanical properties.

For 10F0.25 sample, it shows better properties compare to the rest of the samples. It might be due to the effect of the shorter length of the fibre since it tends to dispersed well in the composite system [10]. Thus, it reduces the formation of intratow voids that caused by the agglomerated fibres. The short fibres aligned themselves in a pack formation thus better stress distribution throughout the region of the samples. As for 5FHyb sample, a slight improvement also observed in physical and mechanical properties by the combination of both 0.25mm and 5.0 mm fibres as compared to 10F5.0 sample.

It might be caused by an improvement in stress distribution as the 0.25mm fibre fill the empty gap in the composite sample to disperse the stress to the adjacent 5.0mm long fibre. Thus, this might be the explanation of the improvement in its stiffness of the 5FHyb sample.

**Table 4.** The physical and mechanical properties of 10 wt% of untreated fibre composites fabricated using 0.25mm, hybrid and 5.0mm fibre sizes coded 10F0.25, 5FHyb and 10F5.0 respectively.

| Samples  | Density (g/cm³) | Voids Content (%) | Water Absorption (%) | Tensile Properties (N/mm²) |
|----------|----------------|------------------|----------------------|-----------------------------|
|          | Average Std. Error | Average Std. Error | Average Std. Error | Average Std. Error |
| 10F0.25  | 1.09 0.004 | 6.04 0.02 | 3.62 0.78 | 30.91 1.85 | 1313.57 199.32 |
| 5FHyb    | 1.04 0.001 | 10.63 0.01 | 5.04 0.24 | 27.76 0.55 | 1544.80 33.97 |
| 10F5.0   | 0.95 0.013 | 18.60 0.04 | 13.19 0.47 | 20.33 0.20 | 1188.38 30.04 |

Note: Density of pristine epoxy at 24 °C moulding temperature is 1.16 ± 0.002.
3.4. Analysis 4 (Types of mould)
Table 5 shows the physical and mechanical properties of 5 mm fibres that fabricated using both flat-top and plunger-type mould. It was observed that the 5 mm fibre that known have lower properties improved by the usage in the plunger-type mould. It might be influenced by the constant load and temperature applied by the thick plunger mould. It suppressed the formation of the voids that formed inside the composite system by efficiently aerate-out the voids from the mould cavity. Thus, it improves the composites physical and mechanical properties.

Table 5. The physical and mechanical properties of 10 wt% of untreated 5.0 mm fibre composites fabricated using flat and plunger-type moulds coded 10FFlat and 10FPlun respectively.

| Samples   | Density (g/cm³) | Voids Content (%) | Water Absorption (%) | Tensile Properties (N/mm²) |
|-----------|-----------------|------------------|----------------------|----------------------------|
|           | Average         | Std. Error       | Average              | Std. Error                 | Stress               | Std. Error | Modulus   | Std. Error |
| 10FFlat   | 0.95            | 0.002            | 18.60                | 0.04                      | 13.19                | 0.47       | 20.33      | 0.20        | 1188.38     | 30.04       |
| 10FPlun   | 0.98            | 0.002            | 15.91                | 0.03                      | 6.04                 | 0.13       | 26.30      | 0.87        | 1232.64     | 141.5       |

Note: Density of pristine epoxy at 24 °C moulding temperature is 1.16 ± 0.002.

3.5. Analysis 5 (Mixing methods)
By referring to Table 6, it is the physical and mechanical of 0.25 mm fibre fabricated using mixing method 1 and 2. It was observed that, by using mixing method 1, the physical and mechanical properties of the composite (10F50(1)) is better than the composite using method 2 (10F50(2)). The thinning of the epoxy due to the application of heat contribute to the better surface contact onto the surface of the fibre. Thus, leads to reductions in voids and water uptake and improvement in tensile properties.

Table 6. The physical and mechanical properties of 10 wt% of untreated 0.25mm fibre composites fabricated at 50 °C using mixing method 1 and 2 coded 10F50(1) and 10F50(2) respectively.

| Samples   | Density (g/cm³) | Voids Content (%) | Water Absorption (%) | Tensile Properties (N/mm²) |
|-----------|-----------------|------------------|----------------------|----------------------------|
|           | Average         | Std. Error       | Average              | Std. Error                 | Stress               | Std. Error | Modulus   | Std. Error |
| 10F50(1)  | 1.17            | 0.001            | 1.20                 | 0.001                      | 1.30                 | 0.02       | 56.58      | 0.23        | 1667.42     | 28.73       |
| 10F50(2)  | 1.15            | 0.002            | 3.67                 | 0.005                      | 2.91                 | 0.12       | 46.04      | 0.78        | 883.73      | 23.31       |

Note: Density of pristine epoxy at 50 °C moulding temperature is 1.17 ± 0.001.

3.6. Analysis 6 (Fibres treatment)
Table 7 shows the physical and mechanical properties of untreated, treated NaOH/Sil and coated 1:4, 1:5 and 1:6 samples. It is observed that the physical and mechanical properties of treated and coated samples is higher than the untreated sample. It might be due to the presence of pectin and lignin that contribute to the incompatibility between fibre and matrix [11] for 10FUn sample. The result followed by the low in properties by the 10F1:4 and 10F1:5 samples. It might be influenced by the coating behaviour since the coating only coats at the outer part for 10F1:4 fibres whereas at half part of the 10F1:5 fibres [12]. Since, the coating was deteriorated due to the effect of the pulverisation process that resulting in a reduction of its fibres size [13]. Therefore, the coated fibre in both samples exposed the surface of the uncoated natural fibre thus resulting in reduction of its properties.

Vice versa for 10F1:6 sample since the high penetration of coating throughout the fibres structure contribute to its stiffness [12]. Thus, it reduces the samples deformation as better surface contact as it can be seen in the improvement in its density as well as low in voids content that leads in low in water
uptake. The 10FTr also showing good physical and mechanical properties as it might be the effect of the chemical treatment coalition as agreed by Ghaztar [10].

The NaOH treatment is able to increase the surface interlocking and making the fibre stiff as it converts the cellulose I to cellulose II to become high in crystalline region [14]. With the combination of APS treatment, the fibre surface able to create good surface contact since the said treatment able to create the chemical link on the fibres surface to attach the different polarity between matrix and fibre. Thus, it increases the compaction and leads to reduce in voids formation, water uptake and improvement in tensile properties.

**Table 7.** The physical and mechanical properties 10 wt% filled composites fabricated at optimised parameters using untreated, treated and coated 1:4, 1:5 and 1:6 fibres coded 10FUn, 10FTr, 10F1:4, 10F1:5 and 10F1:6 respectively.

| Samples | Density (g/cm³) | Voids Content (%) | Water Absorption (%) | Tensile Properties (N/mm²) |
|---------|-----------------|-------------------|----------------------|----------------------------|
|         | Average         | Std. Error        | Average              | Std. Error                 | Stress | Std. Error | Modulus | Std. Error |
| 10FUn   | 1.16            | 0.002             | 2.82                 | 0.02                       | 1.50   | 0.03       | 34.47    | 0.37       | 1639.91  | 53.63     |
| 10FTr   | 1.18            | 0.001             | 1.19                 | 0.01                       | 1.37   | 0.04       | 39.29    | 0.12       | 1663.02  | 39.00     |
| 10F1:4  | 1.17            | 0.001             | 1.43                 | 0.01                       | 1.47   | 0.04       | 35.88    | 0.29       | 1795.62  | 41.64     |
| 10F1:5  | 1.18            | 0.002             | 1.17                 | 0.02                       | 1.35   | 0.02       | 36.06    | 0.17       | 1942.08  | 18.76     |
| 10F1:6  | 1.18            | 0.002             | 1.08                 | 0.04                       | 1.34   | 0.02       | 42.57    | 0.65       | 2056.09  | 11.73     |

Note: Density of pristine epoxy at 50 °C moulding temperature is 1.17 ± 0.001.

4. Conclusion

All the optimisation parameters of the thermoset plastic using the press-moulding fabrication method were studied. It is observed that, better understanding of the fabrication parameters able to improve the properties of the short fibre-based biocomposites. With the analysis on fabrication temperatures, mixing time, fibre size, types of mould, mixing methods and treatments that afflicted to the fibre is crucial to get the optimised properties of a simple press thermoset sample. The properties improvement can be seen as the composites were fabricated at 50 °C, in 5 minutes, using plunger-mould type, 0.25-mm shorter fibre size that use mixing method 1 and coated fibres. The improvements are in better fibre compaction that suppress the formation of the voids which leads to low water uptake that parallels with the improvement in its stress dispersibility and retaining ability throughout the region of the samples. In summary, better understanding on the materials characteristic and fabrication process are crucial in order to obtain the optimum performance of the bio-composites.

5. References

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