https://chemclassjournal.com/
ChemClass Journal Vol. 8 Issue 1 (2024); 162-171
e-ISSN:0198-2734 p-ISSN:0198-5680
doi.org/10.33003/chemclas_2024_0801/014

Thermo-mechanical Properties of a Chemically Modified Buffing Dust Reinforced Waste HDPE Composites for the Production of Boot-last

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Abstract

The thermo-mechanical properties of a chemically modified buffing dust reinforced waste HDPE composites for the production of boot-last has been investigated in this work. The tensile strength, impact energy and dynamic mechanical properties of chemically modified and untreated buffing dust fibre composites with variable weight fractions (10 wt%, 20 wt%, 30 wt%, 40 wt% and 50 wt% respectively) were carried out using standard methods. In the case of alkaline treatment, sodium hydroxide (NaOH) was used and subsequently, benzoyl chloride and permanganate. In the case of BD-wHDPE composites, $KMnO_4$ treated composite sample exhibited an improvement in ultimate tensile strength (UTS) with the highest tensile strength of 18.28 MPa at 10 % weight fraction of reinforcement. The KM-BD reinforced wHDPE composite with 40 wt% fibre fractions indicated the highest Young's modulus with a value of 1.54 GPa when compared with the 0.96 GPa of the wHDPE matrix. The composite produced at 10 wt % of KM-BD produced the highest percentage elongation at break of 19.71 %. This is about 1.26 % higher than the untreated BD sample, 1.15 % higher than ammonium hydroxide treated samples and 1.43 % higher than benzoyl chloride treated samples. Therefore, it could be observed that, chemical treatment of the BD fibres improved the percentage elongation at break of the composites. The impact strength indicated that, 10 wt % of the UBD-wHDPE recorded the highest impact strength of 2.7 J/mm^2, higher than 2.4 J/mm^2 of the control and as well the chemical treated fibres. The dynamic mechanical analysis of the composites proved that, both UBD5 and KBD1 composites can withstand a temperature range of 56 – 62 ºC. These thermos-mechanical properties achieved has established the fact that, these wastes can be utilized in the production of boot-last.

Keywords: Buffing dust, High density polyethylene, Benzoyl chloride, Permanganate

Introduction

Chemical modification of fibres before compounding with polymer matrix is important, because it tend to produce lignocellulosic-based composite materials with long life and also improved interfacial bond between the fibres and the polymer matrix [1]. Chemical modification is aimed at replacing some of the hydroxyl groups on the cell wall polymers with bonded chemical groups, reducing the hygroscopicity of the lignocellulosic material. In order to formulate a better buffing dust reinforced waste high density polyethylene composite with optimum interface bonding, various chemical treatment need to be put in place which include, alkaline, benzoylation, permanganate and silane treatment [2]. Thus, this could decrease the hydrophilicity of the buffing dust, enhance the wettability of the buffing dust by matrix polymer, and eventually promote the interfacial adhesion of the constituents within the composite [3]. In recent research, thermoplastic polymers have experienced great application growth in pipeline and aerospace engineering owing to their low cost, excellent resistance to chemical agents, and increased recyclability [4]. However, their relatively poor mechanical properties limit the development of pipelines with a large diameter and high bearing capacity, which requires higher tensile strength to resist internal pressure, a higher tensile modulus to improve the ring stiffness, and a higher impact strength to resist dynamic loads during construction and service [4, 5].

Materials and Methods

Materials

Polymer Waste Collection and Pre-treatment

Discarded waste gallons made from High-Density Polyethylene (HDPE) with recycling code “2” (Society of Plastic Industries, 1987) were collected from a recycling centre at Sabon-Gari Recreational Club Road, Kaduna State. It was ensured that all the samples collected were of the same colour, since this is one of the criteria considered in plastic waste recycling. Plate I represent samples of HDPE plastic wastes obtained from the collection centre.

Buffing Dust

The Buffing dust fibre was obtained locally from Unique Leather Finishing, Sharada, Kano. Thereafter, the removal of impurities such as sand and oil were done. The buffing dust fibre was then dried for about three (3) days. Finally, it was sieved to obtain sample particle size of 2 mm.

Methods

Composite Production

The thin film specimen of the composites was obtained through the addition of waste HDPE flakes into the rolls as it rotates in anti-clockwise direction for 10 mins and at a temperature of 150 degree Celsius. After the matrix melted, the buffing fibres were introduced manually through a gradual application at 500 rpm. The formulation adopted were 0, 10, 20, 30, 40 and 50 % fibre loads, while the 0 % is the control. The mould was lubricated using paraffin oil and the melted sample was poured into it. Thereafter, the pressing of the sample was done under the compression moulding machine at a temperature of about 150 ºC. The curing was achieved at 5 mins under cooling and the final composite sample was removed [6].

Test for Tensile Strength

The test samples were cut in the dimension of 100 mm length and 47 mm gage length. The testing was done according to ASTM D638 [7] standard method. Subsequently, the dumb bell gauge length and thickness parameters were measured using a digital Vernia caliper to obtain the cross-sectional area. Afterward, the specimen was subjected to the Tensile machine with a model number TM2101-17. The tests were done in triplicate.

Charpy Impact Test

The impact test was done in accordance to ASTM D256 [8] using the Charpy testing machine with a model number CAT NR412. The specimens were cut according 10 130 mm x 12.7 mm dimension and a thickness of about 3 mm. The test sample was fixed in between the sample holder with the notch facing vertically towards the impact origin. After the strike, the specimen breaks at the notch area. The upward swing of the pendulum was used to predict the energy absorbed in J/mm^2.

Dynamic Mechanical Analysis (DMA)

DMA was carried out using DMA 242E machine in strength of materials laboratory, Mechanical Engineering Department, ABU Zaria according to ASTMD4065, [9]. The test parameters: E', E" and tangent of delta (Tan ∂) were configured via the Proteus software using personal computer. Instrument set up included the sample holder (3-point bending), furnace temperature range of 30-110 ℃ dynamic load of 4N, frequency range of 2-10 Hz and heating rate of 3K/min will be configured. Sample dimensions of 60 x 12 x 5 mm were produced for each test. The specimens were loaded into the machine using a three-point bending and locked into the furnace.

Results and Discussion

Tensile Strength

The tensile strength of BD-wHDPE reinforced composites is shown in Figure 1.

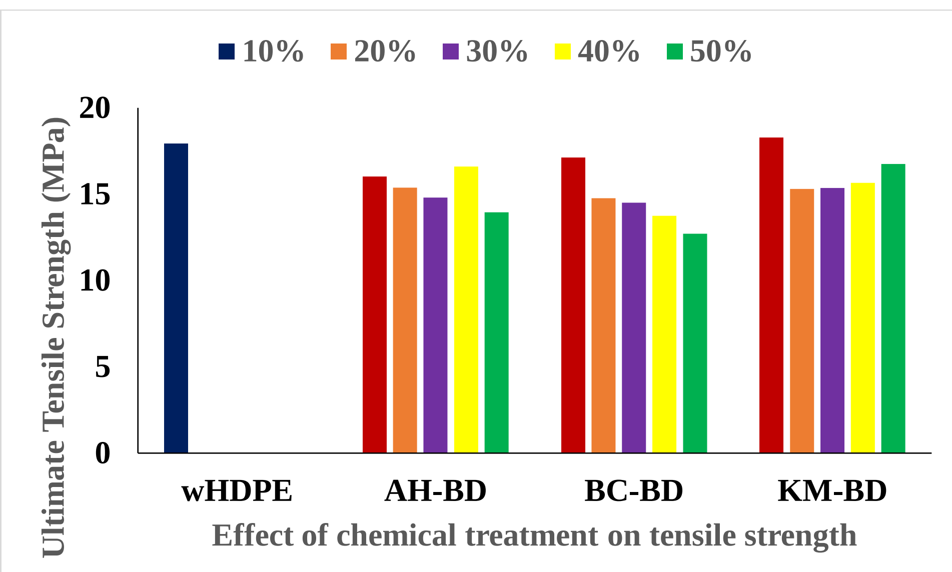

Figure 1: Ultimate Tensile Strength of Buffing Dust Reinforced wHDPE Composites

The results depicted the effect of chemical treatment on the ultimate tensile strength of the buffing dust reinforced wHDPE. Across the three (3) chemical treatments, 10 wt% composite species show improved mechanical strength due to increase in ductility of the composites. Whereas, as the fibre loads increases, the tensile strength decreases for the 20, 40 and 40 wt% due to increase in brittleness properties of the materials. Similar situation was reported by Peretomode *et al*. [10]. Looking at the effect of the chemical treatment accordingly, the permanganate treated buffing dust (BD) indicated an ultimate increase in tensile strength (18.28 MPa) at 10 wt % compared to alkaline and benzoyl chloride treated samples. The $KMnO_4$ treatment leads to better adhesion to fibre-matrix interaction during mixing. This is in accordance to the reports of some researchers [11, 12]. Considerably, the treated at 10 wt % fraction showed improvement in ultimate tensile strength as compared to the unreinforced (control) sample having a tensile strength of 17.92 MPa.

Elongation at Break

Elongation at break is a reflection of the ductility of a material and also, direct opposite of brittleness. The result of the effect of chemical treatment and weight percentage of reinforcement on the % elongation at break of BD-wHDPE composites shown in Figure 2 depicts a decrease in elongation (%) at break as the weight fraction of BD increases.

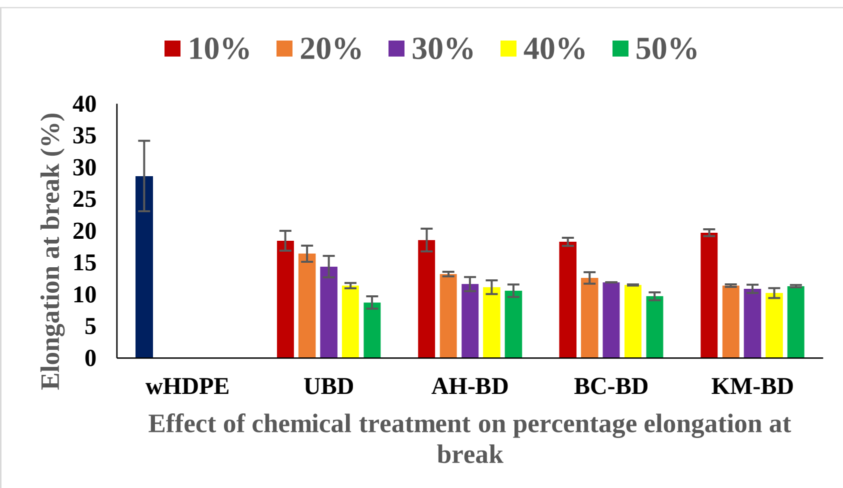

Figure 2: Elongation at Break of Buffing Dust Reinforced wHDPE Composites

The decrease observed is supposedly dependent on the amount of BD incorporated. Increase in weight percentage of the reinforcement lead to the hardening and stiffening properties of the composites. This reduced its toughness and resilience, thus lowers elongation at break [13]. As the hardness increases, the ductility of the material decreases. Similar observations have been reported by other authors [14, 15]. The composite produced at 10 wt % of KM-BD produced the highest percentage elongation at break of 19.71 %. This is about 1.26 % higher than the untreated BD sample, 1.15 % higher than ammonium hydroxide treated samples and 1.43 % higher than benzoyl chloride treated samples. Therefore, it could be observed that, chemical treatment of the BD fibres improved the percentage elongation at break of the composites. This is in agreement with the research reported by Abdul-Motaleb [16], who stated that, the elongation at break, tensile strength and elastic modulus of alkali treated fabric composites are said to improve when compared to the untreated fabric composite. Wang *et al*. [17] also reported that, the alkali treatment results in a gradual removal of excess lignin and hemicellulose from raw bamboo fibres to refine celluloses with relatively high content chemical modification. The removal of impurities may have clean-up the fibre surface for better adhesion with the matrix [18]. The control has therefore, shown better % elongation of 28.63 %, due to its high ductility as brittle BD is not incorporated in wHDPE material. This is about 8.92 % higher than the KM-BD samples.

Young's Modulus

Young's Modulus can be said to be a measure of the stiffness properties of a material under an applied stress [19]. It is also regarded as the measure of a materials resistance to elastic deformation. The Young's modulus of elasticity of the buffing dust reinforced wHDPE composites are indicated in Figure 3.

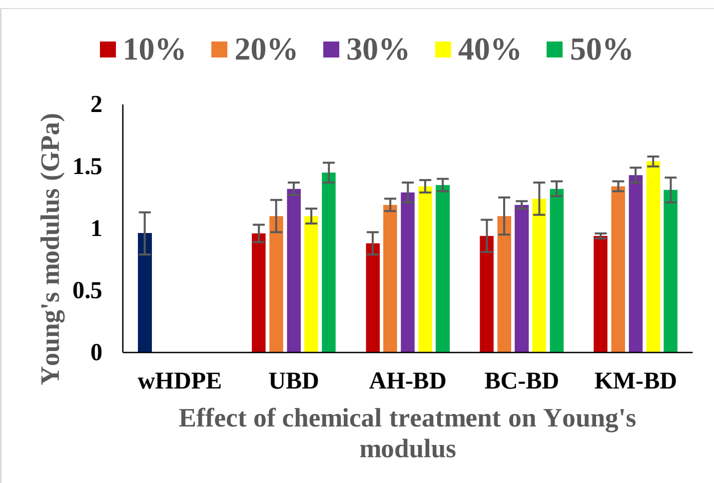

Figure 3: Young's Modulus of Buffing Dust Reinforced wHDPE Composites

The graphical representation of the results depicted that the Young's modulus increases as the weight fractions of the fibre increases. These could be attributed to the increase in stiffness properties of the composite materials as the buffing dust fibre fractions increases [20]. In the case of the untreated buffing dust reinforced wHDPE composites, at 40 wt% fraction, an apparent decrease was observed and it could be as a result of poor mixing during the compounding processes [21]. The KM-BD reinforced wHDPE composite sample with 40 wt% fibre fractions indicated the highest Young's modulus with a value of 1.54 GPa when compared with the 0.96 GPa of the wHDPE matrix and other developed composites (both treated and untreated).

Impact Energy

Figure 4 shows the impact energy of buffing dust (BD) reinforced wHDPE composites. In this case, it could be observed that the impact energy tends to decrease as the fibre loads increases.

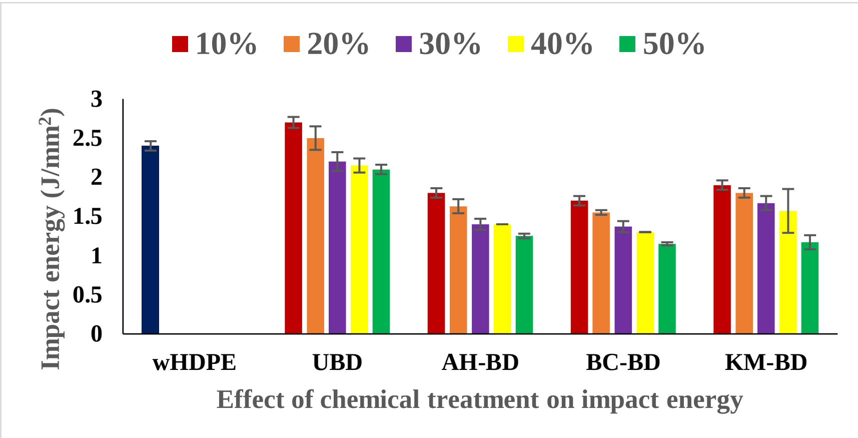

Figure 4: Impact Energy of Buffing Dust Reinforced wHDPE Composites

Increasing the weight fraction of the fibre, implies decrease in the amount of thermoplastic content of the composites, which has the capacity to absorb the stress more efficiently than the fibre. This is in agreement with the work of El-Shekeil *et al*. [22] who stated that, increase of fibre loading has resulted to decline in impact strength of the kenaf fiber reinforced thermoplastic polyurethane composites. Chemical treatment of the fibre didn't really improve the impact energy of the composites as the untreated buffing dust (UBD) reinforced wHDPE composites recorded high ability to absorb the impact stress. The impact stress decreases in a decreasing order of fibre loads (10, 20, 30, 40 and 50 wt %) as compared to the treated. It is indicative from the results that, 10 wt % of the UBD-wHDPE recorded the highest impact energy with an impact value of 2.7 J/mm^2, higher than 2.4 J/mm^2 of the control and as well the chemical treated fibres.

Dynamic Mechanical Analysis (DMA)

Storage modulus (E') refers to the stiffness of a material and is proportional to the energy that is stored during one period under load [23]. Figure 5 shows the variation of storage modulus with temperature of unreinforced and BD-wHDPE composites at 2 Hz. From the graphical representation of the results, it could be observed that the storage modulus increased with weight percent of the BD fibres.

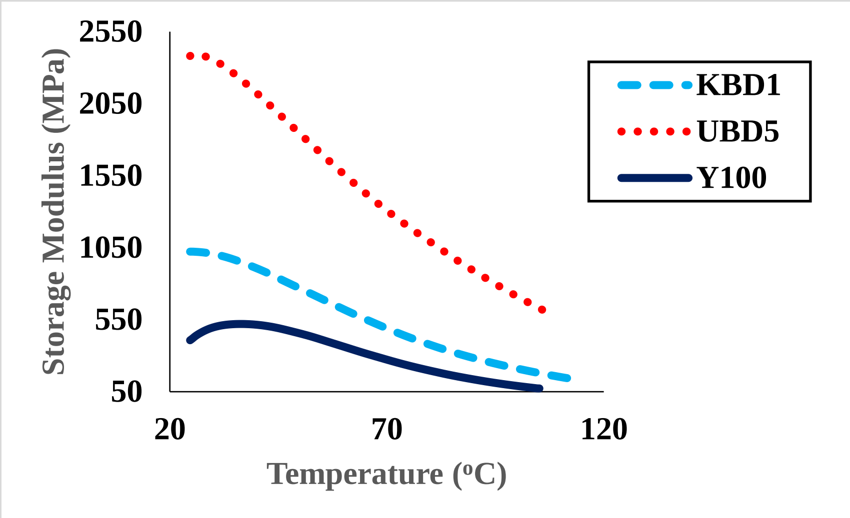

Figure 5: Variation of Storage Modulus with Temperature of BD-wHDPE Composites at 2 Hz

The highest value of E' was shown by UBD5 while the lowest value was shown by the unreinforced sample (control). The resultant large value of E' shown by the UBD5 could be attributed to the high content of BD fibres incorporated in the wHDPE matrix with uniform dispersion. Similar observation had been reported by other researchers [24]. It is evident that both the UBD5 and KBD1 composites can withstand a temperature range of 56 – 62 ºC.

Conclusion

In this study, $KMnO_4$ treated buffing dust fibres show improvement in mechanical and thermal properties. The 10 wt% KM-BD could be used as a composite formulation for the production of boot-last.

Acknowledgments: The authors here by wish to acknowledge and thank the Management Team of NILEST, Zaria.

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