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Optimization of Desert Date Particles Reinforced Composite for Vehicular Instrument Panel

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Abstract: Finding suitable material for a certain application in engineering is an essential task at early state of the product development. To achieve this, various materials selection methods have been developed. This study adopted the use of computational method in evaluating the material properties which is quite easy and bereft of complex mathematics, as against experimental techniques of trial and error characterized by time consuming effort and cost. Appropriate volume fraction (V_f) of randomly distributed reinforcing agents (Desert date particles) in polypropylene resin that gave suitable candidate properties at a minimum deviation errors were computed using classical method (weighted sum) in simulink MATLAB environment. The composite produced was found suitable to replace the synthetic particles reinforce composites used for vehicular Instrument panel which are relatively heavy, expensive, emits bad odor when exposed to heat energy, not biodegradable and pose risk to health during processing. The optimum value of volume fraction 19% was used to prepare and produced two samples-212 μm (sample B) and 300 μm (sample E) sizes using compression molding technique.
Keywords: composite, vehicular instrument panel, Matlab, volume fraction

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Introduction

Manipulations in material technology have yielded materials with improved service life, manufacturing, economics and environmental properties. Among the recent developments in engineering materials are composites which have the potentials of integrating metals, ceramics, polymers and other natural materials in order to obtain new materials with high strength, hardness and other properties that make them withstand various service conditions (Swamy and Chandru, 2015).

Composite are heterogeneous materials, that is, they composed of two or more discontinuous components at a microscopic scale and have physical and chemical distinct phases embedded in a continuous phase that results in better properties that are not found in either of the individual material. The matrix binds the reinforcement together and the loads applied to the composites are then transferred into the reinforcement through the matrix, enabling the composite to withstand operational condition. The ability of composites reinforced with fibers or particulate to support loads of any kind is dependent on the presence of the matrix as the load transfer medium, and the efficiency of this load transfer is directly related to the quality of the fibre/matrix bond phase (Wang *et al*., 2016).

Finding suitable material for a certain application at early state of the product development could reduce the high cost of materials production (Atuanya *et al.,* 2014). To achieve this, various materials selection methods have been developed in recent time. Ashby (2005) provided a chart that can be used for materials selection process in a compact and easy way. The chart provided relationships between materials constituents, structure and properties at a level that allows composition and processing parameters to be selected to create composite materials with target properties. Such relationships can be detected with empirical experiments, mathematical and computational models (Zhang and Tian, 2008). Sapuan *et al.*, (2011) designed a prototype expert system for material selection. This system known as knowledge-based system enables the designers to choose most appropriate polymeric composite materials reinforced with wide number of natural long fibres. The aim of this study is to provide simple means of simulating and optimizing properties of organic (Desert date) particles reinforced polypropylene matrix composite material suitable for vehicular instrument panel from a developed system block using Simulink MATLAB environment.

Desert date (*Balanite aegyptiaca*) is the most widely distributed tree in Africa. It is also found in Israel, Arabia, India and Pakistan (Manji *et al*., 2013). Its high concentration prevails in Sahel and Sudan savanna zone of West Africa and semi-arid regions of East Africa. Every part of the tree is of great importance. Its root and bark are used for fishing, the wood as yoke for draught animals and hand implements, while humans find the leaves and flesh of the ripe fruit very nutritional (Mamman *et al*., 2005). The fruit has thin brittle epicarp, a fleshy mesocarp and a woody endocarp containing the oil seed or kernel. The endocarp is the most important part of the Desert date tree (Shanks and Shanks, 1991). It contains kernel or seed that produces oil and protein in the range of 30-60% and 20-30% respectively. The fleshy mesocarp and the oil are commonly used but the endocarp remains waste as of today.

Materials and Methodology

Desert date characterization

Desert date nuts were collected from Shafali forest and socked in water for 4 hours then stired thoroughly with stick, the epicarps and mesocarps were removed manually. The endocarps Plate I were sun dried for 10 hours and cracked thereby removing the kernels. The endocarps were then ground to micro meter sizes using attrition grinding mill, and the particles powder were sieved using a set of sieves. Particles sizes of 212 **µ**m and 300 **µ**m were obtained as can be seen in plate II (a and b).

Density of particles

Air-dried particles of desert date (10g) were placed in an oven for 24 hours at a constant temperature of 100°C, and the oven-dried particles were measured. Empty density bottles (QQ and OO) were also weighted on an electric weighing machine. The oven-dried particles were pored in density test bottles and soak in distile water for 24 hours. The weight of density bottles plus particles and water were determined after which the weight of displaced water was found (ASTM, D 2395-1989). Log of dry particles and liquid displaced were calculated and the log of liquid displaced was subtracted from the log of dry particles. The result was added to the log of specific gravity of water to obtain the log of specific gravity of the particles. The antilog of the log of specific gravity of the particles gives the specific gravity of the particles. The results were multiplied by the density of water and average was taken to obtain the density of the desert date particles Table 5.

a b

Plate 1: Desert date endocarps. Plate II: Desert date particles, (a) 212**µ**m and (b)300**µ**m

Simulation

A Simulink System Block of the problem was developed to simulate the properties of the Desert date particles reinforced polypropylene composite suitable for Instrument Panel. This was done using tensile modulus, ultimate tensile strength of the matrix and density of matrix and particles as an input in the developed model to determine the appropriate volume fractions of the particulate and the resin at minimum deviation errors.

The following procedure was carried out:

1. Existing mathematical model equations (eqn.5, eqn.6 and eqn.7) connecting the variables were used.

2. Equation was written in to a single multi-objective relations that optimized the required objectives functions (minimize density and maximize ultimate tensile strength and modulus) using weighted sum method thus:

$$E_T = \lambda_1 \left| \delta_C^{desired} - \delta_C^{Actual} \right| + \lambda_2 \left| E_C^{Desired} - E_C^{Actual} \right| + \lambda_3 \left| \rho_C^{Desired} - \rho_C^{Actual} \right| \quad \ldots(1)$$

3. Simulink system block (Figure 1) for the minimization of density and maximizition of ultimate tensile strength and tensile modulus was developed so as to obtain range of values with mimnimal deviations error per run.

4. The range of values with mimnimal deviations error per run were optimized in a MatLab custom requirement and optimal value of the volume fraction obtained was used to prepare samples.

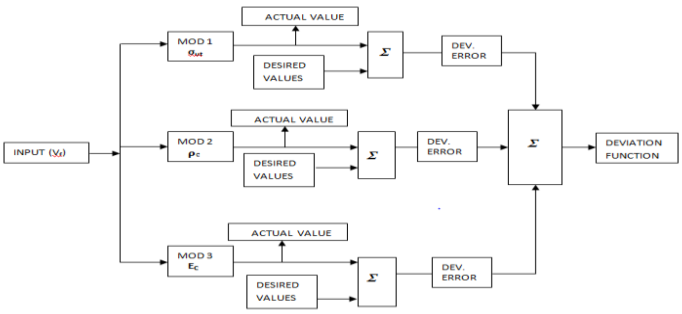

Figure 1. Simulink System Block

Equations

The rule of mixture equations as reported by Xanthox, (2010), are commonly used to describe certain properties of composites. Like the concentrations of constituents in composites are usually expressed by volume, as volume fraction of reinforcements V_f and matrix V_m, obtained from the volumes V_f and V_m of the individual coponents.

$$V_f = \frac{V_f}{(V_F + V_M)} \quad \dots (2)$$

$$V_M = \frac{V_M}{(V_F + V_M)} \quad \dots (3)$$

$$V_f + V_m = 1 \quad \dots (4)$$

Also, volume fractions (V_f) are used to predict the theoretical density of composites based on the respective densities of the components as given by Nicholas, (1976) as thus:

Density of composite, $\rho_c = \rho_m + (\rho_f - \rho_m)V_f$ ... (5)

Where $\boldsymbol{\rho}_c$ is the density of composite, $\boldsymbol{\rho}_m$ and $\boldsymbol{\rho}_f$ are densities of matrix and reinforcement respectively.

The tensile modulus of a particulate composites can be predicted from Neilsen's model,

$$E_C = E_m(1 + 2.5V_f) \quad \dots (6)$$

The ultimate tensile strength of filler is more difficult to predict than the tensile modulus. Unless there is a good bonding between the filler and the matrix, the fillers do not share much load with the matrix; instead, they merely act as source of stree concentration. In the case of no adhesion, the ultimate tensile strength of the filled polymer decrease with increasing volume fraction (Mallick, 2001). Ku *et al.*,(2013) reported that Wong's model known as power law (equation 8) fit well for particulate reinforcement in which adhesion between the reinforcement and the marix is not too bad.

$$\sigma_{cu} = \sigma_{mu}\left(1 - bV_f{}^n\right) \quad \dots (7)$$

$$\sigma_{cu} = \sigma_{mu}\left(1 - 1.21V_f{}^{\frac{2}{3}}\right) \quad \dots (8)$$

Where σ_{cu} is the ultimate tensile strength of the composite, and σ_{mu} is ultimate tensile strength of the polymer, the constant 1.21 represent the particles interaction (b) for organic (spherical) particulates and $2/3$ represent arrangement in the model composite (n).

If there is good adhesion between the polymer particles and the surrounding polymer, there may be some load shearing between the two. However, the extent of load sharing may depend on the shape and size of fillers. If the fillers are platelet or fibrous, there may be some strengthening, otherwise the strength of the composite may not be much affected by the presence of fillers.

Results and Discussion

Simulation Result of the Composite

From the Matlab Simulink system block developed, each of the three models was evaluated for minimal deviation error so as to find the possible combinations referred to as evaluated desire values that can be run. Six desired values were realized, as can be seen in Table 1. The first desired properties are 23 MPa, 2217 MPa and 910 kg/m^3 for ultimate tensile strength, tensile modulus and density respectively (Table 1). The result of the runs shows the volume

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fraction (V_f) at which ultimate tensile strength (σ_{ut}), tensile modulus (E) and density (ρ) could be obtained with their associated deviation errors Figures 2, 3 and 4.

Table 1. Evaluated Desired Values

Properties	σ_{ut} (MPa)	E (MPa)	ρ (Kg/m^3)
1st run	23	2217	910
2nd run	23	2254	908
3rd run	22	2292	906
4th run	22	2329	905
5th run	21	2367	903
6th run	21	2404	901

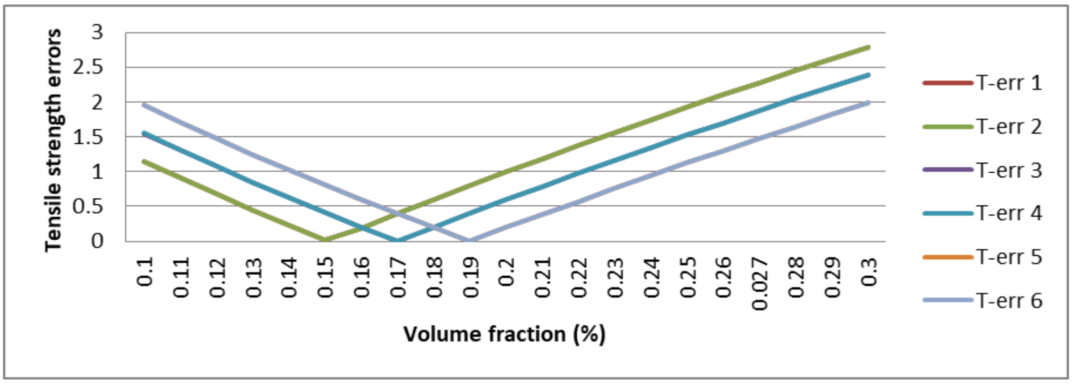

Figure 2. Ultimate tensile strength deviation errors

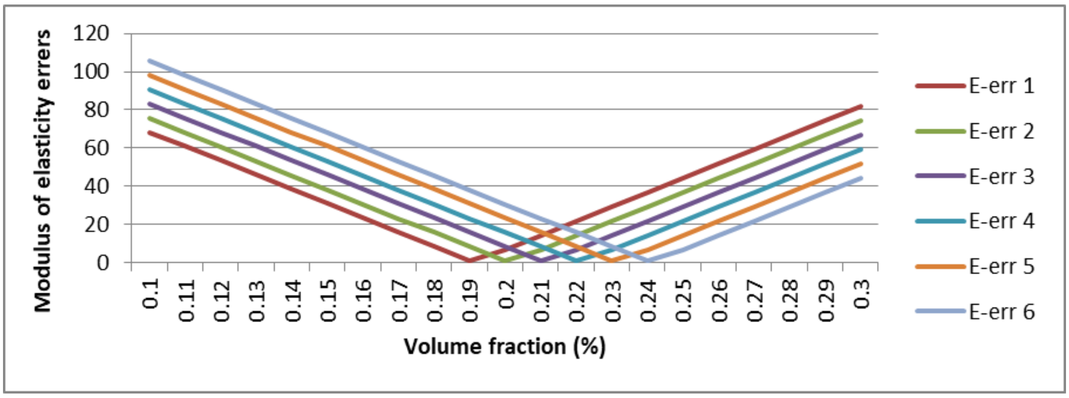

Figure 3. Modulus of elasticity deviation errors

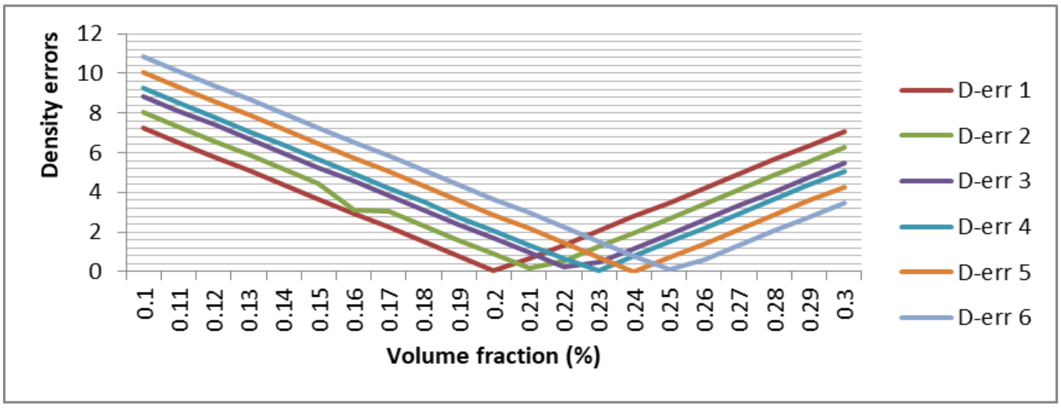

Figure 4. Density deviation errors

From Figure 2, 3 and 4, it is obvious that, the minimal deviation errors for the material's properties is recorded between 0.19 to 0.22 $V_{f,}$ hence these properties becomes new desired values; and therefore were optimized to find values with minimum deviation errors using Matlab Custom Requirement. The optimum result is presented in Table 2.

Table 2. Optimum Material Properties

Properties	$\sigma_{ut\,C}$ MPa	E_C MPa	ρ_C (Kg/m^3)	$\sigma_{ut\,C}$-err	E_C -err	ρ_C-err	V_f
Desired values	21	2325	906.6	0.3849	7.5	0.724	0.20
Optimized values	20.02	2325	911.98	0.3496	13.87	0.8237	0.19

The optimum volume fraction was used to calculate the equivalent mass fraction of the desert date particles, thus:

$$V_{fp} = \frac{V_p}{P_p + V_m + V_{MAPP}} \qquad \dots (9)$$

Where, V_{fp} = volume fraction of desert date particles,

V_p = volume of desert date particles in 100g of the composite $= \frac{mass}{density} = 16/0.767 = 20.86$ cm^3.

V_m = volume of matrix (PP) in 100g of the composite $= \frac{mass}{density} = 80/0.946 = 84.57$ cm^3.

V_{MAPP} = volume of MAPP in 100g of the composite $= \frac{mass}{density} = 4/0.854 = 4.68$cm^3

The volume fraction of desert date particles $=20.86/20.86 + 84.57 + 4.68 = 0.19\%$. Therefore, the volume fractions of desert date particles, PP and MAPP are 0.19%, 0.768% and 0.042% respectively. The summation of this result gives unity as required by law of mixture.

Optimization of the Composite

The optimal material properties evaluated from the developed model is presented in Table 7. It was observed that the optimal values for ultimate tensile strength (20 MPa), modulus of elasticity (2325 MPa) and the density (912 Kg/m^3) are all within the standard range for vehicular instrument panel given by Borealis group (2010). The deviation errors associated with the predicted results of ultimate tensile strength and density were negligible, indicating that Tavman's and Nicholas' models can suit well for prediction of organic particulate ultimate tensile strength and density as opposed to only synthetic particulate as presented by Ku *et al.*, (2013). The deviation errors associated with modulus of elasticity are much; this resulted to obtaining experimental value below standard of vehicular instrument panel.

Ultimate Tensile Strength of Composite

The results of ultimate tensile strength of developed composites are presented in Table 3. It was observed that Tavman's model could not predict the ultimate tensile strength of glass powder filled epoxy as reported by Ku *et al.*, (2004) accurately because the factor of 'b' used is for poor adhesion and spherical particles, a clear characteristic of organic rather than inorganic particles. As such, Tavman's model was found suitable for this study because the prediction of ultimate tensile strength (20 MPa) was satisfactory. The least value required for ultimate tensile strength of vehicular instrument panel is 20 MPa (Borealis and Borouge, 2010 and 2014) and tensile strength of 22 MPa was observed for sample E and 26.3 MPa for sample B which is 16.3% higher than that of sample E. The low value of tensile strength for sample E is due to inadequate dispersion of the desert date particles and large inter-particles distance.

Table 3. Ultimate Tensile Strength of Sample B and E

Samples Specimens		Major unit (N)	Minor unit (N)	Result of major and minor units	Area	Result of area
B	B_1	8x120	9x12	1068	10x4.5	45.00
	B_2	9x120	6x12	1152	10x4.4	44.00
	B_3	9x120	8x12	1176	9.4x4.3	40.42
			Result	3396	Result	129.42
			Average:	**1132**	**Average:**	**43.12**
Ultimate tensile strength (UTS) = $Load/Area = 1132/43.12 = 26.3\ N/mm^2$						
E	E_1	7x120	6x12	912	9.8x4.4	43.12
	E_2	7x120	5x12	900	10x4.4	44
	E_3	8x120	2x12	984	9.5x4.5	42.75
			Result	2796	Result	129.87
			Average:	**932N**	**Average:**	**43.29** mm^2
Ultimate tensile strength (UTS): $Load/Area = 932/43.29 = 22\ N/mm^2$ **or (MPa)**						

Modulus of Elasticity of Composite

It was discovered from flexural strength results in Table 4 that sample B (212**µ**m) exhibited more modulus of rupture than sample E (300 **µ**m). This implied that particles distribution is directly related to modulus of rupture. Reverse is the case for modulus of elasticity; meaning, the higher the particles distribution the lower the modulus of elasticity. This is why sample E (300 **µ**m) exhibited higher modulus of elasticity. The result is in line with what Mallick, (2001) reported, that the tensile modulus increases with decreasing particle size. The result is less than optimized and standard value required; this can be associated to unsuitability of Neilsen's model for prediction of Modulus of organic particlec reinforced composites materials.

Table 4. Flexural Stress and Moduluse of Elasticity of Sample B and E

Samples	Flexural stress (MPa)	Modulus of elasticity (MPa)
B	78.79	1199.5
E	70.73	1347.5

Density of the composite

The experimental density of samples B and E are shown in Table 5. It was found from the optimized result of the density (911.98 (Kg/m^3**)** that Nicholas' model predicted the result quite well, because the result is not far away from that of standard. Also, the optimized densities are close to that of experimental.

It was observed that sample E density is higher than that of sample B. This indicates that there is better encapsulation of the particles in sample B than in sample E. Both of them yielded results lower than the maximum value required (1180 Kg/m^3) by the (Borealis and Borouge, 2010 and 2014). This confirms that the composites are lighter as presumed. Since the results obtained are very close to the optimized, by the void content of the samples are also very low (less than unity); a value that judges composites as good.

Table 5. Density of Sample B and E

Samples	B	E
W_1 is weight of empty Pycnometer (g),	485.31	485.31
W_2 is weight of empty Pycnometer + weight of dry sample (g),	527.12	526.61
W_3 is weight of empty Pycnometer + weight of saturated sample + weight of water (g),	1367.73	1367.34
W_4 is weight of empty Pycnometer + weight of distil water in full.	1371.21	1371.21
Results (kg/m^3)	**0.92316** **∴ρ = 923.2**	**0.9256** **∴ρ= 925.6**

Conclusion

The followings conclusions can be drawn from the studies undertaken:

1. The desert date particles used was found to have less dense and therefore can be used to produce lighter particulate reinforce polypropylene matrix composite material that can be used for vehicular instrument panel.
2. The existing mathematical equations were used to develop system block diagram in Matlab simulink environment that simulate the material properties and the results were optimized. The volume fraction of desert date particles at the optimum properties was considered for the production of the composite material. The volume fraction was found to be 19 %.

Recommendations

It is recommended that:

1. The existing mathematical models should be improved to incorporate reinforcement particle sizes.

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