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ORIGINAL RESEARCH ARTICLE

SIMULATION AND EXPERIMENTAL STUDY OF TENSILE STRENGTH OF UKAM FIBRE REINFORCED POLYESTER COMPOSITES USING ANSYS

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ABSTRACT

Polymers are commonly used in different applications even though it causes environmental problems. Natural fibre reinforced composites can be used as substitute for the synthetic fibre composites because of their biodegradable properties which will be a key to solving environmental problems although, the strength of natural fibres is not as high as glass fibres, their specific properties are comparable. The hand lay–up method of fabrication was employed in preparing the composite. This study investigates the tensile strength of the composite using experimental and numerical method. The test specimen of natural composite was fabricated using ASTM standard and the tensile strength of the composite determined using Hounsfield Tensometer. A 3D Finite Element (FE) model was created to simulate tensile strength in ANSYS 18. Alkali treated samples exhibited the highest increase in tensile strength at all fibre loadings. Modulus of elasticity (MOE) and percentage elongation also increased with increase in fibre loading for all treatments. The experimental values of tensile strength at 25 % were in agreement with the FEM tensile strength using ANSYS.

1.0 Introduction

Over the past few decades, there has been a growing interest in the use of natural fibres in composite applications and the needs for Green environment has motivated researchers to seek for an eco-friendly alternative (Jeyasekaran, 2016; Nishieo et al., 2003; Aondona, 2017). These types of composites present many advantages compared to synthetic fibres, such as low tool wear, low density, cheaper cost, availability, and biodegradability (Zampaloni, 2007). Fibre reinforced composite materials have been increasingly used as structural members in many structures such as airplane, which in flight condition undergoes temperature as low as -60°C or in acryogenic tank which may be exposed to temperature below -150°C (Ogakwu and Okpanachi, 2016). Composite materials have the potential of reducing costs in construction, operation and development while improving structural reliability and enhancing safety. Because of these unique specifications, they are widely used in high technology structural applications, such as aeronautic and aerospace (Nishiro et al., 2003).

Cochlospermum planchonii known locally as *Ukam* fibres grow in savannah and forest savannah in West Africa. They are cellulose based natural fibres with good mechanical properties, low density, abundant and renewable (Aondona, 2017 and Olusegun et al., 2012). The people of the area where these plants are found use their fibres as sponge and also to reinforce clay with which they produced intricate earthen pots and silos (Ihom and Onah, 2016).

Olusegun et al. (2012) evaluated the mechanical properties of ukam, banana, sisal, coconut, hemp and e-glass fibre reinforced laminates to assess the possibility of using them as new material in engineering applications. Samples were fabricated by the hand lay-up process (30:70 fibre and matrix ratio by weight) and the properties evaluated using the INSTRON material testing system. The mechanical properties were tested and showed that glass laminate has the maximum tensile strength of 63 MPa, bending strength of 0.5 MPa, compressive strength of 37.75 MPa and the impact strength of 17.82 J/m^2. The ukam plant fibre laminate has the maximum tensile strength of 16.25 MPa and the impact strength of 9.8 J/m among the natural fibres.The mechanical properties such as tensile strength, flexural strength, impact strength and water absorption properties of ukam, sisal and banana fibres reinforced composites have been observed and found that there is the significant improvement in mechanical strength and reduction in water absorption rate while hybridizing the banana fibre with sisal fibre reinforced composites (Ihom and Onah, 2015). The ukam/glass fibre reinforced composites have good tensile property with minimum deflection when compared to the flax/glass composites (Aondona, 2017). Also the ukam fibres reinforced composites hold more flexural and impact strengths when compared to the flax/glass fibres reinforced polymer composites. Banana, hemp and glass fibre reinforced hybrid composites have been developed and the mechanical properties of these composites were evaluated (Olusegun et al., 2006).

Velmurugan et al. (2015) carried out the analysis of tensile properties of palmyra fibre reinforced epoxy composite. The simulation according to Jeyasekaran et al. (2016) was carried out using FEA under different fibre volume fraction and fibre length and validated with the experimental result and found to have less error percentage. Ramakrishnan et al. (2010) investigated the mechanical properties of vinyl ester resin reinforced with different weight fractions of 17 selected natural fibres by mathematical modelling and ANSYS simulation. From the observations, it is evident that increase in fibre content significantly improves the mechanical properties. The theoretical and ANSYS results indicate that vinyl ester reinforced with the fibres abaca, hemp and banana shows better tensile strength properties. The highest tensile modulus values are obtained for the fibres ramie, abaca, and sisal incorporated in vinyl ester. Similarly, for toughness and impact strength applications, the fibres banana, sisal and cotton are found to be suitable reinforcement for vinyl ester resin. Venkateshwaran et al. (2010) suggested in construction, automobile and manufacturing industries, composites with natural fibres are highly expected because of its high tensile strength and modulus, as well as for its low density and low elongation.

From the available literature, it has been found that, the quantitative analysis on the mechanical properties of these composites is still a valid problem, and hence, there is a need for carrying out such studies on composite materials. To take the advantage of ukam fibres, they have been reinforced with a polyester resin, so that an optimal and economical composite is obtained. Hence the objective of the present study is to investigate the tensile strength of the composite. The experimental results are compared with results obtained from finite element analysis (FEA) using ANSYS software.

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2. Materials and Methods

2.1 Materials

Some of the materials used in this study include;
Cobalt
Methyl Ethyl Ketone Peroxide (MEKP)
Ukam Fibre
Polyester resin
Polyvinyl Alcohol (PVA)
Potassium Permanganate (KMnO4)
Acetic Acid
Silane Solution
Sodium Hydroxide
The ukam fiber utilized is presented in Figure 1.

Figure 1: Produced *Ukam* Fibres

2.2 Methods

2.2.1 Alkali treatment

This treatment is carried out in order to produce the modified fibres for the composites and the treatment process involves the use of Sodium hydroxide solution in accordance with Liu et al., (2009). The Ukam fibres were then soaked in NaOH of 5 % concentration at room temperature for 24 hours. To remove any alkali solution sticking to the fibre surface the fibres were washed severally with water neutralized with dilute acetic acid and then washed again with water.

2.2.2 Silane treatment

The treatment is carried out in order to produce modified fibres for the composites and the treatment process involves the use of Silane solution dissolved in water (Valadez – Gonzalex et al., 2008). The Ukam fibres were immersed in silane dissolved in a water-ethanol mixture for 3 hours. The Potential of Hydrogen of the solution was 9.0. This contains 60 % ethanol and 40 % water mixed well and allowed to stand for an hou

2.2.3 Potassium permanganate ($KMnO_4$) treatment

The treatment is carried out in order to produce modified fibres for the composites and the treatment process involves the use of 0.5 % of potassium permanganate dissolved in acetone was used in soaking the alkali treated fibres for half an hour after been thoroughly washed with water. Distilled water was used in soaking the permanganate fibre for ten minutes in order to catalyse the reaction. Furthermore, the fibres were sun dried after it was decanted

2.2.4 *Acetylation*

The treatment is carried out in order to produce modified fibres for the composites and the treatment process involves the use of Ukam fibres been soaked in demineralized water for an hour, filtered and placed in a flask, containing acetylating solution (Bledzki et al., 2008). Acetylating solution is made of 250 ml toluene, 125 ml acetic anhydride and a small amount of catalyst per chloric acid (60 %). The process temperature of acetylation was 60°C and duration of 1 to 3 hour. After modification, the fibre was washed thoroughly with distilled water until acid free. The treated fibres were sun dried before the manufacturing of the composites.

2.2.5 *Determination of Tensile strength*

Tensile strength test was conducted using Hounsfield (Monsanto) Tensometer (model No. S/N 8889) according to ASTM D 638 – 03 (Croccolo et al., 2013). The width and the thickness of the specimens were measured and recorded (360mm by 20mm by 5mm) From the test, elastic modulus, ultimate tensile strength and percentage elongation were determined.

2.3 Finite Element Modeling and Analysis

Finite Element Analysis provide safe simulation of destructive load conditions and failure modes. A 3D FE model was created to simulate tensile in ANSYS 18. Solving the numerical simulation was conducted based on laboratory conditions used in a practical test for the tensile test where the shape and geometry of the sample process and the boundary conditions were taken into consideration. For performing this analysis the material property, Young's modulus, Poisson's ratio, density, boundary conditions and load conditions were applied similar to the experimental condition and these were obtained from the experimental results. Shell elements are typically used for structure where the thickness is negligible compared to its length and width. Nevertheless, a plate modeled with solid element would provide similar results. The disadvantage lies in the computation time. ANSYS provides large choices of elements (Desal and Abeljf, 1977). Two main aspects of the procedure are modeling the specimen, and calculating the stresses to failure.

2.3.1 Preprocessor steps

The 3D model was created using the dimension of the specimens used in the experiment as shown in Figure 2 (D638 – 03, 2005). The model created is made up of the polyester resin and the fibres. The model of the composite is to discretize the model into small elements. The mesh of the model (SHELL 181) is created with 8-nodes and each node has (6 degrees of freedom) with element size of and using the free meshing type to mesh all the models as shown in Figure 3.

2.3.2 Solution processor

The Analysis of the composite is conducted using ANSYS. The tensile load is applied as distributed load on the nodes at one end of the model the same as the load values in experimental test and with the model at the other end fixed. These steps are repeated for each model of tensile composition with fibre surface treatment (Hassan et al., 2013).

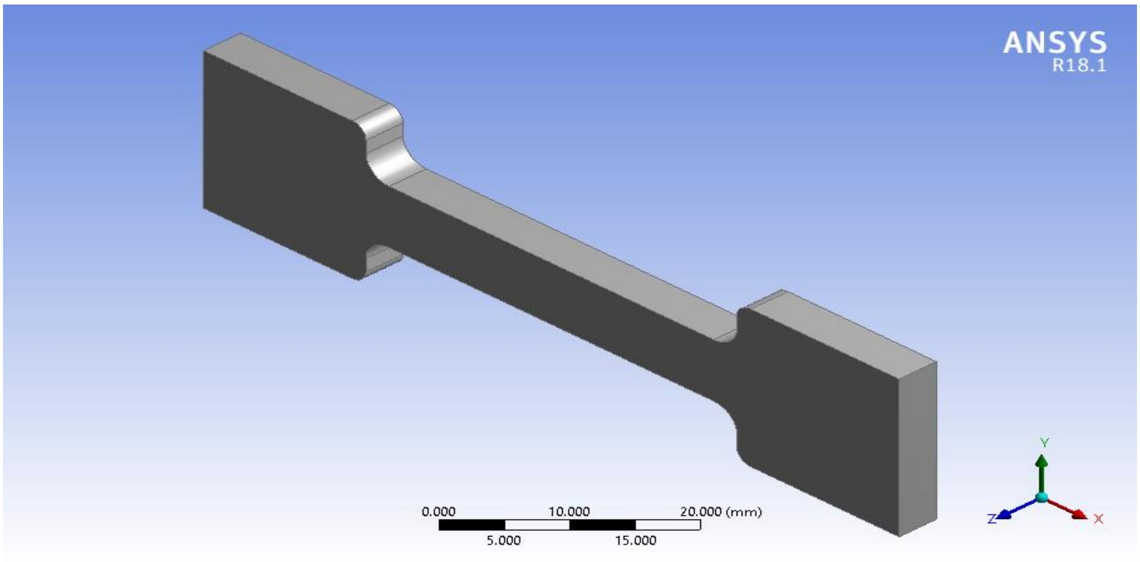

Figure 2: Geometry of tensile simulation specimen on ANSYS workbench

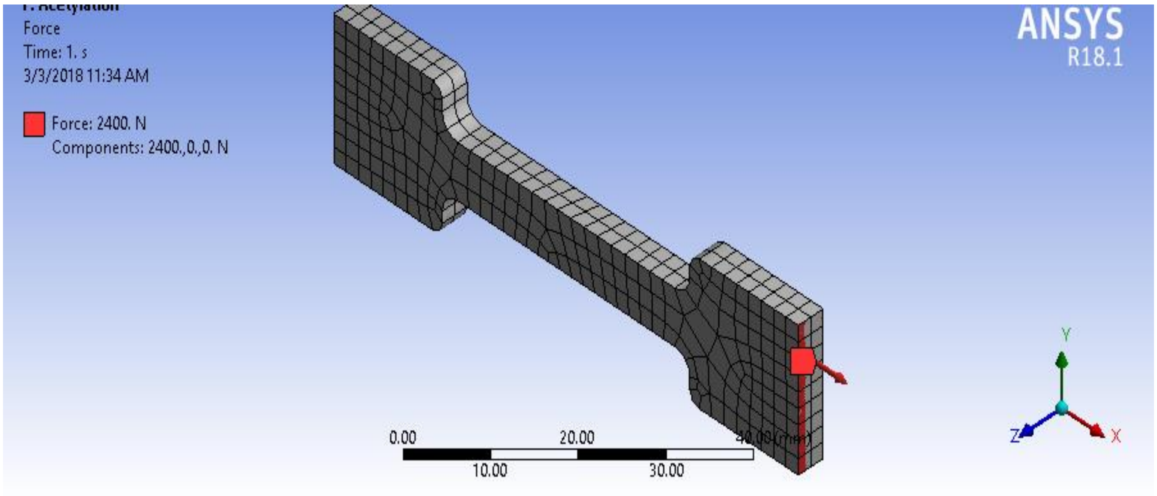

Figure 3: Boundary condition and load applied for ANSYS work bench model

3. Results and Discussion

The experimental tensile strength as presented in Figure 4 and Table 1 was observed to increase with increase in fibre loading for all the treatments. Fibres are normally stronger and stiffer than the matrix, therefore strength of composites are generally seen to increase with increased fibre loading (Olusegun et al., 2012). An exceptional increase in tensile strength was noticed in alkali treated samples at all fibre loading. This means that alkali treated samples exhibited the highest increase in tensile strength at all fibre loadings. This is because during alkaline treatment, hemicellulose and lignin are removed, the interfibrillar regions are likely to be less dense and less rigid, and that makes the fibrils moreable to rearrange themselves along the direction of tensile loading. Olusegun et al. (2012) was of the opinion that physical and chemical treatments improved the wettability of fibre and thus improve the interfacial strength leading to improvement in mechanical properties as the cellulose structure is totally modified.

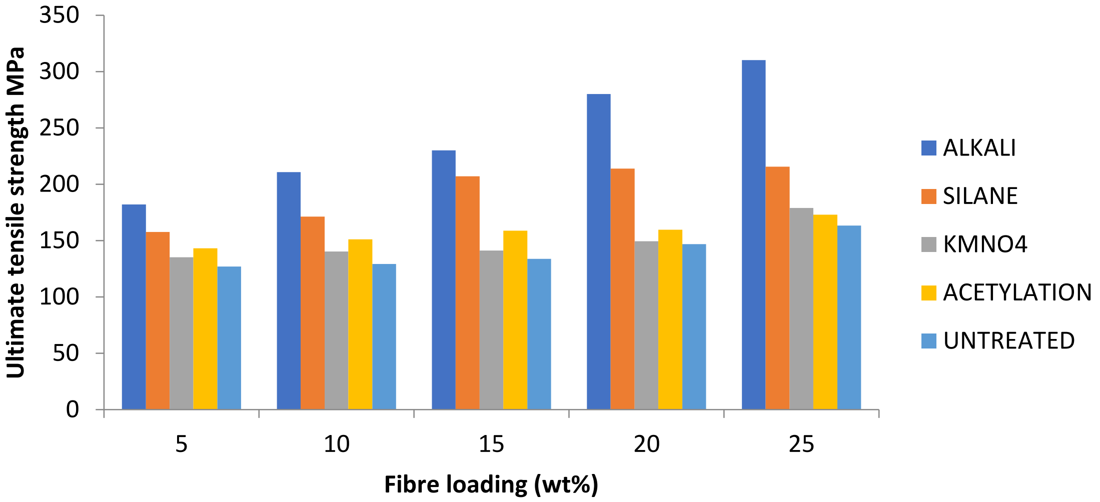

Figure 4: Influence of Surface Treatment and Fibre Composition on Tensile Strength of Composites

Table 1: Summary of tensile strength test results

Summary	Composition (%)	UTS(δ) (MPa)	% Elongation	Modulus of Elasticity
	5	181.95	12	1.5276
Alkali	10	210.60	15	1.5531
	15	326.35	20	1.7504
	20	333.2	21	1.9578
	25	326.9	23	2.7521
	5	157.54	13	1.5046
	10	171.24	15	1.9319
Silane	15	207.04	17	2.0808
	20	213.83	17.9	1.4196
	25	224.59	19	2.3668
	5	135.23	7	1.4120
	10	140.22	9.3	1.7703
$Kmno_4$	15	135.13	7	1.5922
	20	149.45	10	1.3238
	25	223.22	18	1.906
	5	143.17	8	1.2640
	10	151.07	10	1.0543
Acetylation	15	158.97	11	1.2640
	20	159.67	11	1.6852
	25	172.81	15	1.7677
	5	126.86	5	1.0218
	10	129.31	6	1.0364
Untreated	15	133.83	6	1.1582
	20	146.86	9	1.2061
	25	163.22	14	1.7837

Figures 5 – 9 present the FE (ANSYS) simulation results for the composite to study the effect of fibre surface treatment and fibre loading on the tensile properties of composites at 25 % fibre loading for all the treatments. Colours were used to differentiate regions of stress concentration with red showing regions with the highest value of stress concentration. The highest levels of stress concentrations were observed to be at the sharp corners of the Von Mises sample. The predicted tensile strength values by FE model matched with the experimental values. This was also confirmed by the regression of the predicted and experimental tensile strength presented in Figure 10. However, there was high correlation between the predicted and experimental tensile strength with R^2 value of 0.9994. Hence, the visual checking of predicted and experimental values confirms that the FE model was successful in predicting tensile strength. Moderate percentage error was observed between experimental and FEA. The slight difference in results between FEA and experimental analysis is due to true loading condition and method of composite fabrication compared with the experimental tensile test (Prasad et al., 2014).

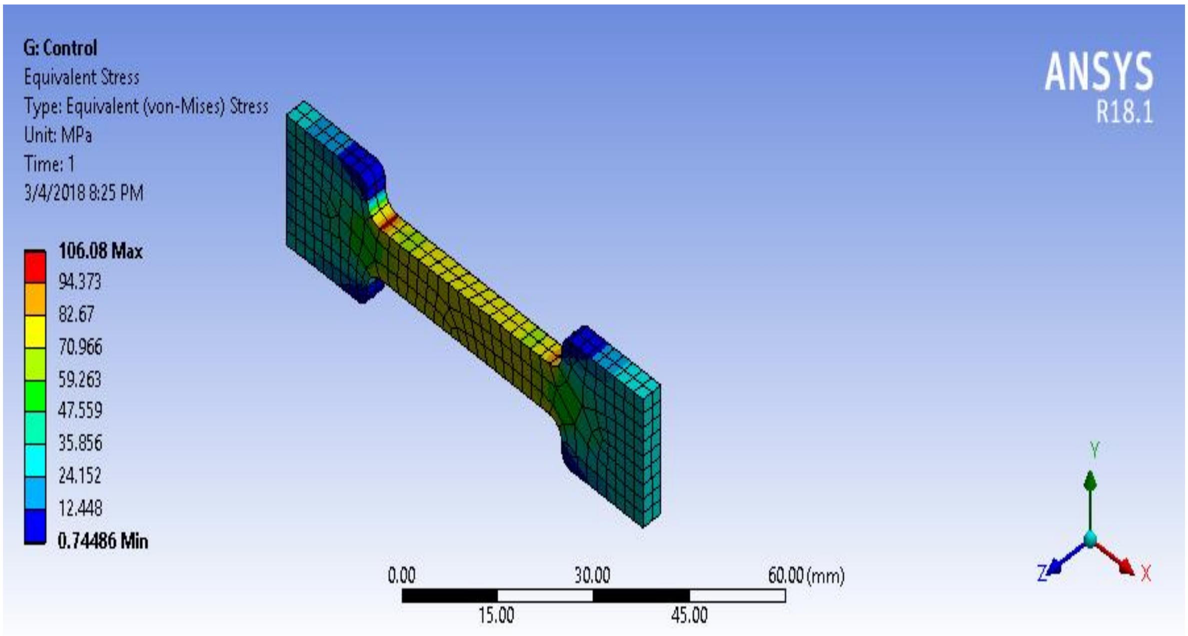

Figure. 5: Contour Plots Showing Regions of Stress Concentration for Untreated Fibres

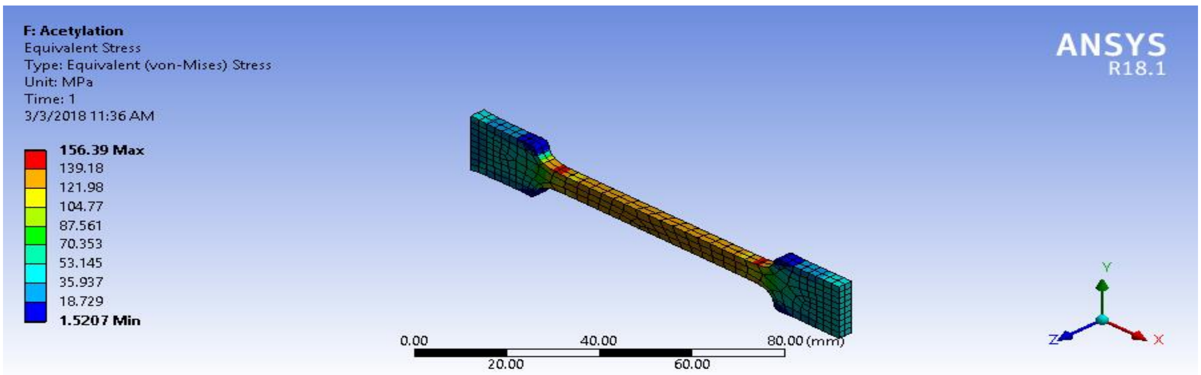

Figure. 6: Contour Plots Showing Regions of Stress Concentration for Acetylation Treated Fibres

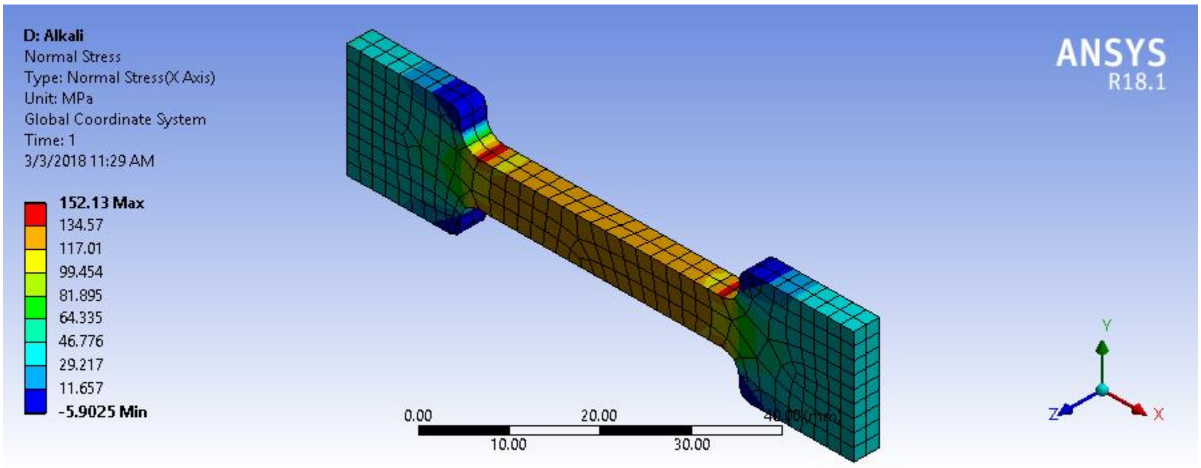

Figure.7: Contour Plots Showing Regions of Stress Concentration for Alkali Treated Fibres

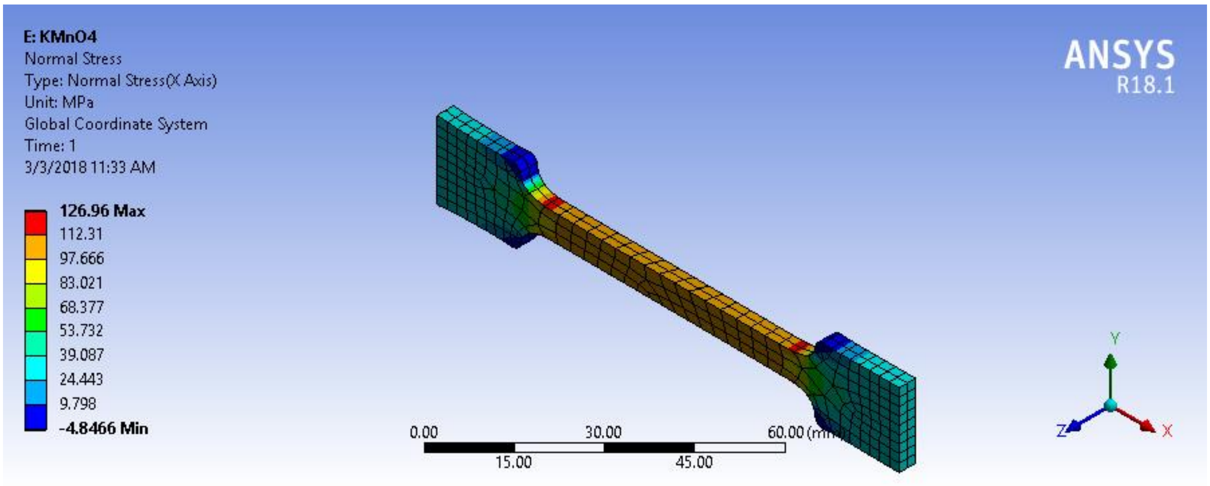

Figure. 8: Contour Plots Showing Regions of Stress Concentration for $KMnO_4$ Treated Fibres

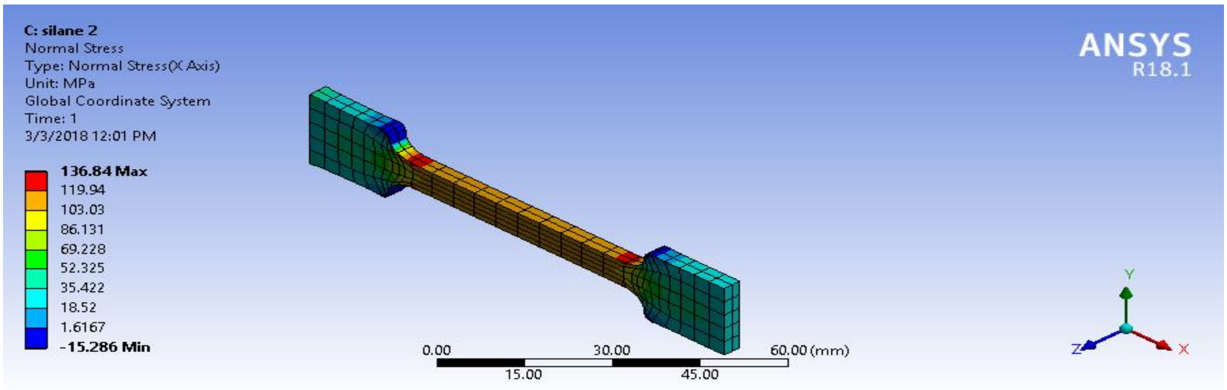

Figure. 9: Contour Plots Showing Regions of Stress Concentration for Silane Treated Fibres

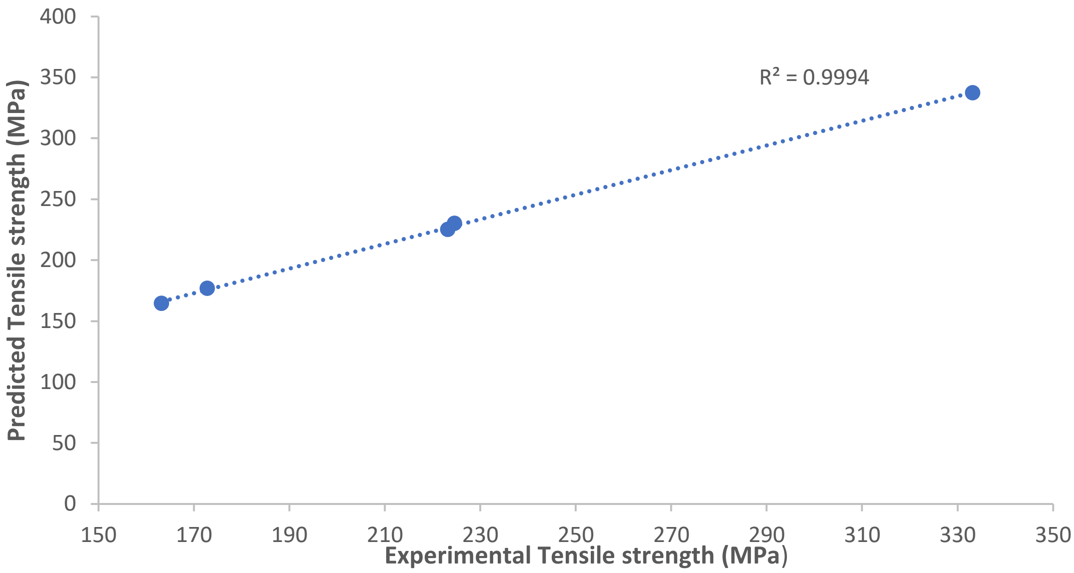

Figure. 10: Correlation of Predicted with Experimental Tensile Strength using Finite Element Modelling

4. Conclusion

Ukam fibre reinforced composites was prepared to experimentally investigate the tensile strength of the composites. A 3D FE model was created using the experimental data and ANSYS software to numerically investigate the tensile strength of the composites. Additionally, the experimental result was compared with numerical result which shows that Alkali treated samples exhibited the highest increase in tensile strength at all fibre loadings. Modulus of elasticity (MOE) and percentage elongation also increased with increase in fibre loading for all treatments. The experimental values of tensile strength at 25 % were in agreement with the FEM tensile strength using ANSYS. There was high correlation between the predicted and experimental tensile strength with R^2 value of 0.9994. The objectives set out in the study was achieved.

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