The Tensile Strength Analysis of Kenaf Fibre Reinforced Epoxy Composites by Using Weibull Distribution

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ABSTRACT

This paper presents the tensile strength analysis of unidirectional kenaf fibre reinforced epoxy composites that statistically analyzedby usingtwo parameters Weibull distribution. The specimens were made from hand lay-up techniques and compressed in a mould for fabrication process. Pure epoxy specimen and two fibre volume fractions ratios of 15% and 45% were fabricated and subjected to tensile load up to failure. The two parameterWeibull distribution has confirmed that the increasing of fiber volume fraction in composites showed an improvement in tensile strength and lowering dispersion of fracture strength, as well described by the scanning electron microscope evaluation.The confidence level and reliability of kenaf/epoxy composites is presented in a graph form in which the probability material will failed was obtained. For safe utilization in design and manufacturing, this method is likely more appropriate instead of taken as a single mean tensile strength. It is found that the high reliability values of tensile strength of 15% and 45% kenaf reinforced epoxy composites are 30 MPa and 60 MPa respectively.

Key Words:,Kenaf fibre, Polymer composites, Weibull distribution

INTRODUCTION

The introductions of natural fibre such as kenaf (Hibiscus cannabinus, L.) in polymer composites are become popular as they are cheap, renewable, recyclable,biodegradable alternative with low weight and density. Another substantial reason for growing interest is that kenaf offer good strength per weight ratio in which make numerous of researches in different part of the world is done to explore the potential of kenaffibre as a reinforcement in polymers composites (Aji,2009)(Oshi,2008).

Being reinforcement in polymer composites, this material remains inhomogeneity and anisotropic properties in which the mechanical properties are different at every direction. It is very common for a composite materials present varying strength value due to its internal structures. In worst circumstances, the strength of kenaf fibre alone does not always consistent although the same of bunch of fibre plants are used in making composites. They are varying even at different part in a same kenaf plant. (Frollini, Leao&Mattoso, 2000). This mean there is absolutely no specific strength to present their true mechanical properties. In engineering perspective, it is therefore necessity to employ statistical analysis for design and manufacturing for safe utilization.

Out of many statistical analyses used, Weibull distribution is a unique method and among practitioner due its versatility. Many engineering samples including determination of static and dynamic properties is done according to this distribution (Doan, Gao&Mader, 2006). The concept of reliability was considered by Nelson (Nelson, 1985) in Weibull distribution in the case where the shape parameter is known and derives confidence limits for the scale parameter based on few or no failures. Written in his paper, Barbero (Barbero, Fernandez-Saez& Navarro, 2000) suggested thatthe Weibull distribution is a practical method to apply in determination 90% and 95% reliability values when it comes to design structural and mechanical components. No studies appear to have reported on statistcal analysis of kenaf fibre reinforced polymer composites and how this relates to the structural application if positive confidence in this material is to be given.

In this study, the variation tensile strength betweenpure epoxy specimen, 15% and 45% fibre volume fraction of unidirectional kenaf/epoxy composites were investigated by using two parameters Weibull distribution. It is hoped that the findings from this study will be beneficial in the study of polymeric composites.

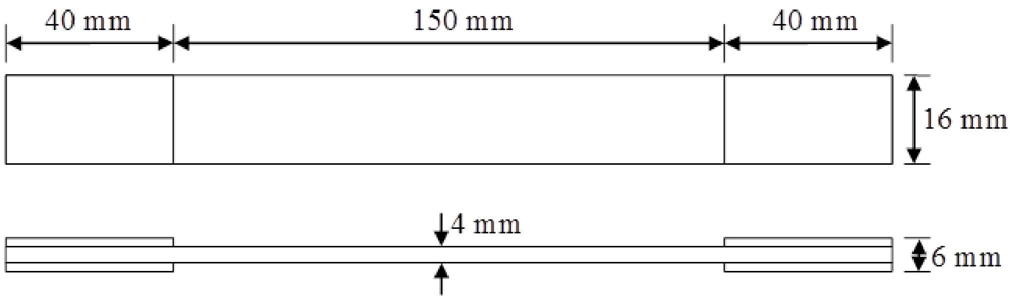
EXPERIMENTS AND PROCEDURE

Materials and Composites Fabrication

The composite specimens used in the experiments were prepared from a unidirectional kenaf fibre obtained from InstitutPerhutananTropikadanProdukHutan (INTROP),Universiti Putra Malaysia, Serdang, Malaysia. and originally planted from Shenzhen, China. The kenaffibre was 3 meters in length and density was measured at 1.12 g/cm3. The kenaf fibers were treated with Sodium Hydroxide (NaOH) solution prior composites fabrication. Previous research (Edeerozey, Akil, Azar&Ariffin, 2007) reported that the treated fiber in reinforced composites offer better mechanical properties in comparison with untreated fiber because the treated fiber change their structural and surface properties by physical and chemical methods, and thereby improve the fiber-matrix. The matrix material in this study was a commercial graded Diglycidyl Ether of Bisphenol-A epoxy resins supplied by Miracon, Malaysia. The composites with fibre volume fraction of 15% and 45% of volume fraction and pure epoxy specimen were fabricated using hand lay-up techniqueaccordance to ASTM D 3039 (Standard Test Method for Tensile

Properties of Polymer Matrix Composite Materials. American Society of Testing Materials, 2008). Tabs were applied at both ends of specimens. The dimensions were shown in Figure 1. Initially, the mixtures of epoxy/hardener were poured and fibres were placed into mould cavity (23 mm x 17 mm x 5 mm)prior it was closed by mould cavity cap. A compression pressed at one tonne was applied for 24 hours before it was removed and cut accordingly.

Figure 1 Composite Specimen and Its Dimensions



Tensile Test

The tests were carried out according to ASTM D-3039 (Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. American Society of Testing Materials, 2008)usingInstron 3366 universal testing centre. Preliminary tests were conducted to ensure that no slip on the grip occurred. A total of 30 specimens or 10 specimens for each fibre volume fractionswere loaded at constant crosshead rate of 2 mm/minute until fracture and 25±2 ºC ambient temperature was present during the test. The term of tensile strength in this experiment is referred as the tensile stress at breaking point of a material.

Figure 2A Specimen Was Loaded on a Instron 3366 Universal Testing Centre

Surface Morphology

The surface morphology after tensile loading was studied using a scanning electron microscope (SEM) model Phillips XL 30 ESEM. The SEM settings used were 10.0 kV and 0.8 Torr to examine the fracture specimens. Each fracture specimens were coated with chemical agent for 24 hours prior to imaging in the SEM. Note that an SEM can scan damage only the surface of the composites.

Weibull Distribution

The two parameter Weibull cumulative distribution function is given by;

$$F(\sigma)=1-\exp\left[-(\sigma/\sigma_0)^\alpha\right], \quad \alpha\geq0,\sigma\geq0,\sigma_0\geq0 \qquad (1)$$

Where F is the probability of rupture of material at any given of uniaxial tensile stress , α is shape parameter and σ_0 is scale parameter respectively. The parameters of the distribution function are estimated from observation. The classification of data as can be either complete or censored (or incomplete) (Prabhakar, Murthy, Min &Renyan, 2004). Let tndonate a sample of n-independent random variable from a distribution function. The data set available for estimation is therefore the set (t1, t2, ..., tn). In this case, the data is completed; corresponding to the known actual failure strength values for each observation in the data set. The estimation of these parameters could be employed by many methods including methods of moments, methods of linear regression, Bayesian methodand method of percentiles and methods of maximum likelihood (Prabhakar, Murthy, Min &Renyan, 2004). Method of linear regression is the easiest technique and among practitioners because of their simplicity and will be used in this study. Then, the equation (1) is transformed into double logarithms of both sides and hence a liner regression model of is expressed by;

$$\ln\left[\ln\left(1/(1-F(\sigma))\right)\right]=\alpha\ln\sigma-\alpha\ln\sigma_0 \qquad (2)$$

Then, the F values are formed in the sample on the basis ith position of n ordered and -values which are estimated from observed values: order n observations from smallest to largest, and let $\sigma(i)$ denote the ith smallest observation. Hence, a good estimator of Fifor median ranked values is used (Barbero, Fernandez-Saez&Navarro, 2000);

$$F_i=(i-0.3)/((n+0.4)) \qquad (3)$$

When linear regression based on least square technique for the model in Eq. (2) is applied, the parameter estimates for $\alpha$and$\sigma_0$are obtained. The mean tensile strength of Weibull distribution is computed with gamma function,Γevaluated at the value of$((1+\alpha)/\alpha)$ defined by;

$$\sigma_u=\sigma_0\,\Gamma((1+\alpha)/\alpha) \qquad (4)$$

Using equation (1), the reliability in which the probability of fractured strength at any given uniaxial stress, is given by;

$$R(\sigma)=\exp[-(\sigma/\sigma_0)^\alpha] \qquad (5)$$

Where *R* is the probability of survival of material at any given of uniaxial tensile stress.

RESULT AND DISCUSSIONS

Tensile Tests Data

The tensile strength of each individual specimen is shown in Table 1. These results are then computed into mean tensile strength(Normal distribution) as listed in Table 2, showed the tensile strength increased along with fibre content, 32.90 MPa, 56.21 MPa and 96.93 MPa respectively and similar trend was reported by Ochi (Ochi, 2008), attributed by improving interfacial adhesion.More fibres fibre volume ratio in composites increases more adhesion between fibre-matrix interfacials and ultimately, more energy can be dissipated by the fibre-matrix interfacial (Gu, Wu, Kampe& Lu, 1999),(Hill & Cetin, 2000).

Although there was an improvement in tensile strength generally, some of the individual values were actually considered closer between these two groups. For an example, it was possible to notice the highest tensile strength values of 15% kenaf/epoxy composite, 69.5 MPa were almost closed enough to hit 77.3 MPa, the lowest tensile strength of 45% kenaf/epoxy composite by chances.This result suggests that not only the strength of kenaf fibre alone does not always consistent and uncertain but it is including their composites too.

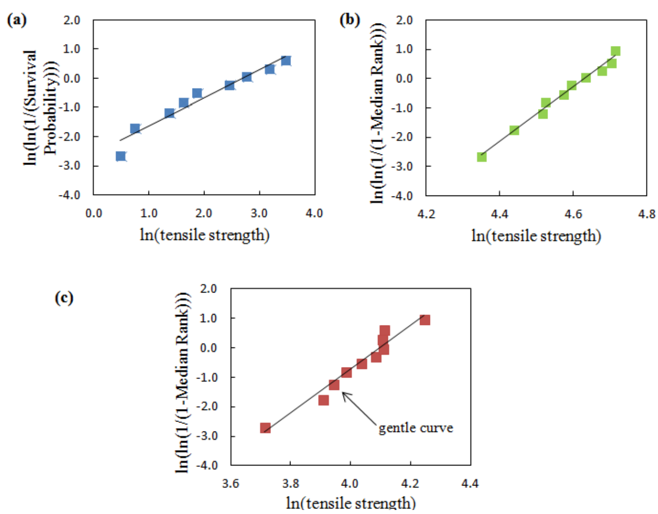
Table 1 Tensile Strength Values of Tested Specimens

Sample	Strength (MPa)		
	Pure epoxy	15% kenaf/epoxy composites	45% kenaf/epoxy composites
1	32.3	56.2	60.4
2	35.0	51.3	96.6
3	33.8	49.6	91.3
4	30.1	59.1	91.7
5	36.0	53.7	109.8
6	31.9	41.0	107.0
7	31.5	69.5	98.2
8	33.3	60.5	111.2
9	34.5	60.8	101.8
10	30.5	60.4	84.4

Regression Line Plot

The results obtained from the Table 1 were then computed into equation (2) and equation (3). The Weibull shape parameter, (α) and scale parameter, σ_0 are a measure of variability slope of the results and is found by linear regression on a plot of In(In(1/survival probability)) against In(tensile stress) is shown in Figure 3.The linear regression plotsare inspected to determine how well the failure data fit a straight line. It was found that the data plotted were fall on gentle curves in which clearly visible to 45% kenaf/epoxy composites followed by 15% kenaf/ epoxy composites and pure epoxy specimens.Obviously, the data are trying to describe something in these cases. Weibull himself illustrated this concept in his paper 1951 (Robert, 2004).The bad fit may relate to the physics of the failure or to the quality of the data.Since the failure specimens weresubjected to the tensile load and the tensile evaluations were accordance to ASTM D-3039, the quality of data is not the main issues. Perhaps, the quality of specimens that lead to physics of failure should be considered. These individual specimens were hand-made since there is no appropriate method for composites fabrication unlike to those synthetic fibres such as glass and carbon fibres.In fact, there is no guarantee of each composites consist similar amount of fibre, fibres orientation or even the quality of kenaf fibre and larger fibre volume ratio seems to be affected most.

Figure 3 Regression Line Plot of (a) Pure Epoxy Specimens, (b) 15% Kenaf/Epoxy Composites and (c) 45% Kenaf/Epoxy Composites



Effect Of Shape Parameter and Scale Parameter

The estimation of Weibull parameters of shape parameter, α and scale parameter, σ_0 obtained from Figure 3 is listed in Table 2. The most important parameter of the Weibull parameter is shape parameter. This parameter is related to the scatter of the data whereby the higher values the lower the dispersion of fracture stress(Barbero, Fernandez-Saez& Navarro, 20007). The results showed that the pure epoxy specimens scored the highest αof 18.29 as compared to its composites; indicates lack of reliability although there was an improvement of composites tensile strength.

However, the α values were improving from 7.54 to 9.46 respectively for the 15% kenaf/epoxy composites and 45% kenaf/epoxy composites. This trend was similarly reported by Kalam and co-worker (Kalam,Sahari, Khalid & Wong, 2005) on tensile strength of unidirectional oil palm fruit bunch/epoxy composite. Their obtained shape parameter was increased between 9.43 and 16.25 for the fibre volume fraction of 35% and 55%. This suggeststhat the confidence of these natural fibre composites can be improved by the increasing of fibre volume content.

The scale parameter determines the range of the distribution, 63.2% of all values fall below the characteristic life regardless of the value of the shape parameter and closely related to the mean fracture stress (Caruta, 2006). The scale parameter obtained as the fibre volume increases were 33.79 MPa, 59.69 MPa and 101.83 MPa respectively. However, according to Kalam and co-worker (Kalam,Sahari, Khalid & Wong, 2005), the increase in fibre volume ratio has weakened in OPFB/epoxy composites from 49.90 MPa to 47.58 MPa respectively. Thus, it can be assumed that there is significant improvement of tensile strength as the fibre volume increasing in kenaf/epoxy composites system.

Table 2 TheTwo Parameter Weibull Distributions

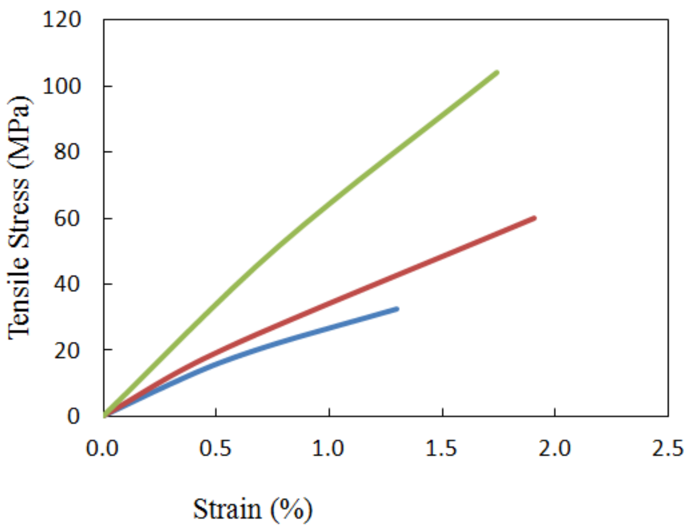
Material	Shape parameter	Scale parameter (MPa)	Mean Tensile Strength (MPa)	
			Weibull dist.	Normal dist.
Calculated				
Pure Epoxy	18.29	33.79	32.82	32.90
15% kenaf/epoxy composites	7.54	59.69	56.05	56.21
45% kenaf/epoxy composites	9.46	101.83	96.64	96.93
Kalam and co-worker [13]				
35% OPFB/epoxy Composites	9.43	49.90	47.35	47.78
45% OPFB/epoxy Composites	16.25	47.58	46.06	46.13

Class of Failure

According to Prabhakar Murthy [9], theshape parameter of Weibull distributioncould describes class of failure. Aα< indicates a decrease of failure rate (infant mortality); failure cause by material defects. A α = 1.0 means random failures (independent of age). A α> 1.0 indicates an increasing of failure rate. Therefore, this suggests that 45% kenaf/epoxy composites tend to fracture with higher probability for every increased unit in tensile stress and obtained lower dispersion of tensile strength in term of data scatter compared to 15% kenaf/ epoxy composites (Barbero, Fernandez-Saez& Navarro, 2000).

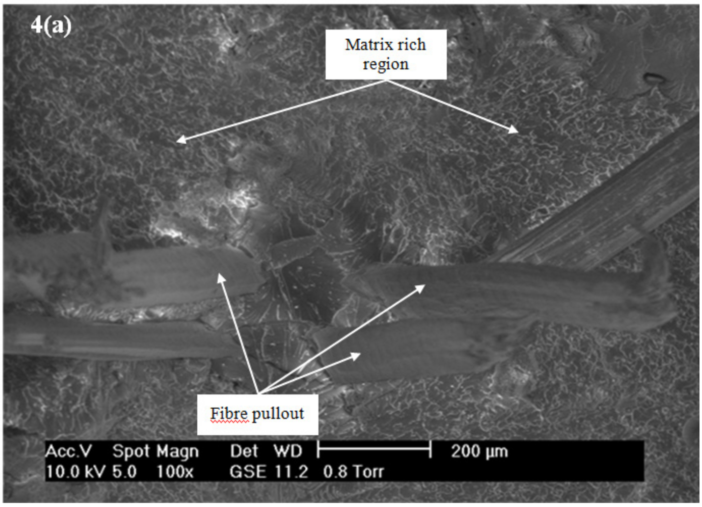
In fact, the specific class of failure of can α> 1.0 can be described too. The stress-strain curves of specimens are shown in Figure 3. For a typical stress-strain behavior in composites, the line might follow a linear-elastic, elastic-plastic, or linear elastic perfectly plastic behavior (Aidy, Sanuddin, Saifuliwan&Ezzeddin, 2010)(Mallick, 2008). Clearly, these materials show similar ultimate tensile strength and breakingstrength properties. The yield stress however could not be determined since the term of yield point itself referred to a point in the stress-strain curve at which the plastic deformation begins to occur (Mallick, 2008). On the other word, the specific failure types of these composites are linear-elastic brittle fracture. A common typical α are 5 for blackboard chalk and 10 for ceramics, exhibits completely brittleness characteristic while 100 for steel that exhibits elastic and followed by strain hardening deformation (Burrowa, Thomas, Swain &Tyas, 2004). Blackboard chalk and ceramic are therefore examples of a material that has a similar deformation characteristic of failure that can be defined within a reasonably of obtained shape parameter,in contrast to steel.

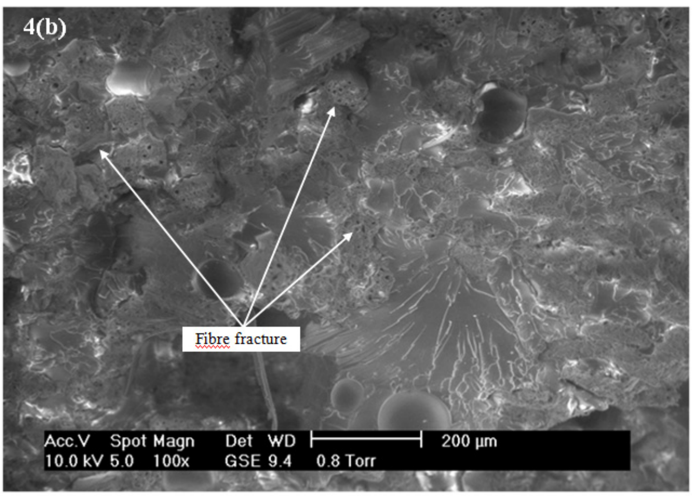
Figure 4 Stress-strain Curves of a) Pure Epoxy Specimens, (b) 15% Kenaf/Epoxy Composites and (c) 45% Kenaf/Epoxy Composites



Fibre-matrix interfacial and fracture behaviour of both 15% and 45% kenaf/epoxy composites that could be related to this shape parameter values can be studied using SEM of the tensile fractured specimens. Both types of composites were examined on similar magnification of 100x. For a composite material, the damage can occur separately and simultaneously of fibrefracture, delamination, matrix cracking and fibre-matrix debonding (Chamis,1989). In cases of the 15% kenaf/epoxy composites in Figure 4, fibre pullout were observed clearly on fractured specimen,which are a result of poor interfacial bonding between the fibre and matrix. On the other hand, the fractured surface of the 45% kenaf/epoxy composites showed in Figure5 is considered brittle texture with extensive fibre fractures and less fibre pullouts, thus revealing efficient interfacial adhesion between fibre and matrix. This suggests that the increasing of fibre volume contentcreated good interfacial adhesion and improved theshape parameter values.

Figure 4: SEM Micrograph of 15% Kenaf/Epoxy and 45% Kenaf/Epoxy Composites at 100x Magnification. Figure 4(a) Showed Fibres Pull Out and Figure 4(b)Showed Fibres Fracture.



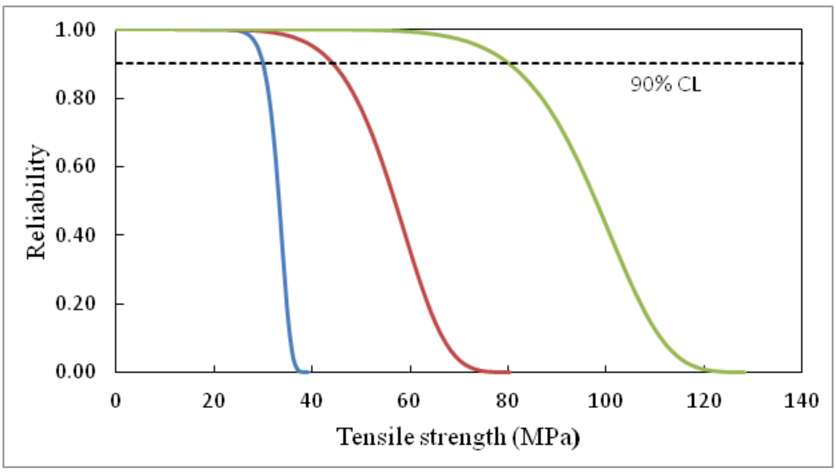


Reliability

The unique of Weibull parameters over the other distributions are that the plot of confidence level (CL) or reliability could be determined by given shape and scale parameter. The plot of reliability curve constructed from equation (5) is shown in Figure 4. This method allows of means predicting the likelihood of failure of composites at any stress values, possibly allowing engineers to select the suitable composites depending on the expected level of stress that may be subjected to the desire application.

The term of confidence level tells how sure the data can be and represents how often the true percentage of the population. Let consider a 100% confidence level; it is possible to observe the 45% % kenaf/epoxy composites sustained longer before the gradually decreasing values in the curve while the pure epoxy specimens and 15% kenaf/epoxy composites were almost similar. This suggests the addition of the 15% fibre volume in composites may not give significant impact as the 45% fibre volume in composites. Nevertheless, if the confidence level decreases by let say 90% as proposed by Barbero(Barbero, Fernandez-Saez& Navarro, 2000), the tensile strength of 15% kenaf/epoxy composites may present remarkable results rather than pure epoxy specimens.

Figure 4WeibullReliability Distribution of a) Pure Epoxy Specimens, (b) 15% Kenaf/Epoxy Composites and (c) 45% Kenaf/Epoxy Composites



Using equation (4), the mean tensile strength was calculated by using the obtained two Weibull parameters earlier. As listed Table 2, comparing these values to the mean tensile strength calculated using normal distribution showed that the different was likely insignificant.

Nevertheless, as a new emerging material, taking as a single number of mean tensile strength may not describe its reliability or even increasing confidence level, when it come into demanding structural application.

Table 3 listed the confidence level of the tensile strength taken as a mean compared to the 90% confidence level as proposed by Barbero(Barbero, Fernandez-Saez& Navarro, 2000). Surprisingly, the mean tensile strength of all specimens wasaround 55% confidence level; 5 out of 10 specimens might be failed instantly.In other perspective outlook, the differences between "Mean Tensile Strength" (55% CL)and "Tensile Strength as proposed by Barbero" (90% CL) showed relatively small, 3 MPafor pure epoxy specimens and perhaps taken mean as the tensile strength can be accepted.Nevertheless, its composites showed larger differences from 12 MPa and 17 MPa respectively, assuming high for natural fibrecomposites since this material has limited tensile strength values compared to those syntheticfibres composites (Paul, Jan &Ignaas, 2003). This suggests that the tensile strength of natural fibre composites should not be taken as an average of the experiment results but rather the highest possible reliability if safe utilization in design and manufacturing is being concern.

Table 3: Comparison of Tensile Strength Between Taken As a Mean and Proposed Barbero [7]

Table 3: Comparison of Tensile Strength Between Taken As a Mean and Proposed Barbero [7]

Material	Mean Tensile Strength (MPa)	CL (%)	Tensile Strength as proposed by Barbero [7] (MPa)	CL (%)	Differences (MPa)
Pure epoxy specimen	32.90	56	29.88	90	+3
15% kenaf/epoxy composites	56.21	54	44.25	90	+12
45% kenaf/epoxy composites	96.93	54	80.27	90	+17

CONCLUSIONS

This work is focused on the two parameter Weibull distribution, used to describestatistically the tensile strength of kenaf fibre epoxy composites. The composites were made from kenaf were successfully fabricated by using hand lay-out technique. The Weibull distribution allows the researcher to examine failure characteristic of the natural fibre composites. The influence of fiber volume fraction ratio on the shape and scale parameter was investigated and showed significant finding. The confidence level and reliabilityof the natural fibre composites' tensile strength can be described in a simple Weibull reliability curve.This method is likely more appropriate instead of taken as an average of the experiments results for safe utilization in design and manufacturing.

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