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Effects of Alkaline Treatment and Particle Size on Physical and Mechanical Properties of Melonhusk-Cellulose/Expandable Polystyrene Composites

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ABSTRACT

The research investigated effects of alkaline treatment and particle size on physical and mechanical properties of melon-husk (MH) filled expandable polystyrene composites. In the process, MH particulate material size of 75 μm, 150 μm, 300 μm, and 600 μm were prepared and modified with alkaline (1%, 2 %, and 3 %,) based on weight volume fraction. The modified fillers, Melonhusk-cellulose (MHC) were analyzed using FTIR after which were subsequently compounded with expandable polystyrene at filler loading to matrix ratio of 25/75 % on a two roll mill compounding machine. The compounded material was passed through a molding and compression machine and after which was cut into dimensions required for analysis and characterization of samples. The result showed that composite prepared with 75 μm particle size and treated with 1 % alkaline has better physical and mechanical properties. The average density and water absorption of the composite was found to be 0.75 gcm^{-3} and 0.78 % respectively. The tensile strength, modulus of elasticity and elongation at break of the composite were measured and found to be 34.87 MPa, 0.4478 GPa and 8.369 % respectively. The composite had flexural strength and modulus of 56.716 MPa and 2.958 GPa respectively.

Keywords: *Alkaline Treatment, Particle Size, Melon-husk, Expandable Polystyrene*

INTRODUCTION

In general, the amalgamation of two or more materials components of which performance characteristics exceed those which are not achievable from its individual components give rise to composite (Sharma *et al.,* 2018; Shahabaz *et al.,* 2015). Agricultural industries produced significant volume of by-product that could be reused as a source of natural fillers, for examples, palm oil empty fruit bunch, coconut shells, and many other alternatives (Chunk *et al.,* 2016; Yusuf *et al.,* 2010). Polystyrene (PS) been one of the most important commodity polymer which is widely used in household goods, packaging, automobiles, construction and other engineering applications, is also hard, stiff, and brilliantly transparent synthetic resin, that is produced by the polymerization of styrene. Polystyrene foam (expandable polystyrene which is abbreviated as EPS), also known as Styrofoam, is commonly used in many industries for packaging and storage purposes (Alewo *et al.,* 2015, Bismark *et al.,* 2002). Unfortunately, due to its high demand and production, it is reported that at least 1000 tons of polystyrene foam are being disposed into landfills and this causes environmental issues (Chand and Fahim 2008).

Melon seeds (*Citrullus vulgaris*) grow in gourds and yields more in warm, sunny regions and well-drained soils (Dhakal *et al.,* 2007). The areas of high melon seed production in Nigeria include Enugu, Benue, Nasarawa, Taraba and Kogi state. Melon is rich in fat and protein and comes from the family of cucurbitaceous (gourd) together with watermelon, muskmelon, and others, it is small and flat, and has greyish white, green and yellow colour. Application of Melon Husk polymer composites can replace the existing composite materials in building and construction industries considering the low cost and lightweight factors (Shahabaz *et al.,* 2015).

In Nigeria, Niger state produces an average of 1000 tons of Melon Husk per year, much of which is burnt in the field. Open-field burning of Melon Husk is a major source of air pollutants. It is known to emit particulate matters, and other elements such as dioxins and furans that affect human health (Gadde *et al.,* 2009; Tipayarom and Oanh, 2007; Torigoe *et al.,* 2000). Evidence of researches showed that burning of melon husk and other agricultural waste contribute more dioxins and furans to air and land than vehicle emissions (Dost, 2006). Furthermore, because melon husk is burnt up and not properly returned to the soil, studies show that nutrients in the soil are lost (Dobbermann and Fairhurst, 2002).

MATERIALS AND METHODS

Materials/ Equipment

All the chemicals used were in analytical grade and were used without further purification. The chemicals were purchased in Romptech chemical store in Nigeria, which include Sodium Hydroxide, Acetic Acid, Expanded Polystyrene, Melon-husk waste, Distilled water, Filter paper, Analytical, Balance (Digital). The equipment used include: Two Roll-mill, Moulding machine, FTIR Machine, Oven, Ball mill Grinding machine, Standard Sieve, Beakers, Metallic trays all were in standard grade.

Preparation of composite

Cleaned and conditioned melon husk was grinded with crusher (Retsch masch Nr. 70992) obtain powdered fillers. The powdered MH was passed through standard mesh of 75µm, 150µm, 300µm, and 600 µm to obtain different particle sizes. Sodium hydroxide pellets were dissolved in deionized water to prepare sodiumhydroxide (NaOH) solutions at different concentrations based on weight to volume ratio percent (1 %, 2 %, and 3 %,). The prepared melon-husks of particle sizes (75µm, 150µm, 300µm, and 600µm) were separately immersed in the prepared solutions of NaOH. The treatment was carried out in alkaline solution at a boil for 7 hours. After removal from NaOH solution it was neutralized with 45 % solution of acetic acid followed by thorough washing with distilled water until neutral pH was obtained. The treated powder was then dried in an oven at 90 ˚C for 24 hours after which the effect and extent of sodium hydroxide (NaOH) treatment on removal of hydroxyl groups (OH) on samples of Melon-husk was investigated by using Fourier Transforms Infra-red Spectroscopy (FTIR) before compounding.

The flakes of expanded polystyrene (75 %) were compounded with melon husk particles (25 %) in two-roll-mill machine in accordance to ASTM D15-627. After compounding, the resulted compounded composite was subsequently placed in a metal mould of dimension, 150×150×5 mm. The composite sheets were cut into required dimensions.

Determination of Physical and Mechanical properties

Density measurement was carried out according to ASTM D1895 standard. Water absorption test was carried out in accordance with ASTM D570 of 2003. The tensile tests were conducted in accordance with ASTM D3039 on universal testing machine.

Results and Discussion

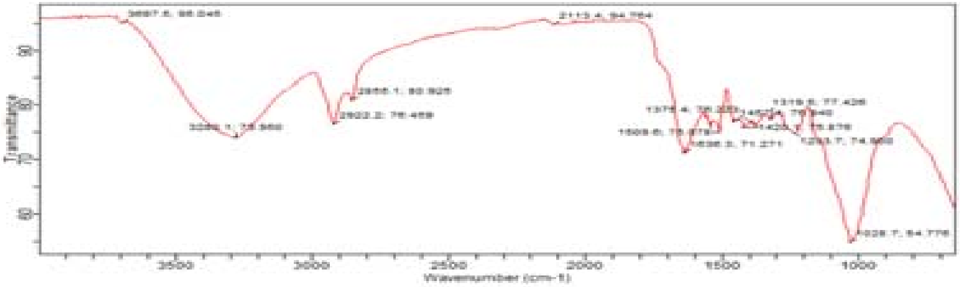

Figure 1: FTIR result of untreated Melon husk

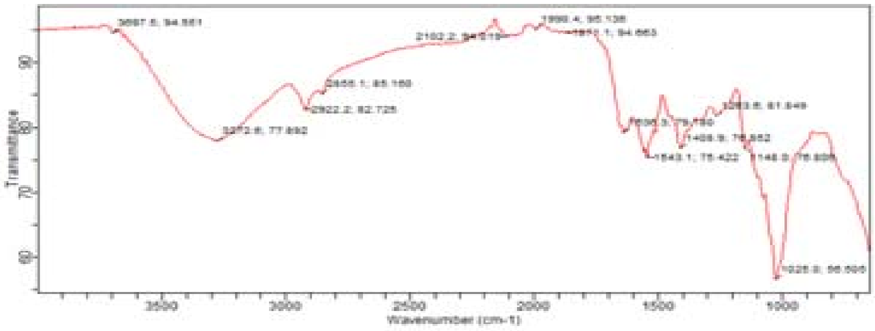

Figure 2: FTIR result of treated melon husk

FTIR Analysis of treated and untreated MH

FT-IR spectroscopy was used to check the changes of chemical structure before and after treatments were introduced to MHC. In untreated sample, an observed broad band around 3697 cm^{-1} present in the spectrum represent the OH-stretching that is equivalent with the intra-molecular hydrogen bonding in Hemicellulose (Halmatuddahliana *et al.,* 2016). The bands present at wave number of 2922 cm^{-1} and 1835 cm^{-1} could be contributed to C-H stretch and C=O stretching in the acetyl and ester groups of hemicellulose and the ester carbonyl groups in p-coumaric acid of lignin (Khazaei, 2008). The ß-glycosidic linkage vibrations that link each monomer in the cellulose structure can be seen around 1635 cm^{-1} in the spectrum. The bands present around 1408 cm^{-1} and 1375 cm^{-1} show the C-H stretching and CH_2 bending confirming that there are no ruptures or alteration in the cellulose structure (Faruh *et al.,* 2010). There was an observed sharp narrow band at exactly 1028 cm^{-1} corresponding to C-OH of cellulose. This was supported by Liu *et al.,* (2010), who declared that the region between 1000 and 1150 cm^{-1} corresponded to the stretch vibration of C–OH side groups and the C–O–C glycosidic bond vibration.

Effects of Alkaline Treatment on Density

Figure 3 shows the effect of alkaline treatment on density of composite prepared with treated and untreated MHC/EPS. The low density on composites prepared with untreated fillers may be attributed to impurities that might be attached to MH. Composites samples prepared 600 µm fillers showed slight increase in density as the alkaline concentration used in treatment increase. This might be due to treatment increases the inherent air space trapped within filler to fillers. According to Jamaludin *et al.,* (2013), low density composite is a material that is capable of trapping moisture than high-density composites. However, composites prepared with 150 µm particle size showed decrease in density as the alkaline concentration increases. The decrease in density might be attributed to irregularities in shapes of particulate fillers.

Effects of Particle Size on Density

Figure 4 shows the effect of particle size variation on density of composites prepared with treated and untreated MHC. From the figure presented, there was similar trend in all the samples. In the trend, there was increase in density as the particle size increase at a point after which the density then decreases as the particle size increase and subsequently increase. The increase in density as the particle size increase might be attributed to porosity of larger particles size. In research conducted by Mehdi *et al.,* (2009) who reported that density is related to porosity therefore larger particulate fillers reduced contact area between the fillers themselves thereby leading to higher porosity.

Effects of Alkaline Treatment on Water Absorption

Figure 5, 6, 7 and 8 showed Effect of water absorption on particle size for samples prepared with untreated, 1 %, 2% and 3 % treated respectively. From the figures it can be observed that composites samples prepared with untreated particulate fillers absorbed more water than composites prepared with 1 %, 2% and 3%. The increase in percentage water absorption in untreated composite may be attributed to the presence of impurities in the fillers. Impurities such as lignin pectin and ash might have absorbed water there by making percentage of water absorption higher. It was reported that decrease in water absorption of treated natural particulate fillers may be due to complete removal of Hemicellulosic component and reduction in lignin component (Walid, *et al.,* 2019). It was observed that as the percentage of alkaline treatment increases the percentage of water absorption increase on composites prepared with 1% treated fillers. This may be attributed to some likely changes in the structural modifications leading to densification cellulosic cell wall of MH (Banjo, *et al.,* 2019).

Effects of particle size on water absorption

From Figure 5 it can be deduced that increase in size of filler particles leads to increase in water absorption. This observation is not only applicable to Figure 5 but applicable to Figure 6 7 and 8. This also implies that composites produced with larger melon-husk particle sizes absorbed more water than those of lower particle sizes. This might be due to larger melon-husk particle size produced less compact material than lower particle size fillers thereby causing water absorption to rise at surface of the composite; similar result was obtained by (Nuhu *et al.,* 2018; Melo, *et al.,* 2018).

Effect of Alkaline treatment on tensile strength

Figure 9 shows the effect of alkaline treatment on tensile strength. From the Figure it can be deduced that there was increase in tensile strength on composite prepared with 1 % treated fillers as compared with composite prepared with untreated. The difference could be attributed to impurities untreated fillers used in MHC/EPS composite leading to poor interfacial adhesion between the polymer and filler which resulted to non uniform stress transfer when load was applied (Akovali 2001; Njoku *et al.,* 2011). However, decrease in tensile strength was observed on 2 % and 3% treated samples. The decrease in tensile strength might be dues to depolymerisation of the cellulosic content of the filler by the alkaline, which deteriorate interfacial adhesion causing weak interlocking between the filler and matrix (Ming *et al.,* 2017).

Effect of particle size on tensile strength

Figure 10 shows the effect of particle size on tensile strength. From the figure, there is increase in tensile strength as the particle sizes decrease. The increase in tensile strength may be due to smaller particle size fillers have more surface area of interaction with the resin thereby improving the uniformity of stress transfer process that will ultimately increased the tensile strength. This is also in agreement with Christopher and Roger (2015), who investigated the mechanical properties of kaoline filled nylon 6 composites and found that the composite strength increases with decreasing mean particle size.

Effects of alkaline treatment on tensile modulus

Figure 11 shows the effect of alkaline treatment on tensile modulus of composite prepared with treated and untreated fillers. From the figure, it can be notice that tensile modulus of the composite decreased. The decrease may be due to cell wall thinning and pores in the fillers as result of leaching of cementing material. This was supported by research findings of (Hong *et al.,* 2018).

Effect of particle size on tensile modulus of elasticity

Figure 12 shows the effect of particle size on tensile modulus. From the Figure it can be deduced that decrease in particle size leads to increase in Modulus. This may be smaller particulate fillers dispersed well in the matrix.

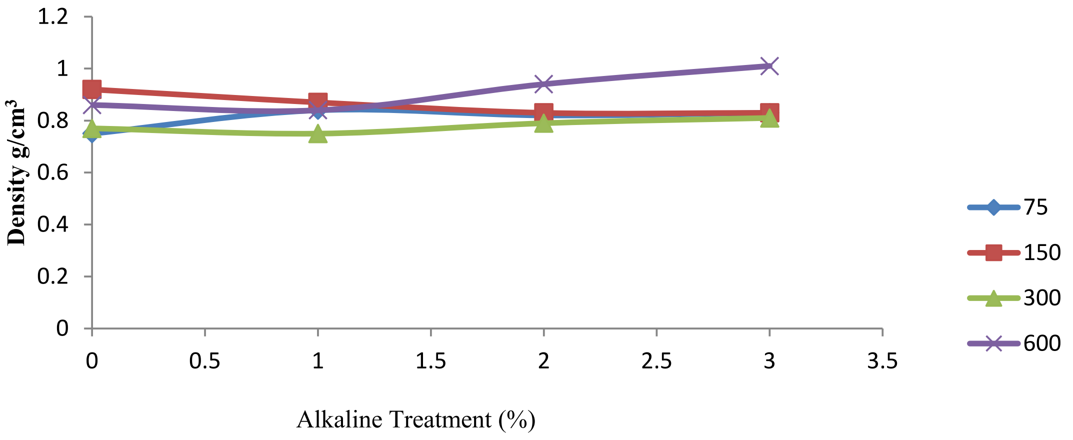

Figure 3: Effect of Alkaline Treatment on Density of Composites

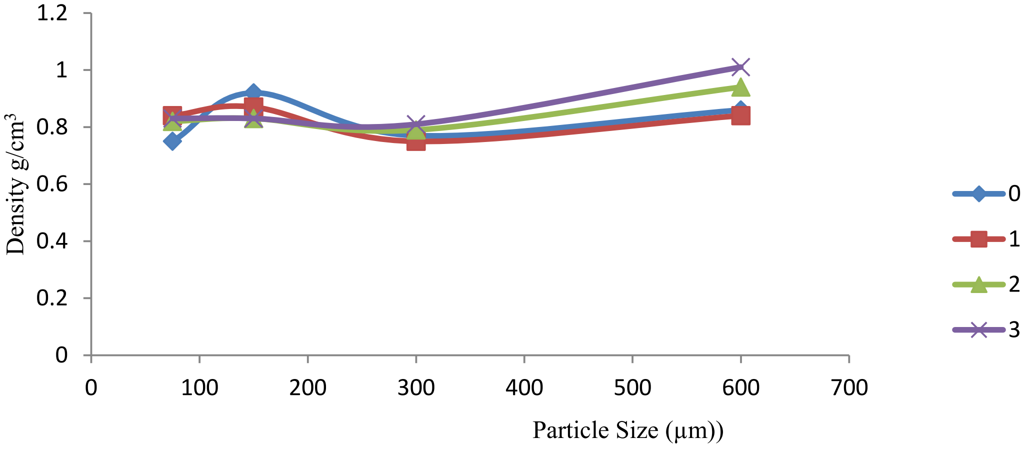

Figure 4: Effects of Particle Size on Density

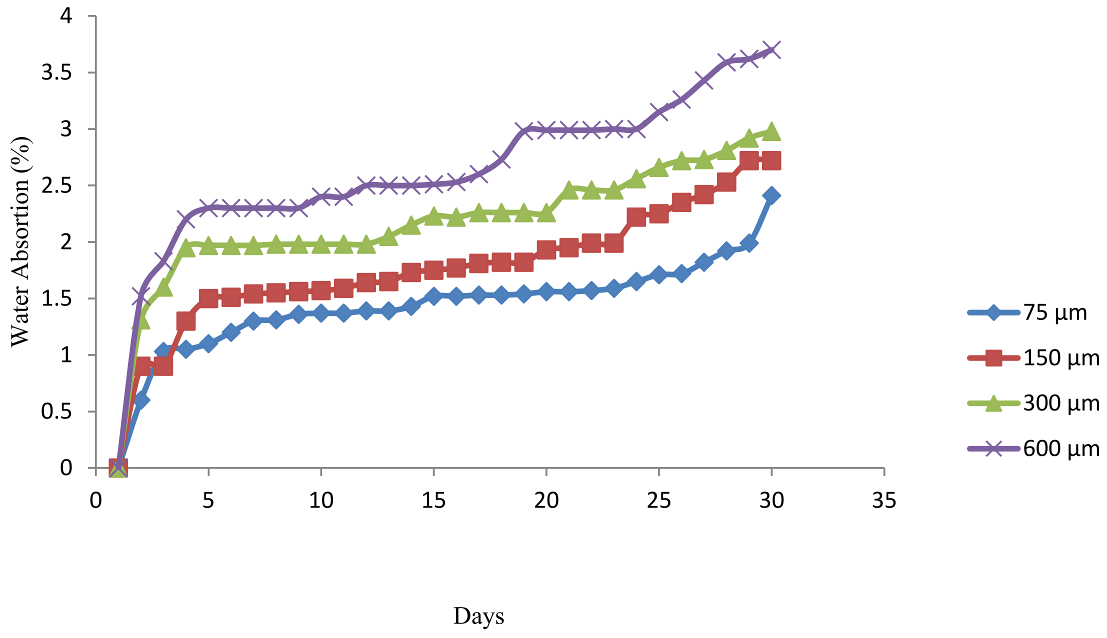

Figure 5: Effects of Water absorption on particle for Untreated Composite

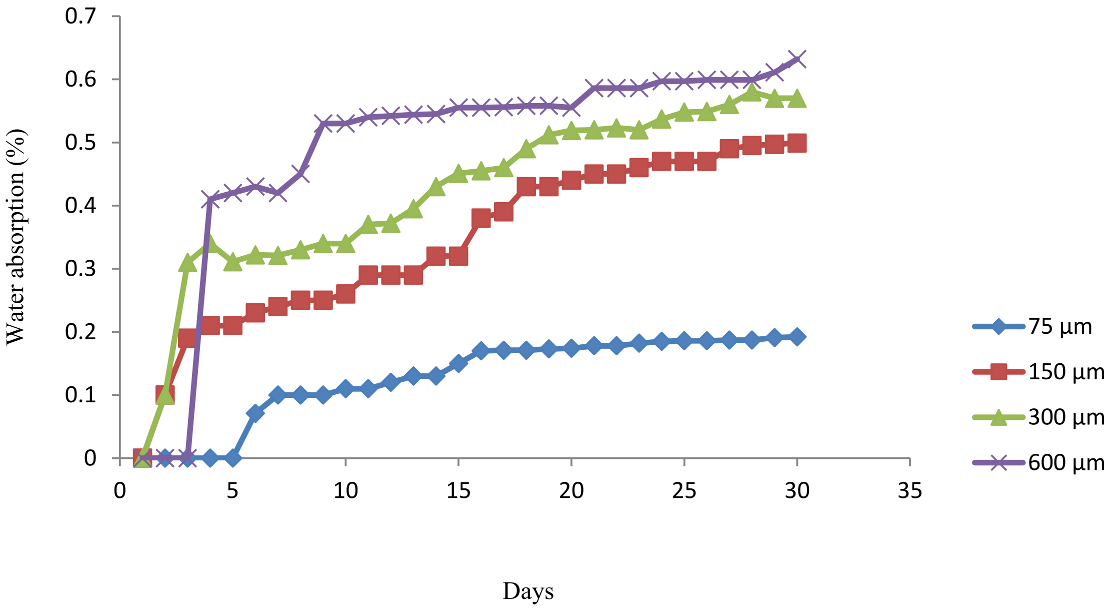

Figure 6: Effect of Particle size on Water absortion of 1 % treated MH/PS

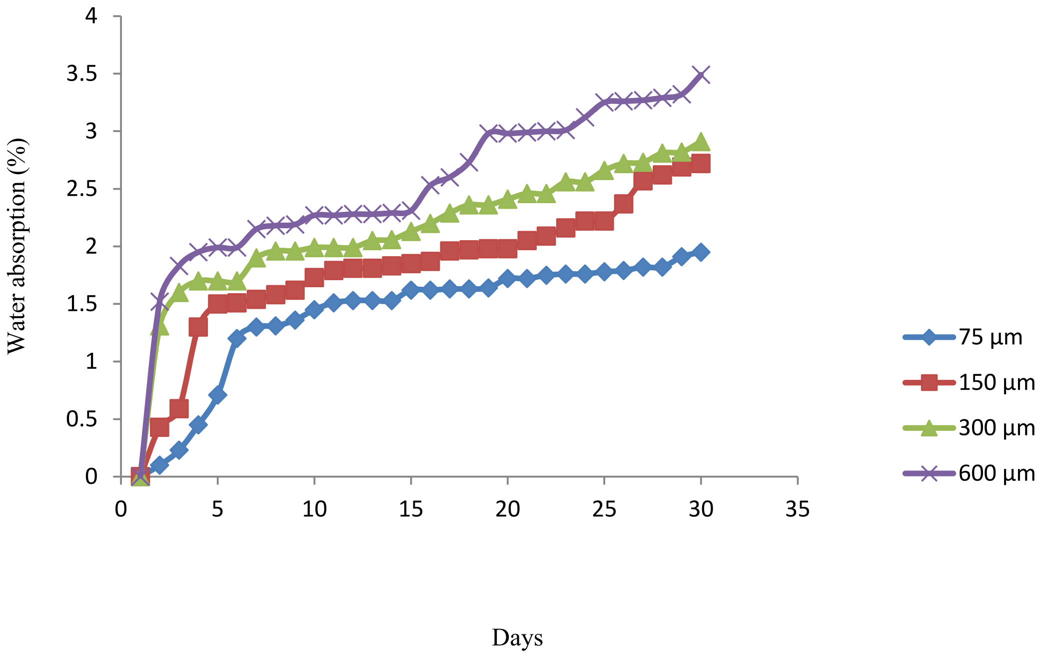

Figure 7: Effects of Particle size on Water absorption of 2 % treated MH/PS Composite

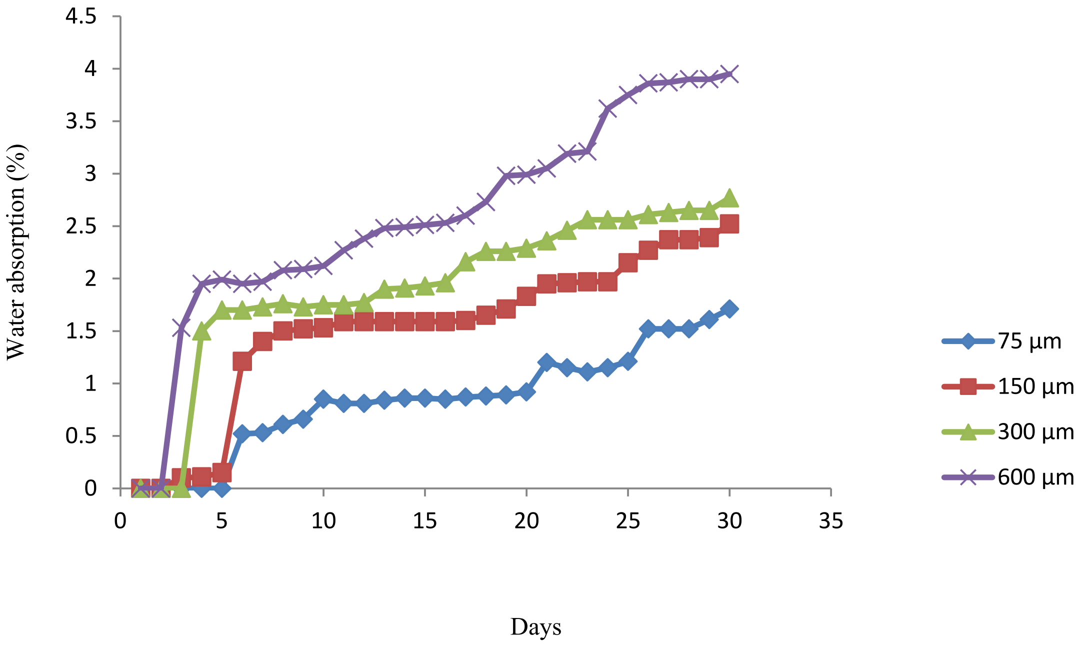

Figure 8: Effect s of Particle size on Water absorption of 3 % Treated MH/PS Composite

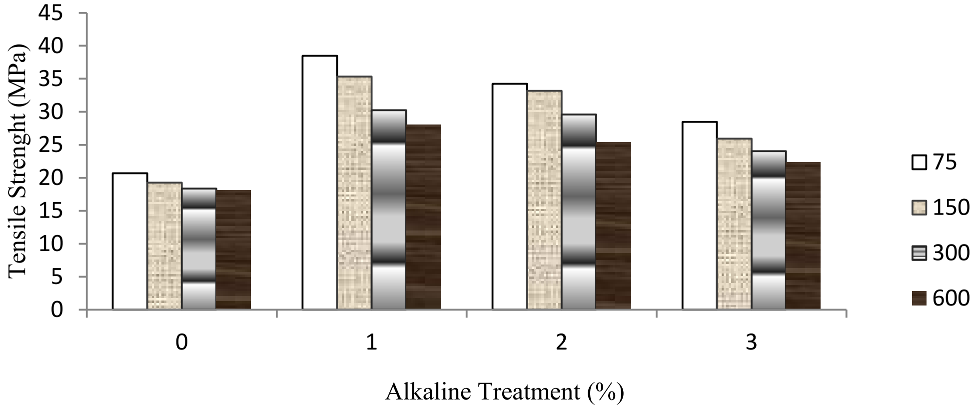

Figure 9: Effect of Alkaline treatment on tensile strenght

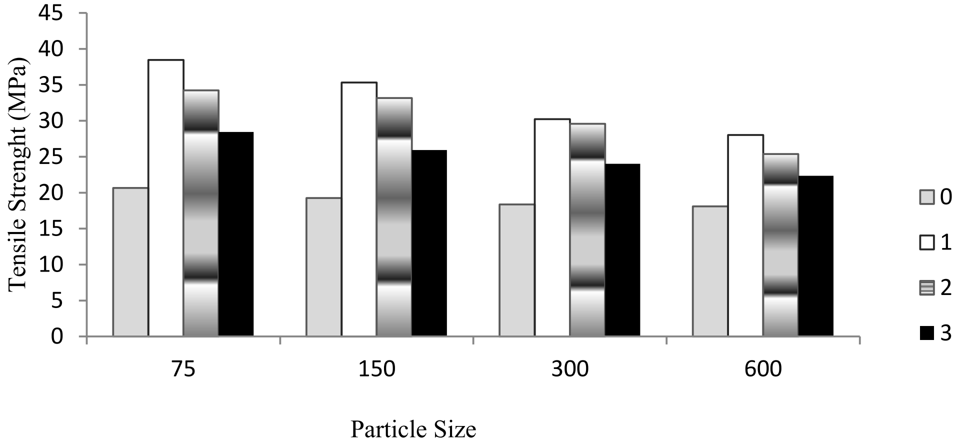

Figure 10: Effect of particle size on Tensile Strength

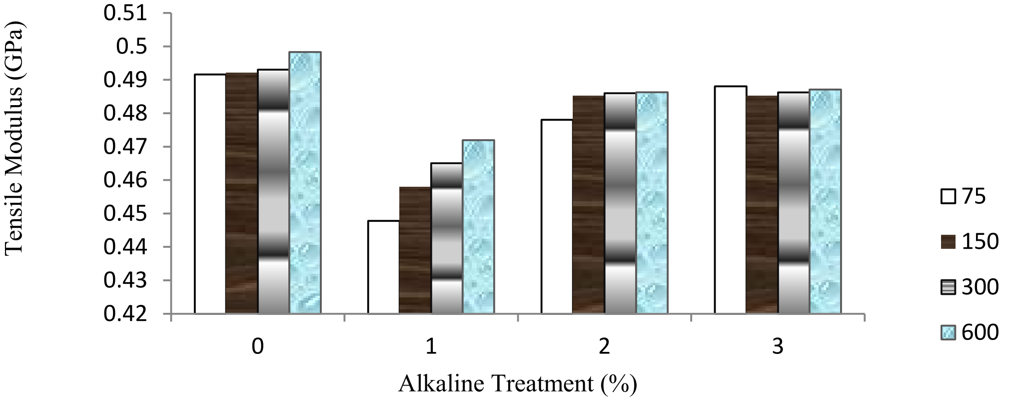

Figure 11: Effect of Alkaline treatment on Modulus

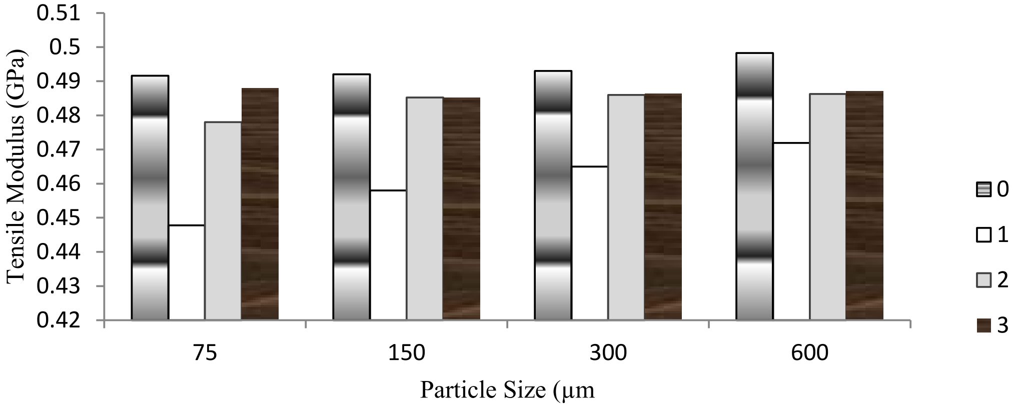

Figure 12: Effect of Particle size on Modulus

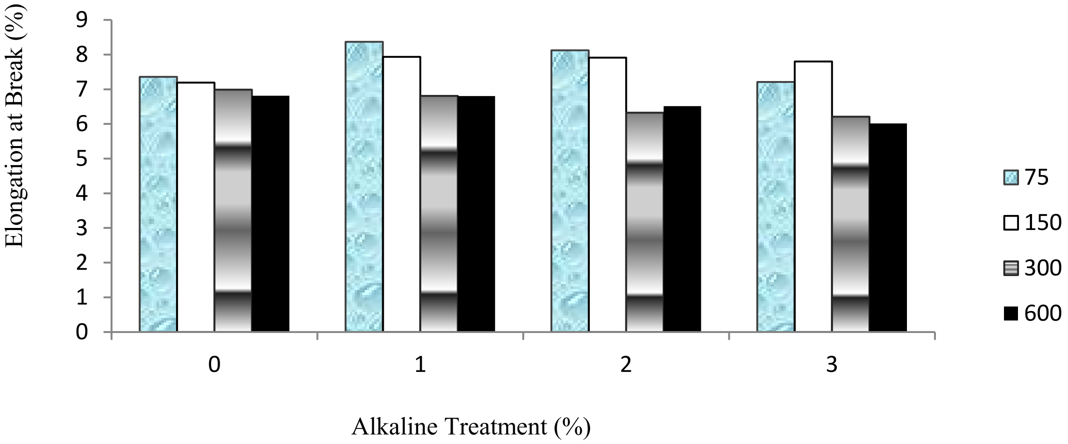

Figure 13: Effect of alkaline treatment on elongation at break

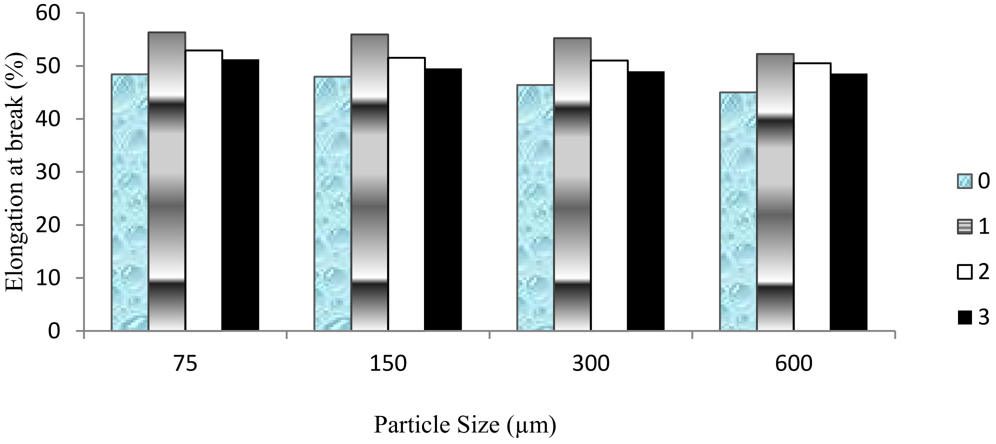

Figure 14: Effect of particle size on Elongation at Break

Effect of alkaline treatment on elongation at break

The effect of alkaline treatment on elongation at break is presented in Figure 13. It shows that the alkaline treatment at 1 % leads to increase elongation at break but as treatment increase to 2 % and 3% it decrease. The increase in elongation at break may be due to removal hydroxyl in MHC fillers by the alkali thereby transforming the MHC hydrophilic fillers to hydrophobic consiquently making the union between the matrix and filler compatible and strong to withstand tension exerted on the material (Joseph *et al., 2022*).

Effect of particle size on elongation at break

The effect of particle size on elongation is presented in Figure 14 and from the Figure, it can be noticed that there is slight increase in elongation as the particle size increase. This may be due to surface area provided by smaller particle size gives better interfacial adhesion than larger particle size (Mohamad *et al.,*2019).

Effect of flexural strength on alkaline treatment

The effect alkaline treatment on flexural strength is presented in Figure 15 and from the figure it can be observed that there is increase in flexural strength on composites prepared with treated 1 % alkaline and as percentage increase to 2 % and 3 % the Flexural decrease. The increase in flexural strength in 1% treated composites could be attributed to the better rigidity and stiffness as a result of fair dispersion and distribution of the MH fillers in the polymer matrix, which efficiently hinders chain movement during deformation. Such an increase in flexural strength was reported by (Mohamad *et al.,* 2019). The decrease in flexural strength on alkaline treated composites (2% and 3%) samples were been attributed to likely micro cracks and voids which may be found during fabrications of the composites (Embu *et al.,* 2000).

Effect of particle size on flexural strength

The result of effect of particle size on Flexural Strength is presented in Figure 16 and from the Figure it could be deduced that particle size of MHC fillers are not much affected by flexural strength. This may be due to the fact that there is agglomeration in the particulate fillers used in fabrication of the composites. However, it was reported that agglomeration affect the ability of the material to resist transversal load as it decreased the flexural strength (Das *et al.,* 2002;

Effects of alkaline treatment on flexural modulus

The result of the effect of alkaline treatment on Flexural Modulus is presented in Figure 17. There is slight noticeable effect of alkaline treatment on composite samples. However, alkaline treatment tends to slightly increase the Flexural Modulus. The slight increase may be due to partial removal of hydroxyl groups in MHC fillers by alkaline which improve filler-matrix compatibility. The decrease in flexural modulus in untreated composite may be due to relatively poor compatibility between MHC untreated filler and PS matrix (Embu *et al.,* 2000; Das *et al.,* 2002).

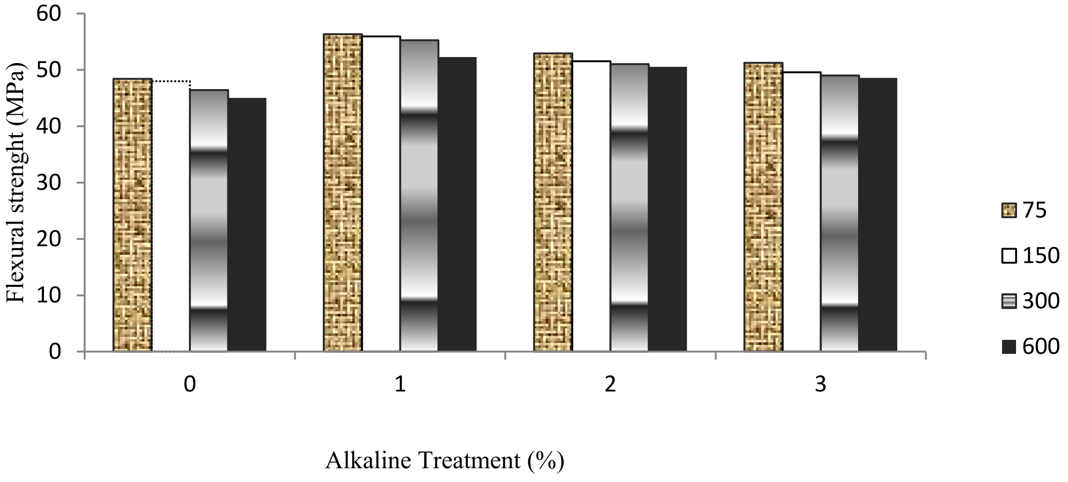

Figure 15 Effects of Alkaline tretament on Flexural Strenght

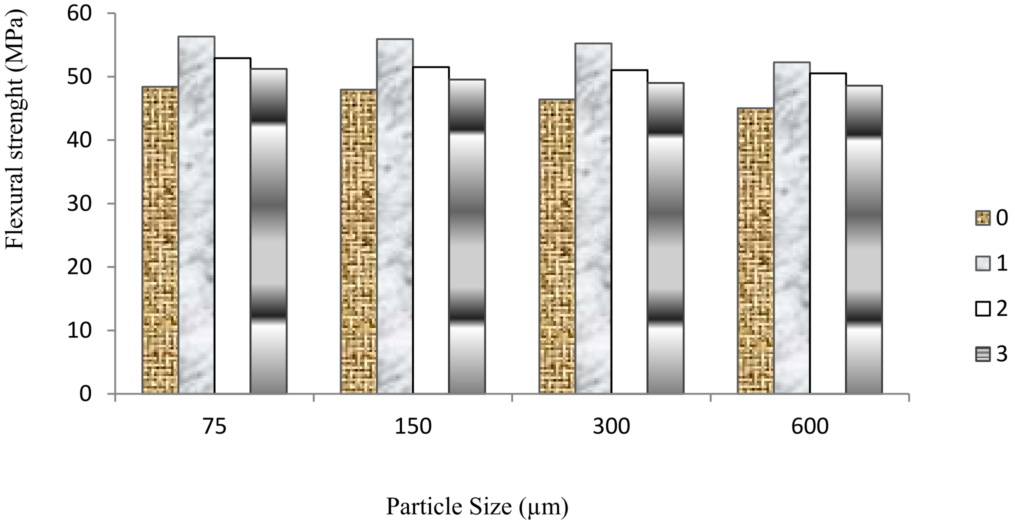

Figure 16: Effect particle size on Flexural strenght

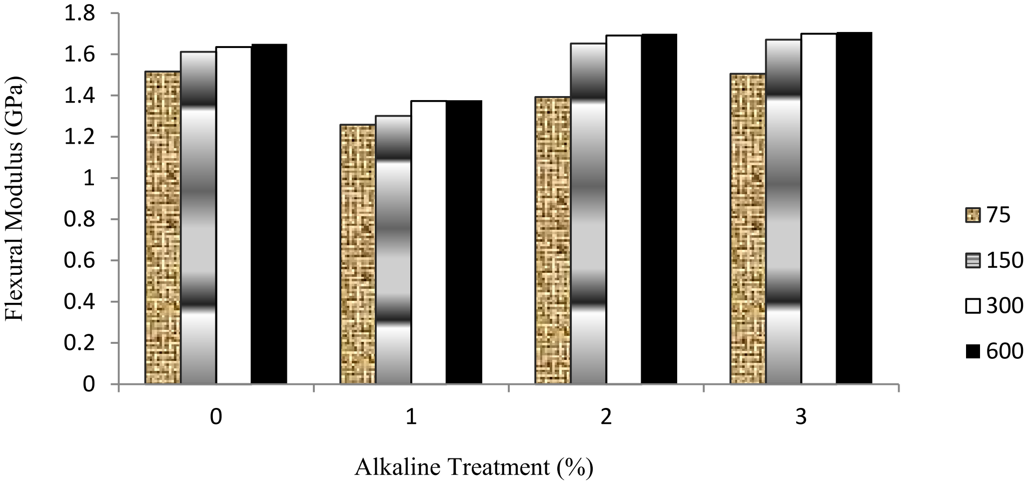

Figure 17: Effects of Alkaline Treatment on Fluxural Modulus

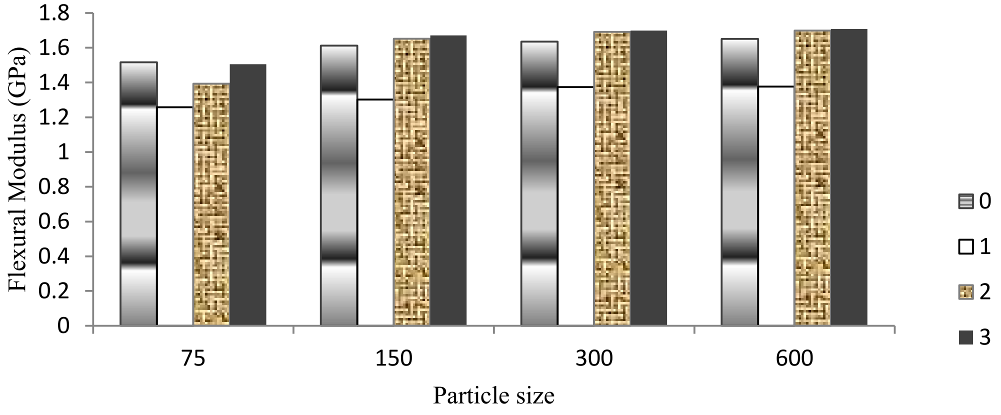

Figure 18: Effects of Particle size on Flexural Modulus

Effect of particle size on flexural modulus

The result of effect of particle size on alkaline treatment is presented in Figure 18 and from the Figure it can be deduced that particle size of 75 µm, 150 µm, 300 µm and 600 µm of MHC fillers do not have much effect on Flexural Modulus. Even though, composites prepared with 75 µm fillers tend to have slight higher Flexural Modulus than 150 µm, 300 µm and 600 µm. The increase in Flexural Modulus at 75 µm may be attributed to finer particles size disperse well in matrix than coarser particles. So homogenous dispersion of finer particle size in matrix may result to increase in load carrying capacity of the material

Conclusion

The FTIR result of treated Melon-husk-cellulosic fillers showed removal of hydroxyl groups; which is an indication of successful alkaline treatment. The result revealed the physical properties, density and water absorption, were not much affected by alkaline treatment and particle size. The result showed that composite prepared with 75 µm particle size and treated with 1 % alkaline has better physical and mechanical properties. The average density, water absorption, tensile strength, modulus of elasticity, elongation at break, flexural strength and flexural modulus of the composites had values of 0.75 gcm^{-3}, 0.78 %, 34.87 MPa, 0.4478 GPa and 8.369 %, 56.716 MPa and 2.958 GPa respectively.

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