Effect of particle size and concentration on the mechanical properties of polyester/date palm seed particulate composites

Alewo Opuada AMEH[1*], Mohammed Tijani ISA[2], Ibrahim SANUSI[3]

[1] *Department of Chemical Engineering, Landmark University, Omu-Aran*
[2, 3] *Department of Chemical Engineering, Ahmadu Bello University, Zaria*
E-mails: *ameh.alewo@lmu.edu.ng; mtisaz@yahoo.com; ibsanusi2012@gmail.com
[*]Corresponding author, phone: +2348035600744

Abstract

The use of cellulosic materials as reinforcement in composites can greatly enhance their properties. The thrust of this study was to investigate the effect of date palm seed particle on the properties of reinforced polyester. Unsaturated polyester resin was reinforced with date palm seed particles of 0.5, 2.0 and 2.8mm particle sizes using variable particle loadings of 5, 10, 15, 20 and 25wt%. The composites obtained were subjected to various types of mechanical and physical tests in order to assess their performance. The optimum tensile strength of 16.7619N/mm^2 and elastic modulus of 343.8N/mm^2 were attained at 15wt% and 10wt% loading (using 0.5mm particles) respectively and percent water absorption was found to be least for 0.5mm particle size. The hardness was enhanced to the maximum of 74 HRF (Rockwell Hardness Factor) by 2mm particle size at 25wt% loading. Pure unsaturated polyester resin recorded tensile strength of 17.5959N/mm^2, elastic modulus of 316.7N/mm^2 and hardness of 33.5 HRF. The results indicated that the use of date palm seed particles as reinforcement can enhance the properties of polyester composites.

Keywords

Date palm seed; Polyester resin; Composite

Introduction

Composites are combinations of two materials in which one of the materials in the form of fibers, sheets, or particles called the reinforcing phase, is embedded in the other material called the matrix phase. The use of natural plant fibers in composites exists since ancient times [1, 2]. The use of vegetable fibers continues to generate interest especially for use in the plastic industry for they are renewable natural resources and biodegradable [2 - 6]. Some natural fibers which have been investigated for use include flax, hemp, ramie, sisal, jute, rice husk, rattan, kenaf, rye, piassava, etc. It is thought that the use of vegetable fibers as reinforcement allows the acquisition of composite products, which, besides possessing smaller apparent specific mass and higher porosity, offers still, satisfactory values of traction and impact resistance, greater control of cracking and ductile behavior during break [7 – 10].

Date seeds are considered as waste product in the production of pitted dates, date syrup and date confectionery from date fruit. The seeds may also be used as food for ruminant, poultry birds and vegetable oil source [11]. The use of natural fibers in thermoplastic composites serves to improve the toughness and strength of the plastic. Fibers sourced cellulosic materials are considered to be of relatively higher strength, lower density, cheaper, more abundant and renewable [12]. The present study is channeled towards producing a composite using an unsaturated polyester resin (as matrix) and date palm seed particle (as reinforcement) and to investigate the effect of date palm seed particles on the mechanical and physical properties of the composite.

Material and method

Date palm seeds were procured from Samaru village, Zaria. The collected seed were rinsed with deionized water and dried under ambient condition. The general-purpose polyester resin, Methyl ethyl ketone peroxide (MEKP) and cobalt napthenate were obtained from Kaduna State, Nigeria.

Crushing of the date palm seed

The date palm seeds were crushed using mortar and pestle alongside the use of two impact crushers (Foss Sample Mill, Cyclotec™ 1093and Thomas Wiley Laboratory Mill,

Model 4) and sieved into the required particle size of 0.5mm, 2mm and 2.8mm. 400g of each particle size was prepared.

Casting of the composite material

Composites were prepared using variable quantities and sizes of date palm seed particles. The mold for every casting was properly scraped, cleaned and well lubricated. Reinforced polyester composites of two thickness (4mm and 10mm were prepared). The quantity of polyester resin required for each sample was measured and poured into the cup. The required quantity of crushed date palm seed was then added and mixed. 1wt% of the catalyst (MEKP) was added and stirred for 2 minutes after which 1wt% of the promoter (cobalt napthenate) was added and stirred for 3 minutes. The mixture was then carefully poured into the prepared mould to cure, which took 24 hours inside the fume cupboard. The cured composites from the mould were post cured in the oven drier, at 60°C for 3 hours. The prepared samples were then cut according to America Society for Testing and Materials (ASTM), and the available machine specification present for testing and analysis.

Hardness test

Hardness test was conducted using the Universal Hardness Tester of Indentec, UK (Model 8187.5 LKV) (Figure 1).

Figure 1. *8187.5 LKV B Indentec universal hardness testing machine*

The dimension of the prepared test samples was (10mm×80mm×10mm) and surfaces smoothness was maintained. The data obtained was analyzed using Equation 1.

$$HRF = E - e \quad (1)$$

where: HRF = Rockwell hardness factor; E = a constant depending on form of indenter, e.g. 130 units for steel ball indenter used; e = permanent increase in depth of penetration due to major load measured in units of 0.002mm.

Tensile test

Hounsfield (Monsanto) tensometer (Universal Testing Machine) (model No. S/N 8889) was used to determine the elastic modulus, ultimate tensile strength and percentage elongation in length of the materials. The specimen geometry was in a dumb-bell shape and the dimensions were ascertained using the vernier calipers. Uni-axial load was applied to each ends of the respective samples until it fails. Stress-strain curves were plotted from the force-extension data obtained on a special graph paper during the tests and the required mechanical properties were determined on the curve. Modulus of elasticity was obtained as:

$$E = \sigma/\varepsilon \quad (2)$$

where: σ = Stress induced in the body; E is the Modulus of elasticity for the material of the body; ε is the Strain produced in the body.

Flexural test

The test was conducted following 3-point ASTM standard. The maximum stresses absorbed were noted and recorded [9]. The data obtained from the test was then analyzed using Equation 3.

$$\sigma_f = (3P_{AV} \cdot L)/(2bd^2) \quad (3)$$

where: σ_f = flexural strength; P is the force (N); L is the distance between the support span (mm); b is the specimen width (mm) and d is the specimen thickness (mm).

Density test

The mass of each sample was determined using an analytical weighing balance and the volume determined using (i.e. length×breadth×width); the dimensions of each side accurately measure using vernier calipers. The density was computed as the ratio of mass to volume (kg/m^3).

Impact strength test

The Charpy impact testing machine was used. Samples of dimensions (10mm × 20mm × 80mm), with a notch of 2mm at 45° radii were place in a Charpy V-notch across the parallel

jaw in the machine. Heavy pendulum was then released from a known height to strike the samples on its downward swing which fractured the samples. The energy absorbed was noted and recorded. This test was conducted on each sample produced. The data obtained was examined using Equation 4.

$$\text{Impact strength} = (\text{average Energy})/ [(\text{Width-Notch}) \times \text{Thickness}] \quad (4)$$

where: Width = 10mm; Notch = 2mm; Thickness = 10mm.

Hence, $[(\text{Width-Notch}) \times \text{Thickness} = (10-2) \times 10 = 80\ mm^2 = 8 \times 10^{-5} m^2$

Water absorption test

Tests samples were weighted after oven-drying for 24 hours at 50°C. The samples were then placed in deionized water for 24 hours after which they were weighted again. Water absorption was recorded as the percentage increase in weight.

Microstructure test

Micro-structural observation of each respective sample was also taking digitally, using computerized metallurgical microscope.

Results and discussion

Figure 2 shows the relationship between the tensile strength, the particles sizes and loadings. The relationship between the elastic modulus, the particles sizes and loadings was obtained as shown in Figure 3. The relationship between the elongation (expressed in percentage), the particles sizes and loadings is presented in Figure 4. Figure 5 shows the relationship between the impact strength, the particles sizes and loadings. The relationship between the hardness, the particles sizes and loadings was as well obtained as graphically shown in Figure 6. Figure 7, shows the relationship between the flexural strength, the particles sizes and loadings. The relationship between the percent water absorbed, the particles sizes and loadings was obtained as shown in Figure 8. The relationship between the density, the particles sizes and loadings was obtained as shown in Figure 9. Micro-structural observations are presented in Figure 10.

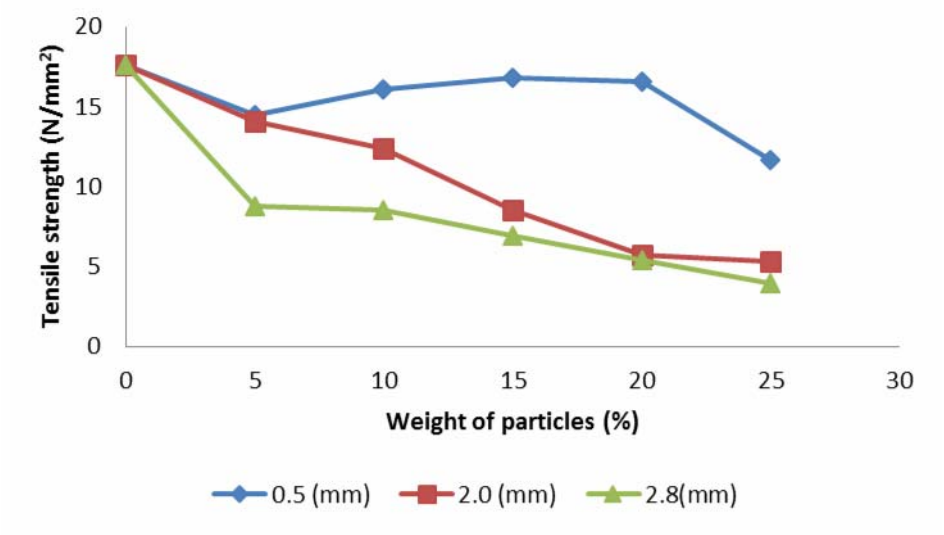

Figure 2. *Effect of particle sizes and loadings on the tensile strength*

Figure 2 shows the relationship between the tensile strength, the particles sizes and loadings. It was observed that, for samples 0.5mm size, the tensile strength first decreased with 5wt% loading due to the poor particles distribution also confirmed by the micrographs in Figure 10b-i and later, the strength increased with 10 and 15wt% loading which agree with the findings of Kumar et al [9], that the reduced size of the reinforcement particles is believed to be effective in improving the strength of the composites. Afterward, it decreased with 20 and 25wt% loading as expected. This decrease and the tensile strength of 2mm and 2.8mm particle sizes that also decreased as the particle loading increased, support the work reported by [13] that, the rate of decrease in tensile strength is higher for higher particles loading and higher particle size. Hence, the optimum tensile strength was attained with 15wt% loading of 0.5mm particle size.

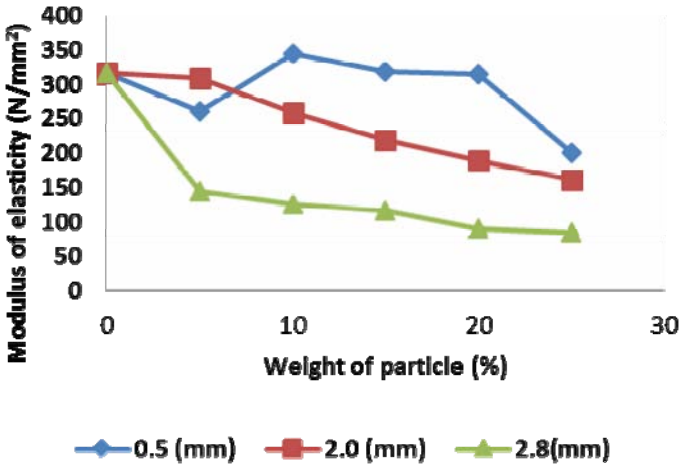

Figure 3*. Effect of particle sizes and loadings on the elastic modulus*

The relationship between the elastic modulus, the particles sizes and loadings was obtained as graphically shown in Figure 3. It was observed that, for samples 0.5mm size, the elastic modulus first decreased with 5wt% loading due to the poor particles distribution within the polyester and afterward increased with 10wt% loading may be due to due to unfavorable geometrical features particles which could moderately increase the modulus as also reported by Aruniit et al [14]. The modulus later decreased with 15 and 25wt% loading due to the fair to poor interface existing between the particle and the polyester as confirmed by the micrographs in Figure 10(d-f). The elastic modulus of the 2mm and 2.8mm particle sizes decreased as the particle loading increased due to the higher particle size of the samples. Hence, the optimum elastic modulus was attained with 10wt% loading of 0.5mm size.

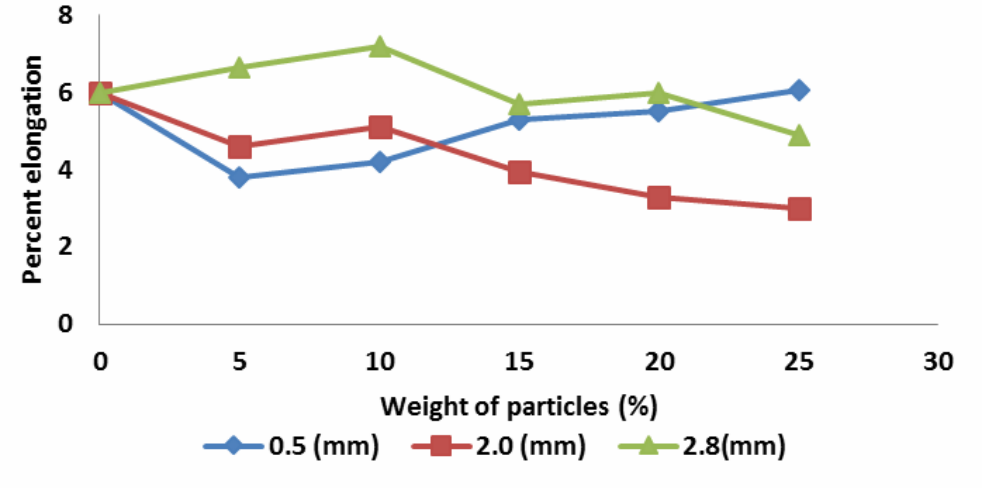

Figure 4. *Effect of particle sizes and loadings on elongation*

Swamy [15] reported that elongation of composite decreases with increase in particles concentration. This was initially observed in Figure 4 for 0.5mm and 2mm sizes. 0.5mm afterward increased as the particles loading increased. This may be as a result of the smaller particle size which enhanced the elongation properties of the material. The elongation of the 2mm samples slightly increased and then decreased as the particles loading increased, due to the weaker interface existing among the composite compositions. The 2.8mm particle size showed no remarkable elongation properties. Though, the maximum elongation was attained at its 10wt% loading.

It was noticed on Figure 5 that, the impact strength of samples 0.5mm and 2.0mm sizes respectively increased as the particles loading increased. Similar observations were made by Aruniit et al [14] that impact strength can be increased by smaller particle size. As

for 2.8mm size, the maximum strength impacted on the composite was observed with 5wt% loading.

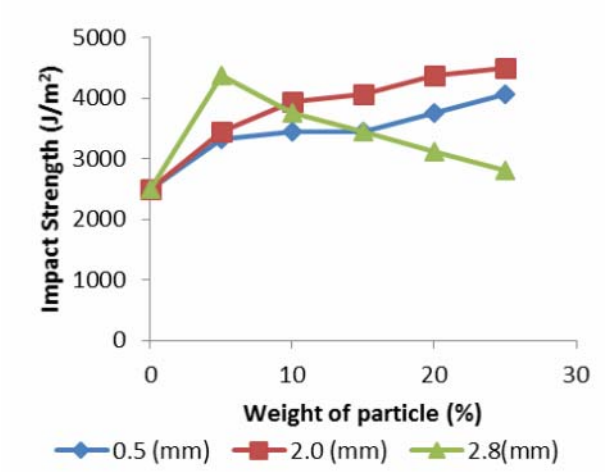

***Figure 5**. Effect of particle sizes and loadings on the impact strength*

Afterward, the strength decreased as the particles loading increased. This declination could be as a result of the bigger particle sizes and their irregular orientation leading to poorer interaction between the composite compositions.

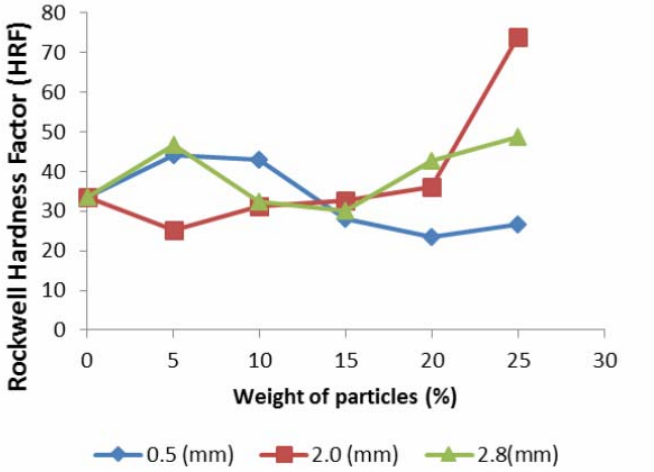

***Figure 6**. Effect of particle sizes and loadings on the hardness*

Hardness, is the measure of a material's resistance to surface indentation, also it is a function of the stress required to produce some specific types of surface deformation [15]. It was clearly observed on Figure 6 that, for sample sizes 0.5mm and 2.8mm respectively, there was no remarkable variation or changes among the hardness properties and loadings. But, a good variation and better hardness property was observed on the 2mm size, of which the hardness first dropped as a result of poor particles distribution and/or orientation, but it afterward, increased as the particle loading increased in support of a report by Aruniit et al

[14] that, hardness of composite increases by increasing the particles loading. The maximum hardness attained was found with 25wt% loading of 2mm size.

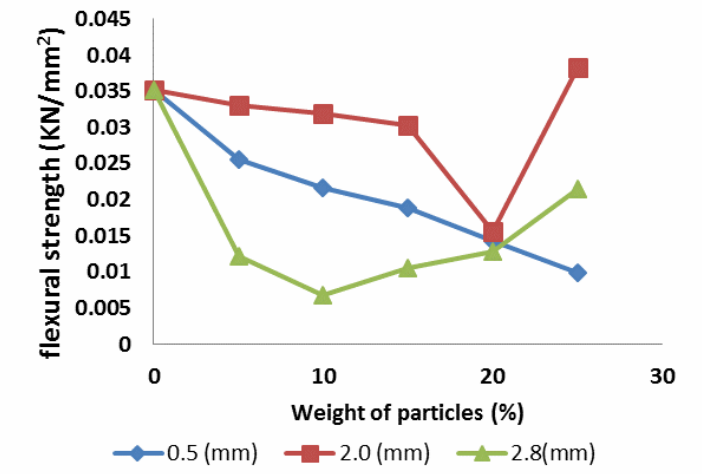

***Figure 7**. Flexural strength variation with particle sizes and loadings*

Figure 7, shows the relationship between the flexural strength, the particles sizes and loadings. The flexural strength of the materials first decreased as the loading increased. But afterward, the strength increased for particle sizes 2.0mm and 2.8mm respectively as their particle loading further increased. The increment followed the report by Aruniit et al [14] that, due to unfavorable geometrical features particle could only make the flexural strength remain steady or make decrease. The optimum flexural strength could be taken as the point of intercept between the particle sizes at 20wt% loading.

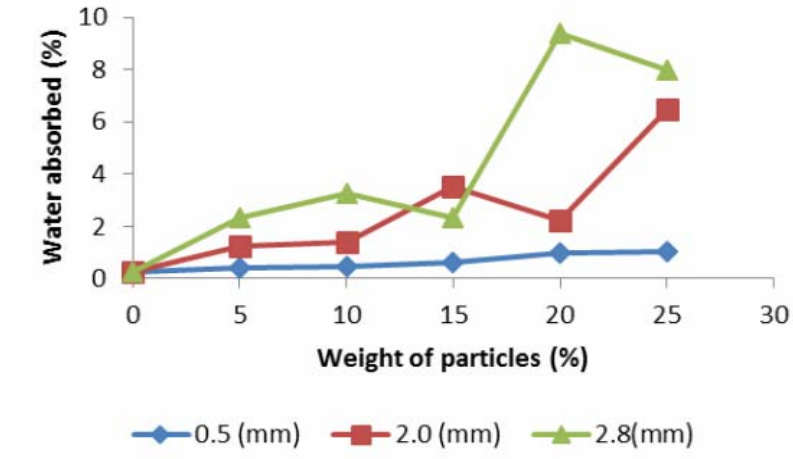

***Figure 8**. Variation of water absorption with particle sizes and loadings*

It was observed on Figure 8 that water absorption increased with increasing particle size and also with loading. It is an established fact that lignocellulosic materials are hydrophilic in nature since their main constituents are cellulose, hemicellulose, lignin and others which is a factor that contributes to their absorption of moisture from the atmosphere [16]. However, the observed trend with respect to increasing particle size runs contrary to the findings of Dagwa et al [17] who reported that the smaller the particle size, the more the moisture sorption. This may possibly be due to high porosity of the date particles.

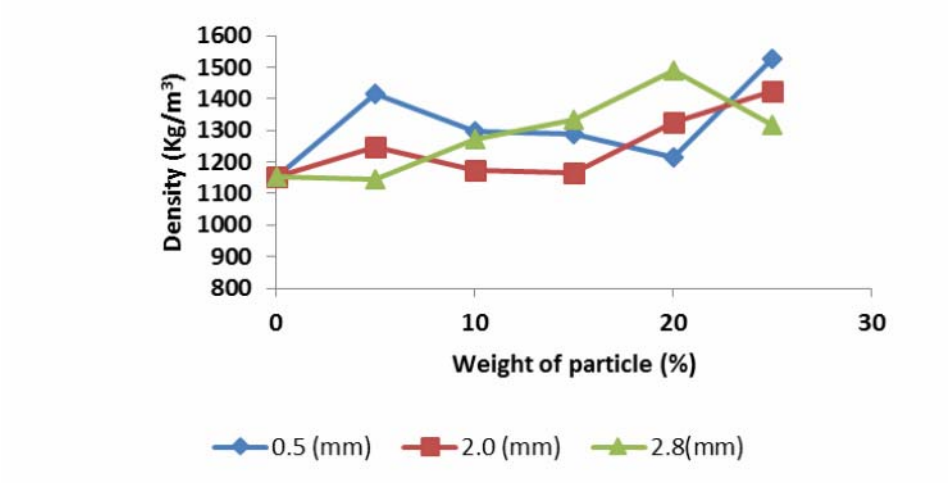

***Figure 9**. Density variation with particle sizes and loadings*

Figure 9 shows that, for sample sizes 0.5mm and 2.0mm respectively, the density of the composite first increased as a result of the weak particles distribution. Afterward, their density decreased of which goes in line with the composite rule of mixture, since the particles are of lower density relative to the polyester with higher density. Samples size 2.8mm shows the direct opposite of the response of 0.5mm of which the density first decreased due to the poor distribution of polyester-particles composition. The increment with 5 - 20wt% could be the result of its larger particle size, resulting to lower surface area and hence decrease in volume which favors the density. The optimum density of the composite was observed to be the intercept on the graph at about 23wt% loading.

From Figure 10, some traces of impurities appearing as dark particles were observed on the unreinforced composite (i.e. 0% weight particle loading) and this could have general effect on the properties of the subsequent fabricated composite.

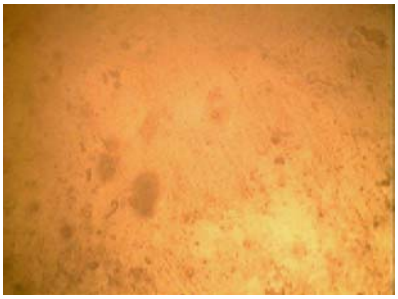

Figure 10a. *Microstructural observation of 0% weight particle loading*

(i) (ii) (iii)

Figure 10b. *Microstructural observation of 5wt% particle loading for particle size (i) 0.5mm, (ii) 2mm and (iii) 2.8mm*

(i) (ii) (iii)

Figure 10c. *Microstructural observation of10wt% particle loading for particle size (i) 0.5mm, (ii) 2mm and (iii) 2.8mm*

(i) (ii) (iii)

Figure 10d. *Microstructural observation of 15wt% particle loading for particle size (i) 0.5mm, (ii) 2mm and (iii) 2.8mm*

At 10% weight particles loading for all particle sizes, a credible uniform distribution was observed and the bonding between the particle surface and the polyester was satisfactory.

Micrographs reveal a fairly uniform distribution and bonding at 15% weight particles loading for all particle sizes.

(i) (ii) (iii)

Figure 10e. *Microstructural observation of 20wt% particle loading for particle size (i) 0.5mm, (ii) 2mm and (iii) 2.8mm*

(i) (ii) (iii)

Figure 10f. *Microstructural observation of25wt% particle loading for particle size (i) 0.5mm, (ii) 2mm and (iii) 2.8mm*

But at 20% and 25% weight particles loading for all particle sizes respectively, a poor interface between the particle and the polyester exist, attributing to the restriction of polyester chain movement with a fairly good distribution of the particle due to the increase in particle concentration.

Conclusions

The results of this investigation show the possibility of using date palm seed particles as reinforcement in composites production. The mechanical and the physical properties were found to be influenced by the particle sizes and loadings as the following conclusions may be drawn from the findings of the investigation:

1. The particle size and loading increased the tensile strength and elastic modulus decreased and the most reduced particles size (0.5mm) gave the optimum tensile strength and elastic modulus with 15wt% and 10wt% loading respectively.

2. The elongation of the composite decrease with increase in particles loading and impact strength increase with smaller particle sizes.
3. The hardness of the composite increase as particles loading increase while the maximum hardness was attained with 25wt% loading of 2mm particle size and flexural strength decrease as particles loading increase.
4. Lower particle sizes have lower percent water absorption and the density of the composite was deduced to be intercept on the density graph.

References

1. Chawla K. K., *Composite materials: Science and Engineering*, 1st Ed. New York, Springer-Verlag, 1987, pp. 292.
2. Taj S., Munamar A. M., Khan S., *Natural fiber-reinforced polymer composites*, Proceedings of the Pakistan Academy of Science, 2007, 44, p. 129-144.
3. Al-Kaabi K., Al-Khanbashi A., Hammami A., *Date palm fibers as polymeric matrix reinforcement: DPF/Polyester Composite Properties*, Polymer Composites, 2005, 26, p. 604-613.
4. Lopez L. F., Correal J. F., *Exploratory study on the glued laminated bamboo Guadua angustifolia kunt as a structural material*. Maderas: Ciencia yTecnologia, 2009, 11, p. 171-182.
5. Chattopadhyay S. K., Khandal R. K., Uppaluri R., Ghoshal A. K. *Bamboo fiber reinforced polypropylene composites and their mechanical, thermal, and morphological: Properties*, Journal of Applied Polymer Science, 2011, 119, p. 1619-1626.
6. Shehu U., Aponbiede O., Ause T., Obiodunukwe E. F., *Effect of particle size on the properties of Polyester/Palm Kernel Shell (PKS) Particulate Composites*, Journal of Materials and Environmental Science, 2014, 5(2), p. 366-373.
7. Chandramohan D., Marimuthu K., *A research review on natural fibers*, Proceedings of the International Journal of current Research, 2011, 3(11), p. 331-337.

8. Chandramohan D., Marimuthu K., *Drilling of natural fiber particle reinforced polymer composite material*, Proceedings of the International Journal of advanced Engineering Research and studied, 2011, 1(1), p. 134-145.
9. Kumar V., Kushwaha P. K., Kumar R., *Impedance-spectroscopy analysis of oriented and mercerized bamboo fiber-reinforced epoxy composite*, Journal of Material Science, 2011, 46, p. 3445-3451.
10. Sen T., Reddy H. N. J., *Applications of Sisal, Bamboo, Coir and Jute and Natural Composites in Structural up Gradation*, International Journal of Innovation, Management and Technology, 2011, 2, p. 186-191.
11. Mohammad B. H. N., *Date seeds: A novel and inexpensive source of dietary fiber*, International Conference on Food Engineering and Biotechnology IPCBEE, 2011, vol. 9, IACSIT Press, Singapoore.
12. Okpanachi G. E., Ogakwu P. l., *Effects of fiber surface treatment on the mechanical properties of ukam fiber reinforced polyester composites*, Journal of Engineering and Applied Sciences, 2010, 2, p. 1-12.
13. Deshmukh S. P., Rao A. C., Gaval V. R., Joseph S., Mahanwar P. A., *Effect of particle size and concentration on mechanical and electrical properties of the Mica Filled PVC*, Journal of Minerals & Materials Characterization & Engineering, 2010, 9(9), p. 831-844.
14. Aruniit A., Kers J., Tall K., *Influence of filler proportion on mechanical and physical properties of particulate composite*, Agronomy Research Biosystem Engineering Special, 2011, 1, p. 23-29.
15. Swamy A. R. K., Ramesha A., Kumari G. B. V, Prakash J. N., *Effect of particulate reinforcements on the mechanical properties of Al6061-WC and Al6061-Gr MMCs*, Journal of Minerals & Materials Characterization & Engineering, 2011, 10(12), p. 1141-1152.
16. Mohanty A. K., Misra M., Drzal L. T., *Surface modification of natural fibers and performance of the resulting biocomposite: an overview*, 2001, Composite Interface, 8(5), p. 313-343.
17. Dagwa I. M., Builders, P. F., Achebo J., *Characterization of palm kernel shell powder for use in polymer matrix composites*, Internal Journal of Mechanical and Mechatronics Engineering, 2012, 12(4), p. 88.