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Analytical Approach in Materials Selection of Natural Fibre Reinforced Polymer Composites for Car Door Handle

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Abstract: Material selection is an important part of design for engineers, due to the availability of different choice of materials that have common properties and meet the product design specification. The application of only statistical analysis makes it hard to ascertain the best composition of the final product. There is need for combination of statistical, analytical and micromechanical models. This work used resultant natural fibre and polymer matrix to calculate density, Young's modulus and tensile strength. Five levels of fibre loading are used to compare the best natural fibre reinforced polymer composites. From the analytical approach, it is revealed that kenaf/nylon 6, 6 with 40% fibre loading is the optimum composite for car door handle. The optimum composite properties are 1.164 g/cm^3, 23.54 GPa, and 423.12 MPa for density, Young's modulus, tensile modulus correspondingly. There is need to improve the Young's modulus of the composite. There is a clear indication that statistical and analytical approaches are required to select the best composite for automotive use.

Keywords: Natural fibre reinforced composite, rule of mixture, material selection, product design specification

1.0 INTRODUCTION

Over two decades now, many studies have focused on the application of natural(green) materials in automotive, construction, textile, electronic and other relevant industries. Many reviews have been done by researchers on the possibility of green materials substituting their synthetic counterparts in automotive industry [1 -4]. Koronis et al. [5] stated that when natural fibre composites are utilized, the use of petroleum resources will decrease. This will be beneficial to manufacturing industries, product consumers and the ecosystem [6-8]. The benefits of renewable and biodegradable materials have been discussed by many researchers [9- 11]. Asin et al [12] pinpointed that natural fibres are available and cost effective which project them as preferred alternative for reinforcing polymer composites. Sapuam [13] verified that a good system for retaining green resources can decrease the social impacts such as child growth, human rights, economic growth and community development. Pineapple leaf, kenaf, sisal, jute, coir, bamboo, banana stem, hemp, sugar palm, cotton, oil palm and sawdust are some of the natural fibres that can blend with polymer matrix. The high demand for natural fibre composites in industries has brought about an increase in its production [14 -16]. The application of natural fibre reinforced composites is not limited to automotive industry, they are also used in construction, textile, packaging and electronic industries [17 -19]. When natural fibre and polymer matrix are well combined, there is an achievement of superb material performance [20]. The peculiar features of NFRCs would indicate diverse performances as regards chemical, environmental, mechanical and physical properties [21 – 23]. Micromechanics of composites can be ascertained by using micromechanical properties such as physical and mechanical properties. Life cycle assessment can be performed using an integrated method with micromechanical model [24]. Also, micromechanical model is applied in the classification of heterogeneous materials such as composites [25, 26]. In general, micromechanical properties of composites are influenced by many parameters, such as size of fibre, fibre and matrix properties, fibre and matrix loading, fibre and matrix sources, orientation of the fibre and interfacial adhesion between the fibre and the matrix [27- 32]. Tsai-Pagano equation, Rule of mixture (ROM) equation, Halpin-Tsai equation and rule of hybrid mixture (ROHM) equation are frequently used micromechanical models. In this study, ROM is used to calculate the mechanical and physical properties of NFRCs. Al-Oqla et al [33] stated that ROM model is a good approximation to forecast or predict the properties of composites. The model equally predicts the properties of particulate fibre, continuous fibre and random continuous fibre [34]. Therefore, identification of appropriate NFRC is a great task for design engineers in the manufacturing process. Ashby et al [35] stated that more than one material can satisfy a product design specification (PDS) because of the large versatility of the materials in the globe. It is pertinent for design engineers to use powerful and practical materials selection tools in multiple criteria decision making (MCDM) that can minimize time and cost. Most of the surveys on MCDM tools point out the pros and cons of each method [36- 38]. Each MCDM has its strength and weakness. Noryani et al [39] have in their recent study proved that statistical analysis can be among the methodologies used for the MCDM method. The methodology is versatile enough to be used in diverse applications, mainly in

automotive component selection. Noryami et al [38] stated that this numerical solution can control this user's judgment preference. It is factual that there have been many researches on materials selection of NFRCs for automotive components, such as body in white, rims, bumper beam, bonnet, anti-roll bar and hand brake packing lever [40 – 44], not all the automotive components have been studied and most work did not consider the effect of fibre loading on the composites. As a result of this, it is important to carry out a thorough study on best possible fibre loading of the selected final fibre reinforced polymer composites. The above review motivates the inclusion of numerical and analytical solution in applying statistical analysis and a micromechanical model to find out the best possible fibre loading in automotive application. In our study, the resultant natural fibre and polymer matrix from preceding study is used to verify the integration of two approaches according to PDS. Finally, the best possible fibre loading is established by juxtaposing the estimated values from ROM with individual levels of fibre loading. This novel combine approach is believed to give more desirable results in materials selection.

2.0 MATERIALS AND METHOD

2.1 Materials

The following materials are used for this analysis:
Fibre: Banana stems fibre, sisal fibre and kenaf fibre
Matrix: Polyester (PET), High density polyethylene (HDPE) and Nylon 6, 6

2.2 Methodology

The study carried out earlier selected natural fibres and polymer matrix using statistical analysis. The focus of this study is to use ROM to optimize the physical and mechanical properties for fabrication purpose. Figure 1 shows the complete methodology.

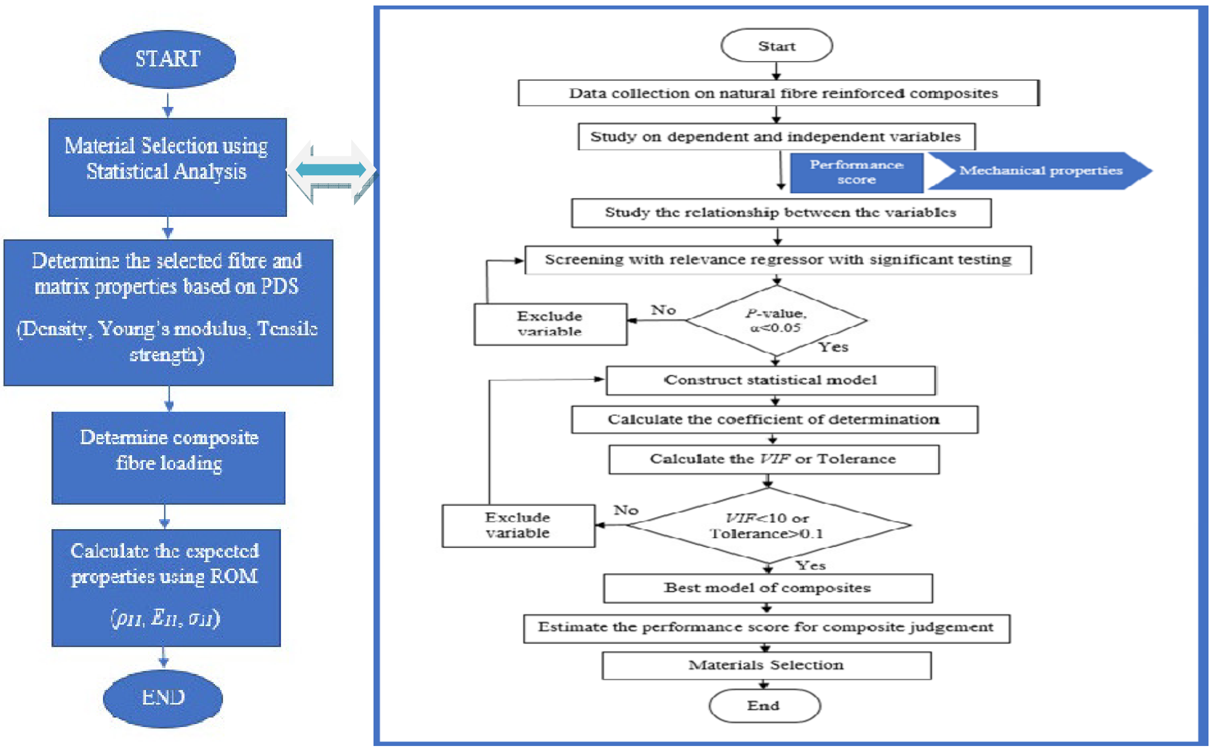

Figure 1: Complete methodology to determine the final natural fibre reinforced composite

2.3 Necessities to Fabricate Car Door Handle

Figure 2 shows that the automotive company should accomplish the PDS to fabricate the car door handle. Density , Young's modulus(Tensile modulus) and Tensile strength are the required properties of the materials that are needed in product design testing for car door handle in the fabrication process [45]. To eschew the failure of the component during testing, the design engineer should choose the appropriate materials that conform to the requirements

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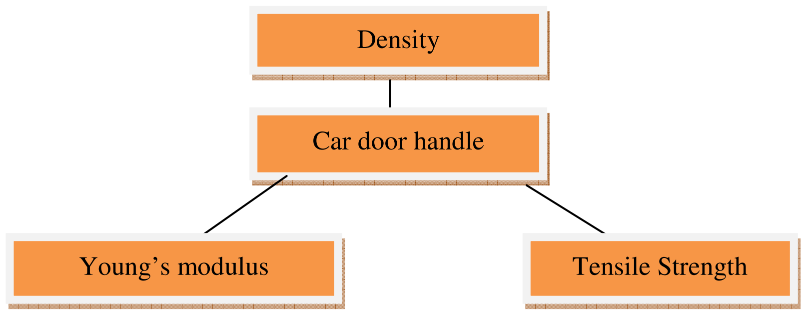

Figure 2: Product design necessity for car door handle

2.4 Analytical approach applying the rule of mixture (ROM)

ROM is a common micromechanical model applied in estimating the mechanical properties of polymer composites of unidirectional continuous long fibre, random discontinuous fibre and particulate fibre. Assumptions made while using ROM are:

a. fibre size and properties are alike for all fibres

b. fibre distribution is uniform and homogeneous

c. there is a good interface between the fibre and matrix

d. deformation of the constituents is within the elastic limit

e. there is no lateral deformation

f. maximum stress is at the middle and zero at both ends of the fibre

g. the fibre and matrix must be void free

Equations 1, 2 and 3 below are used to estimate the density (ρ), Young's modulus (E) and Tensile strength (σ) of the composites

$$\rho_c = \rho_f v_f + \rho_m (1 - v_f) \text{........................} (1)$$

$$E_c = E_f v_f + E_m (1 - v_f) \text{........................} (2)$$

$$\sigma_c = \sigma_f v_f + \sigma_m (1 - v_f) \text{........................} (3)$$

Where:

p_c = density of composite (g/cm^3)

p_f = density of fibre (g/cm^3)

p_m= density of matrix (g/cm^3)

E_c= Young's modulus of the composite (GPa)

E_f = Young's modulus of fibre (GPa)

E_m = Young's modulus of matrix (GPa)

σ_c = Tensile strength of composite (MPa)

σ_f = Tensile strength of fibre (MPa)

σ_m = Tensile strength of matrix (MPa)

v_f = Fibre loading (%)

3.0 CASE STUDY OF MATERIALS SELECTION FOR CAR DOOR HANDLE

By using analytical approach, the final natural fibre reinforced composite is selected for car door handle.

3.1 Problem Statement

In recent time, the demand for the application of natural fibre composites in automotive industry is increasing, the highest annual growth is in Europe where it increased by 48% [46]. Year by year, continuous increase in demand is expected of these materials. The replacement of traditional materials such as steels and cast iron with green-based ones has a positive impact on the environment and the consumers of the product [47]. NFRPC is now attractive to design engineers all over the world. The objective of this study is to find out the optimal fibre-matrix composition to manufacture car door handle based on the PDS proposed by the industry. Design engineers could encounter challenges in selecting the best NFRPC with superb combination. As a result of this, statistical and micromechanical models are relevant approaches to be considered so as to produce a good component for the industry.

3.2 Product Design Specifications of car door handle

Product design specification	Requirement
Tensile strength	460 MPa
Young's modulus	200 GPa
Density	7.85 g/cm^3

Table 1: Materials specifications of car door handle [48]

Natural fibre and polymer matrix	Density (g/cm^3)	Young's Modulus (GPa)	Tensile strength (MPa)
Banana	1.350	30	598
Sisal	1.450	10	550
Kenaf	1.2	53	930
Polyester (PET)	1.345	5	60
HDPE	0.9585	1.5655	4
Nylon 6, 6	1.14	4	85

Table 2: Mechanical properties of natural fibre and polymer matrices

3.3 Analytical solution of NFRPCs using ROM

The volume fraction of the fibre (v_f) is varied from 0 % to 40% and that of the polymer matrices (1-v_f) varied from 60% to 100%.

Fibre Loading	banana+PET	banana+HDPE	banana+nylon6,6	sisal+PET	sisal+HDPE	sisal+nylon6,6	kenaf+PET	kenaf+HDPE	kenaf+nylon6,6
0 vol%	1.345	0.9585	1.14	1.345	0.9585	1.14	1.345	0.9585	1.14
0.1vol%	1.3455	0.99765	1.161	1.3555	1.00765	1.171	1.3305	0.98265	1.146
0.2vol%	1.346	1.0368	1.182	1.366	1.0568	1.202	1.316	1.0068	1.152
0.3vol%	1.3465	1.07595	1.203	1.3765	1.10595	1.233	1.3015	1.03095	1.158
0.4vol%	1.347	1.1151	1.224	1.387	1.1551	1.264	1.287	1.0551	1.164

Table 3: Density data of the three different composites

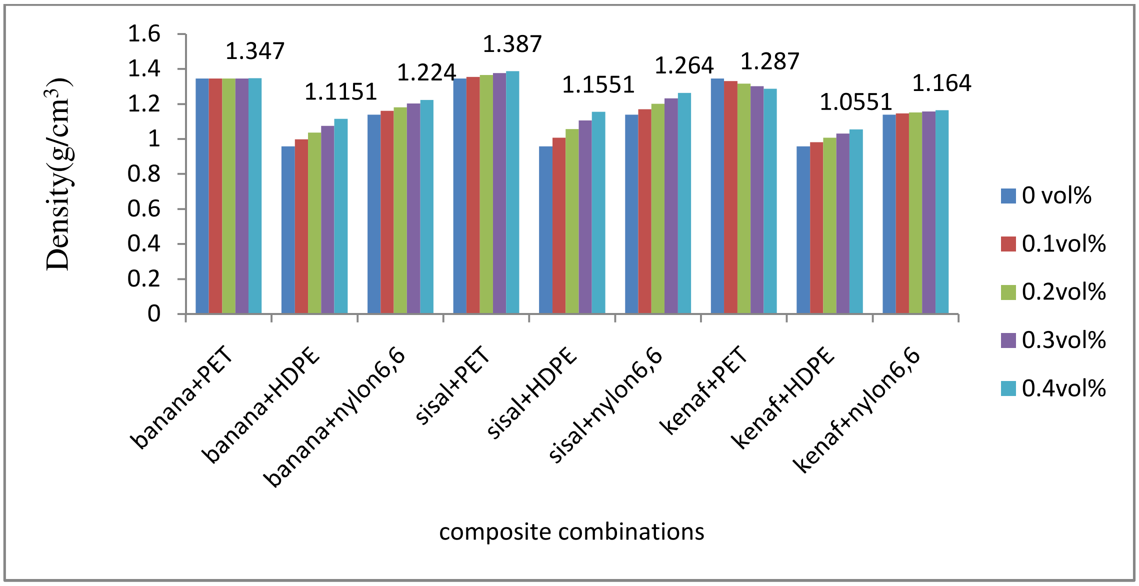

Figure 3: Prediction of the density for natural fibre reinforced polymer composite

Fibre Loading	banana+PET	banana+HDPE	banana+nylon6,6	sisal+PET	sisal+HDPE	sisal+nylon6,6	kenaf+PET	kenaf+HDPE	kenaf+nylon 6,6
0 vol%	5	1.5655	3.9	5	1.5655	3.9	5	1.5655	3.9
0.1vol%	7.5	4.40895	6.51	5.5	2.40895	4.51	9.8	6.70895	8.81
0.2vol%	10	7.2524	9.12	6	3.2524	5.12	14.6	11.8524	13.72
0.3vol%	12.5	10.09585	11.73	6.5	4.09585	5.73	19.4	16.99585	18.63
0.4vol%	15	12.9393	14.34	7	4.9393	6.34	24.2	22.1393	23.54

Table 4: Young's modulus data of the three different composites in GPa

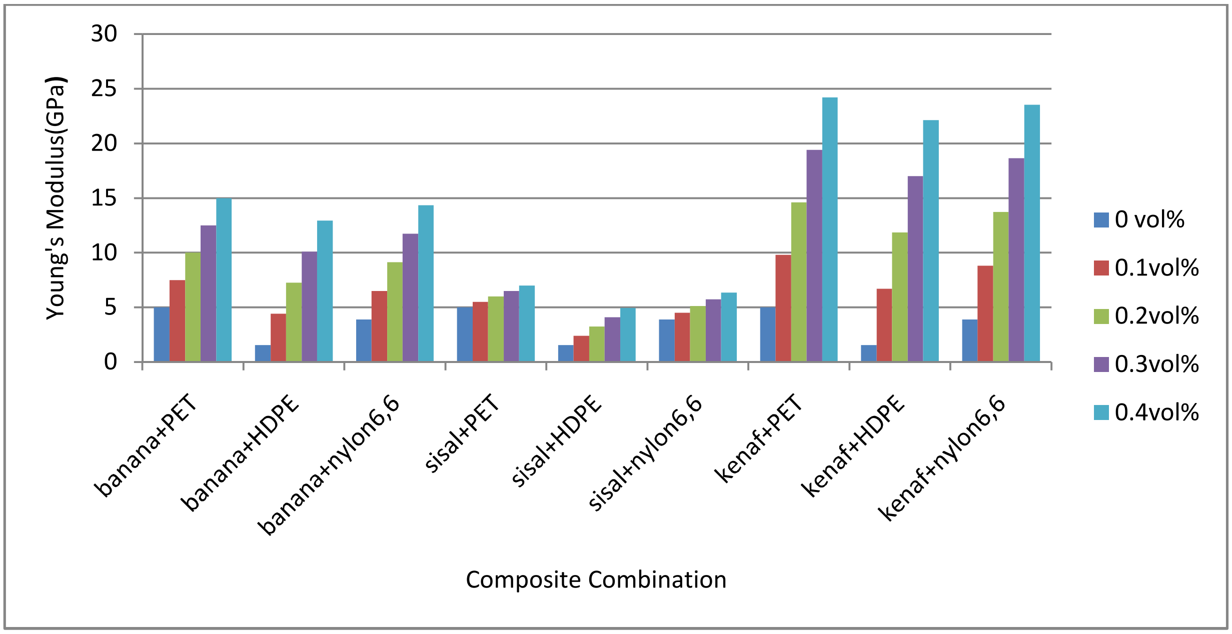

Figure 4: Prediction of the Young's modulus for natural fibre reinforced polymer composite

fibre loading	banana+PET	banana+HDPE	banana+nylon 6,6	sisal+PET	sisal+HDPE	sisal+nylon 6,6	kenaf+PET	kenaf+HDPE	kenaf+nylon 6,6
0vol %	60	4	85.2	60	4	85.2	60	3.8	85.2
0.1vol %	113.8	63.4	136.48	109	58.6	131.68	147	96.42	169.68
0.2vol %	167.6	122.8	187.76	158	113.2	178.16	234	189.04	254.16
0.3vol %	221.4	182.2	239.04	207	167.8	224.64	321	281.66	338.64
0.4vol %	275.2	241.6	290.32	256	222.4	271.12	408	374.28	423.12

Table 5: Tensile strength data of the three different composites

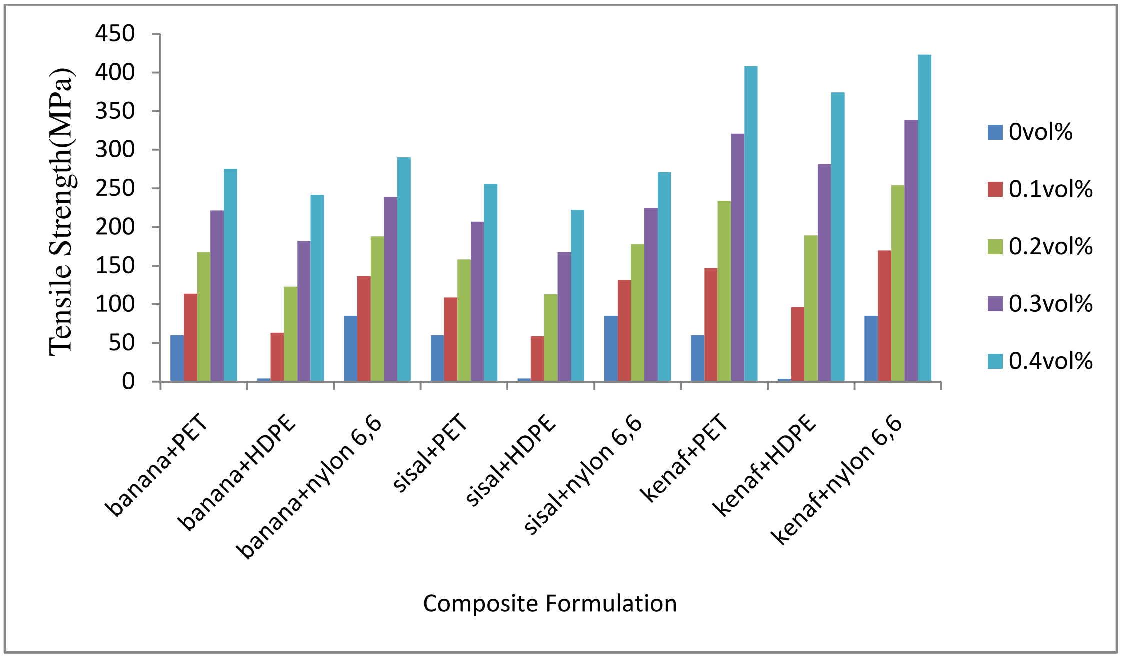

Figure 5: Prediction of the Tensile strength for natural fibre reinforced polymer composite

From figure 5, the kenaf/nylon 6,6 with 40% fibre loading indicates a good tensile strength value which is close to the PDS to manufacture car door handle , which is 460 MPa. In line with this design, kenaf/nylon 6, 6 with 40% fibre loading of tensile strength 423.12 MPa is the best combination. A review by Faruk et al [49] on bio-composite reinforced with natural fibres from year 2000 to 2010 showed a good interaction between the fibre and polymer at 40% fibre loading. Researchers have used a constant fibre loading; for instance, a case study of Pugh selection used 40% fibre loading of kenaf, sisal, flax, hemp, coir, jute, and oil palm empty fruit [50].

4.0 CONCLUSION

The predicted physical and mechanical properties of the PDS to fabricate car door handle were estimated using micromechanical modeling, which is rule of mixture (ROM). Different fibre loadings were utilised from the resultant fibre and polymer matrix values based on the work done before. Nine combinations were done between the natural fibre and the polymer with five loadings. From the analysis done and comparison of density, Young's modulus and tensile strength, the final composite with suitable loading that optimised the performance was selected. The kenaf/ nylon 6,6 with 40% fibre loading is chosen as the appropriate composite to manufacture car door handle with these values, 1.164 g/cm^3, 23.54 GPa and 423.12 MPa of density, Young's modulus and Tensile strength respectively.

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