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Effect of Green Synthesized Fe Nanoparticles on the Mechanical Properties of Waste Polyethylene Nanocomposites

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ABSTRACT

Recycling polyethylene waste through the addition of metal nanoparticles has attracted much attention from researchers due to the increased population of the world which opens space for advanced material. This study explored the effect of green synthesized Fe nanoparticles on the mechanical properties of waste polyethylene. The effect of green synthesized Fe nanoparticles at 0.5 to 2.5 g was investigated using a shore 'A' durometer and an Instron universal testing machine. The hardness of nanocomposite increases from 94.2 to 95.6 N/mm², flexural strength from 13.71 to 14.02 Mpa, and percentage elongation at break from 80 to 90%. The modulus of elasticity decreases drastically from 1.53 to 1.25 Mpa, and the tensile strength of the nanocomposites decreases from 1.1 to 1.02 Mpa. The result showed that green synthesized Fe affects the mechanical properties of waste polyethylene nanocomposites. These may aid the polymer composites for complex applications in the field of electrical and biomedical nanotechnology.

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Introduction

The increase in the world population is one of the driving forces pushing researchers to strive for more studies on advancing material composition and design most especially the recycling of polymer waste into desirable products. Polyethylene waste is one of the biggest problems challenging the world due to the difficulties in degradation and availability in large volumes. Recycling of polyethylene waste through the addition of metal nanoparticles has attracted much attention of researchers. The conversion of this waste polyethylene into polymer metal composites offers a broad range of properties (Obasi *et al*., 2021). These improved properties include mechanical and chemical properties. The mechanical properties of polymers are important factors that determine their application. Research has shown that the addition of nanoparticles affects the mechanical properties by improving the tensile and young modulus as stated by Grigoriadou *et al*. (2013).

It was also reported that the addition of graphene nanoplatelets to polypropylene affects the mechanical properties such as tensile and flexural strength of polymer composites (Patra *et al*., 2023). The effect of titanium dioxide on the properties of polyethylene was investigated the result showed that the tensile test improved compared to the untreated sample (Nguyen *et al*., 2012). Yassien and Jubier (2021) reported that the addition of Ag_2O nanoparticles to PMMA/polypropylene improves the mechanical properties such as hardness and Young modulus.

(Nwapa *et al*., 2020) investigated the mechanical properties of high-density polyethylene (HDPE) and linear low-density polyethylene (LLDPE) blend at various ratios and it was compared with the control.

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It was found that the modulus of elasticity and elongation at break, hardness, and flexural strength rises with an increase in the polymer blend. Maleki *et al.* (2022) conducted an experimental study on the mechanical properties of Fe_2O_3 microparticles on polypropylene. In the studies, the effect of weight fraction and microparticle size on the tensile strength and Young's modulus were investigated. The result indicated that Young's modulus was improved compared to the pure sample, and the elongation percentage was decreased as the weight fraction of the Fe_2O_3 microparticles was increased. The mechanical properties of polypropylene (PP)/organo-muscovite clay nanocomposites with different filler loading and a certain content of hexamethylenediamine (PPHMDA) as a compatibilizer were observed (Zaman and Khan, 2022). The result showed that PPHMDA showed an improvement in the tensile and hardness of the composites. The mechanical behaviors of PE and PE/AgNP composites at different weight concentrations of Ag were studied using molecular dynamics tensile simulations as reported by Su *et al*. (2020). The result showed that Young's moduli of PE/AgNP were larger than that of pristine PE, and the tensile strength increased from 118.55 MPa for pristine PE to 123.56 MPa and 141.09 MPa for PE/AgNP (1.05%) and PE/AgNP (3.10%), respectively (Su *et al*., 2020). The mechanical and antimicrobial polyethylene (LDPE) composites with CaO nanoparticles were reported (Silva *et al*., 2020). The nanoparticles used were modified organically on the surface with oleic acid (Mod-CaO), at concentrations of 3, 5, and 10 wt% in the polymer. The result revealed that Young's modulus of LDPE/Mod-CaO increases greater than that of pure LDPE.

Srikanth *et al*. (2019) reported that CdO–ZnO nanomaterial was synthesized using the solution combustion method. The material was reinforced into a polyvinyl alcohol (PVA) matrix by a solution intercalation technique. The mechanical property was determined and the result showed that mechanical properties revealed that the ultimate tensile strength almost increased at 2.5 wt% CdO–ZnO in PVA as compared to pure pristine PVA. An increase in elastic modulus was also observed for 2.5 wt% CdO–ZnO it was concluded that at 2.5 wt% CdO–ZnO in PVA the mechanical properties were enhanced. Abbas *et al*. (2019) reported that zinc oxide nanoparticles (ZnO NPs) nanoparticles were used in producing nanocomposites. Methods such as solvent casting, solution casting, solvent volatilization, twin-screw extrusion, melt compounding, and extrusion blow molding were employed to produce ZnO nanoparticle-based (bio)polymer composites. The result indicated that tensile strength and Young's modulus were observed to increase by 32% and 57% respectively (Abbas *et al*., 2019). Rifkatu *et al*. (2023) investigated the effect of the addition of Ni nanoparticles on the mechanical properties of waste polyethylene using a shore 'A' durometer and Instron universal testing machine. It was shown that percentage elongation at break, hardness, and flexural strength of the composites increase while the young modulus of elasticity and tensile strength of the nanocomposites.

The recycling of waste plastics is the more dependable solution to reduce the volume of plastic in our environment. Although a lot of research was reported on the recycling of waste polyethylene metal composites, little report was recorded on the effect of Fe nanoparticles on the mechanical properties of waste polyethylene nanocomposites. In this current study, the effect of Fe nanoparticles on waste polyethylene (sachet water leather) was investigated and the result was discussed.

MATERIALS AND METHODS

Sample Collection and Preparation

Waste polyethylene (Sachet water leather) was collected from a domestic waste bin, behind Labour Housing Estate Tunfure, Gombe State, Nigeria to ensure that one brand of the waste polyethylene was used (Atlantis sachet water leather). The method of Streit *et al*. (2022) with slight modification was used in the preparation of waste polyethylene. The waste polyethylene was treated with 20 mL of 0.1 M sulfonic acid then transferred into a 100 cm^3 beaker containing 50 mL of 0.1 M sodium lauryl sulfate, then washed with distilled water to remove any impurities and contaminants. The sample was air-dried in laboratory. The washed waste polyethylene was shredded into small particles using blade.

Dissolution of Polymer Waste

The method of Achilias *et al.* (2007) was adopted with a slight temperature modification as follows; the resized polyethylene waste was crushed and stored in a bottle container. 4 g of the crushed polyethylene waste was placed into a round bottom flask equipped with a condenser and 20 mL of xylene solvent was added into the flask. The system was heated from 350 – 400 ˚C with constant stirring for 30 minutes.

Green Synthesis of Fe Nanoparticles

Preparation of garlic bark extract

Garlic was purchased at Gombe's main market. The skin was removed by hand and the bark was washed with tap water several times before being rinsed with distilled water as reported by Modi and Fulekar (2020) with slight modification. The garlic bark was oven-dried at 40˚C for 7 days before the powder was prepared. During the preparation, 10 grams of garlic bark powder was placed in a 250 cm^3 flask containing 100 cm^3 (80% water and 20% ethanol). The solution was heated at 60˚C for 20 minutes and stirred using a magnetic stirrer for 24 hours. The extract was filtered using a Whatman membrane filter of 0.45 µm at room temperature. 50 cm^3 of filtrate was taken for the synthesis of nanoparticles while the rest of the filtrate was stored at 4˚C.

Green synthesis of metal nanoparticles using Garlic bark

The Method of Amutha and Sridhar (2018) for Green synthesized Fe nanoparticles was used with some modifications. The Fe nanoparticles were synthesized by taking 1g of $FeSO_4.7H_2O$ in a 250 ml beaker. The sample was dissolved in 100 ml distilled water and heated to 80 ˚C with mild stirring using a magnetic stirrer under atmospheric pressure. After 10 minutes, 20 ml of the garlic bark extract was added to the mixture and after another 10 minutes, 20 ml 0.1 M aqueous solution of sodium hydroxide was added to the mixture at the rate of 3 ml per minute the mixture was subjected to an ultrasonicator (Qsonica model Q700) at 30 impulses for 30 minutes and the nanoparticle was precipitated uniformly. The colour of the solution changes green and then to blackish brown. The mixture was allowed to cool down to room temperature and the Fe nanoparticles were obtained by centrifuging (Heraeus Labofuge 300) at 1000 rpm for 20 minutes and then decanting. The nanoparticles formed were washed 3 times with distilled water and 3 times with ethanol and air dried at 70˚C in an oven overnight.

Solution Formulation of Waste Polyethylene/Green Synthesized Fe Nanoparticles

The method described by Alsharaeh (2016) with slight modification was used. From the method, 2.0 g Fe green synthesized metal nanoparticles, and 1 g benzoyl peroxide (BP) were added to 80 g of the waste polyethylene, the mixture was stirred for 1 hour. The temperature of the mixture was maintained at 60 ˚C for 20 hours to allow proper solution-free radical bulk polymerization. The product was stirred in 50 ml methanol for 15 minutes and washed with methanol. Warm water was used to rinse the product and was repeated seven times. It was then filtered and dried in an oven at 30 ˚C overnight. The procedure was repeated for 0.5, 1.0, 1.5 and 2 g respectively.

Mechanical properties of waste polyethylene/ green synthesized Ni nanocomposite

The method reported by Fahim *et al*. (2015) was adopted with some modifications. The samples of waste polyethylene/green synthesized Ni nanocomposites were added into a mold of 3 mL thickness at 100 × 100 mm size and preheated at 150 ˚C. The sample was allowed to cool for 10 minutes; the molded material gave the shape of the molding cavity. A pressure of 2.5 pa was applied to the mold using the heated plates of the hydraulic press. The compressed sample was allowed to cool for further analysis.

Hardness test of waste polyethylene nanocomposite

Hardness tests were performed at the Nigerian Institute of Leather and Science Technology Samaru-Zaria using Shore 'A' Durometer (Din 53505, En Iso 868, D 2240, Iso 7619) by adhering to ASTM D2240 standard testing procedures. The waste polyethylene/metal nanocomposite was labeled by name and indentation location. Moving along the longitudinal axis, the first location was 0.50 inch (12.7 mm) toward the center, on the longitudinal center axis. Subsequent points followed at 0.50-inch (12.7 mm) intervals from the first point toward the opposite end. Each sample had five test locations on one side and the average hardness was calculated as reported by Wei and Denton (2018). The result was represented in the form of a graph.

Average hardness = $\frac{Totalhardness}{Number\ of\ sample}$ ... Equation (1)

Flexural strength test of waste polyethylene nanocomposite

Flexural tests were performed the using Instron Universal Testing Machine, model TM2101-T7 Department of Polymer and Textile Engineering, Ahmadu Bello University, Zaria, Kaduna state of Nigeria. It was tested by ASTM 638(2014). The instrong with a load cell of 5 KN as reported by Mirjalili *et al*. (2014) with a slight modification. The test process used was a three-point loading system utilizing center loading. The crosshead speed and span length were set to 5 mm/minute and 70 mm, respectively. The polymer/metal nanocomposite was cut into rectangular sizes with 2.5 mm thickness, 31.7 mm width, and 40 mm length for each sample. Three replicates per sample were tested from each sample and the average values were determined (Nwapa *et al*., 2020).

Flexural strength = $\frac{3PL}{2bd2}$ ...Equation (2)

Where P = load
L = span
b = breadth (width) of the sample
d = depth (thickness) of the sample.

Tensile strength test of polyethylene nanocomposites

The tensile strength of the samples was determined by cutting them with a dumbbell cutter into dumbbell shape using a tensile testing machine TM2101-T7 according to ASTM D 638 (2014). The dumbbell shape sample was placed in the grips of movable and fixures in an Instron machine taking care to align the long axis of the sample, the grips were tightened evenly and firmly to prevent slippage of the sample during the test. The speed of the test was set at 50 mm/min. and the machine was started and the tensile strength values were read (Nwapa *et al*., 2020). The tensile strength was calculated based on the formula reported by Sabo *et al*. (2021).

T= F/A ... Equation (3)

Where T is the tensile strength, F is the Failure load in (Newton) and A is the area in (mm^2)

A=πD^2/4 ... Equation (4)
where A is the area in mm^2 and D is the diameter in mm. $\pi = \frac{22}{7}$

Young Modulus of polyethylene nanocomposite

This test was done with an Instron Testing Machine at the Department of Polymer and Textile Engineering, Ahmadu Bello University, Zaria, Kaduna State of Nigeria. It was tested by ASTM 638(2014). The samples were cut into dumb-bell shapes using a tensile testing machine TM2101-T7 according to ASTM D 638(2014) standard and the modulus of elasticity (Young's modulus) was determined from the slope of the linear portion of the load (Nwapa *et al*., 2020).

Percentage elongation at break test of waste polyethylene nanocomposite

The sample testing was done at the Department of Polymer and Textile Engineering, Ahmadu Bello University, Zaria, Kaduna state of Nigeria. It was tested by ASTM 638 (2014). The samples were cut into dumbbell shapes using a tensile testing machine TM2101-T7 according to the ASTM D 638 (2014) standard method of Mohammed. (2009) was used to calculate the percentage of Elongation at break.

Elongation (%) = $\frac{L-L0}{L0} \times 100$ ... Equation (5)
where: L = extensional length at breaking point.
Lo = original length

RESULTS AND DISCUSSION

Effect of concentration of nanoparticles on the hardness of waste polyethylene nanocomposites

Figure 1, presents the effect of the concentration of green synthesized Fe nanoparticles on the hardness of waste polyethylene (sachet water leather).

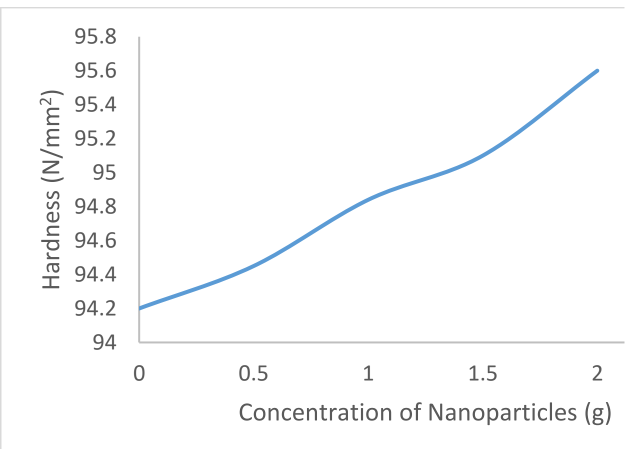

Figure 1: Effect of increase in concentration of green synthesized Fe nanoparticles on the hardness of waste polyethylene

The result showed that, the hardness of control waste polyethylene with 0.0 loading of nanoparticles recorded 94.2 N/mm². It can be observed that an increase in the dosage of the green synthesized Fe nanoparticles to the waste polyethylene increases the hardness of the composites from 94.2 to 95.6 N/mm². This is because the green synthesized Fe nanoparticles were acting like reinforcement which the particles filled in the empty spaces formed by the polymer matrix. Increasing the concentration of nanoparticles may add more strength and stiffness to the polymer composites because the reinforcing action of the nanoparticle improves the interaction between the polymer matrixes. This process helps in distributing the stress within the polymer and nanoparticles thereby increasing the hardness of the polymer composites.

Also, the addition of nanoparticles forces a restriction on the chain mobility of the polymer by forming a physical barrier that hinders the polymer chain from moving or rotating hence reducing their ability to deform under applied load. This action improves stress transfer, and interfacial interaction by transforming the polymer composite material to be rigid hence increasing hardness.

Comparing the result obtained from this work with some literature, report by Mohammed and Ismail (2015) stated that the addition of ZrO_2 nanoparticles and plasma treatment to polyethylene increased the hardness from 82.370 control polyethylene fiber to 92.353 N/mm^2 plasma treatment polyethylene ZrO_2 composites. The result obtained from this work was close to the reported however the nanoparticles were different from that of this present work. Another report from AL-Maatoq *et al*. (2022) revealed that addition of multiwall carbon nanotubes (MWCNTs) to the mixture of high-density polyethylene (HDPE) and ultra-high molecular weight polyethylene (UHMWPE) showed the highest mean value for the hardness, which was 63 ± 0.97 compared to the pure 100% UHMWPE showed the smallest value in this test, which was 54.92 ± 1.84. The reported result was lower than the result obtained from this work because of the nature of nanoparticles involved and the polymer type. Buasri *et al*. (2012) also reported that the addition of $CaCO_3$ nanofiller to polypropylene increases the hardness from 66.7 to 68.7 the increase in the reported result was lower than the result obtained from this study because of the type of the nanofiller involved. Transition metals are harder than alkali and alkaline earth metal.

Hussien and Najwa (2021) also reported that the addition of silver oxide nanoparticles to polymethylmeth/polypropylene showed increase in the hardness from 69 pure polymethylmeth/polypropylene to 88 N/mm^2 polymethylmeth/polypropylene silver oxide composites. The result obtained from this current work was similar to this report however the result obtained was higher than the report due to the type of metal nanoparticles involved. The current work was done using Fe metals that have partially filled 3d orbitals when compared to silver which has 4d partially filled orbitals hence contributing to a higher increase in the hardness obtained from this present work. Mosalman *et al*. (2018) reported that the addition of TiO_2 nanoparticles to poly methyl methacrylate (PMMA) increases the hardness from 76.60 pure PMMA to 80.37 N/mm^2 poly methyl methacrylate (PMMA) nanocomposites. The result of the report was lower than the result obtained from this work this could be because of microstructural bonds between the base matrix and added nanoparticles as reported by Mosalman *et al*. (2018).

However, report by (Zahedi *et al*. (2011) opposes the current result obtained, in the report, nano clay content, was added to polypropylene the result showed the hardness increase from 1955 pure polypropylene to 2120 Mpa. The result was greatly higher than the result obtained from this work this is because nano clay content adds to the high aspect ratio as well as the surface area of stiff silicate layers in the polymer matrix (Zahedi *et al*., 2011). Another report from Obasi *et al*. (2021) reported that the addition of inorganic coconut shell filler into polypropylene decreases the hardness from 34 virgin polypropylene to 26 N/mm^2 of the polypropylene nanocomposites.

The hardness reported was lower than the result obtained from this work because the inorganic content of the filler employed and the metal nanoparticles used in this research are different. The nanoparticles used in the present work are transition metals that have valance electrons on their outer energy level which makes them more difficult to lose therefore resulting in strong metallic bonds thereby enhancing the hardness of the composites. Also report by Panin *et al*. (2021) showed that addition of Cu particles to polyetheretherketone the hardness decreased slightly after loading with Cu metal particles from 80.1 ± 1.17 to 79.5 ± 0.5. Głogowska and Majewski (2017) also reported that the application of wheat bran filler into low-density polyethylene (LDPE) results in a decrease in the hardness from 51.24°ShD to 51.24°ShD of the entire polymer blend. This is because the hardness of a polymer blend depends on factors such as filler hardness, filler grain size, and the interactions on the filler-polymer matrix interphase. Powdered filler grains can act as nucleates in the polymer crystalline phase (Głogowska and Majewski, 2017).

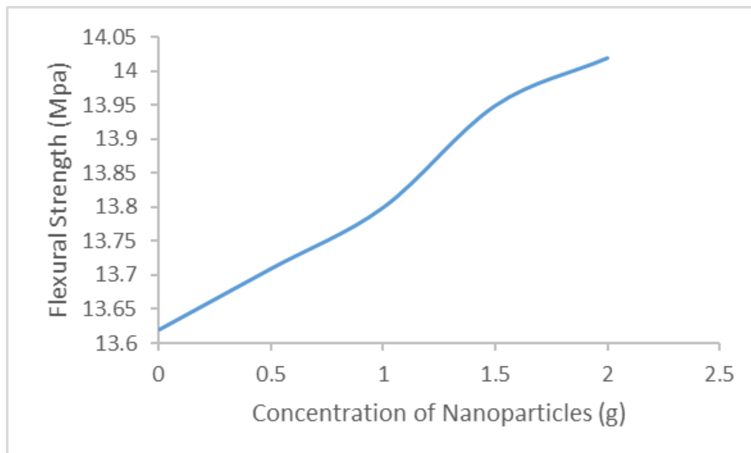

Figure 2: Effect of Fe nanoparticle concentration on the flexural strength waste polyethylene

Figure 2, represents the effect of green synthesized nanoparticles on the flexural strength of waste polyethylene (sachet water leather).

Effect of green synthesized nanoparticles on flexural strength of waste polyethylene

The control waste polyethylene flexural strength was observed at 13.62 Mpa. It can be seen that the flexural strength of polyethylene/green synthesized Fe nanocomposites increased from 13.62 to 14.02 Mpa at different loading of green synthesized Fe nanoparticles from 0.5 to 2. The result obtained revealed that the increase in the incorporation of the metal nanoparticles generally improves the flexural strength of polymer nanocomposites.

The increase in the flexural strength of the product depends on the size, shape, and the number of particles distributed during formulation. This particle grain size is easily distributed at higher loading. However, there are differences in sizes some appear to be smaller while others are large. The smaller size of nanoparticles makes it easier to be uniformly distributed within the polymer matrix. These particles effectively serve as a bridge between the empty spaces of the polymer chain promoting efficient stress transfer during loading thereby enhancing the flexural strength of the polymer composites.

Proper and uniform particle distribution during formulation may reinforce the polymer matrix because the nanoparticles serve as a shield reinforcing the polymer against external load by transferring the stress uniformly between the polymer chain and the nanoparticle. Therefore, an increase in the concentration of the nanoparticles may create a high surface area and a strong interfacial interaction among the polymer matrix. This mechanism increases the stiffness and toughness of the polymer making it more resistant to bending deformation by enhancing the interaction between the polymer matrix and the filler loading leading to effective stress transfer as a result the flexural strength was increased.

Comparing the result obtained from this work with the literature, Munikamaiah *et al*. (2018) stated that modification of polymethyl methacrylate with Silver colloidal nanoparticle increased the flexural strength in both curing cycles from 79.07 MPa control to 84.84 MPa curing polymethyl methacrylate /Silver colloidal nanocomposites. The result obtained from this work was lower than the result due to the type of polymer involved and the nanoparticles. However, the aging of the polymer used in this work may also affect the yield of the flexural strength. Another report by Vikram and Chander (2020) revealed that the addition of ZnO nanoparticles to polymethyl methacrylate (PMMA) denture base resin increased the flexural strength from 61.3 MPa to 91.31 MPa this was due to increases in the surface hydrophobicity and reduce the agglomeration of biomolecules as reported (Vikram and Chander, 2020). The result obtained from this work was lower than the reported result due to the type of polymer and nanoparticles used. Also, Kati (2019) showed that the incorporation of zinc oxide nanoparticles on the auto-polymerized acrylic resins increases from 133.27 to 176.45 Mpa. The increase was greater than the result obtained from this work this work due to the greater bond between ZnO particles and the polymer matrix as stated (Kati, 2019).

A further report from Ayaz *et al*. (2016) revealed that the addition of TiO_2 to polypropylene impacts the flexural strength of polypropylene/nano-titanium composites from 72 pure polypropylene to 78 Mpa. The result reported was higher than the result obtained from this work due to the type of nanoparticles and also due to a decrease in the bonding strength due to the aging of the polymer in the current result of this work. Also, Ou and Li (2009) reported that the addition of TiO_2 content on polypropylene/polyamide-based (PP/PA6) compounds increases the flexural strength by 50 to 64 Mpa. The increase was higher than the result obtained from this work because of nanoparticles tend to agglomerate together (Ou and Li., 2009). Mosalman *et al*. (2017) stated the addition of Al_2O_3 nanoparticles to polymethylmethacrylate (PMMA) increases the flexural strength of 4.020 to 4.171 Mpa PMMA/Al_2O_3 nanocomposites. The increase reported was lower than the result obtained. This is because of the unique properties of nanoparticles and the polymer used.

Effect of green synthesized Fe nanoparticles on the tensile strength of waste polyethylene

Figure 3 shows the effect of the increase in the loading of green synthesized Fe nanoparticles on the tensile strength of waste polyethylene.

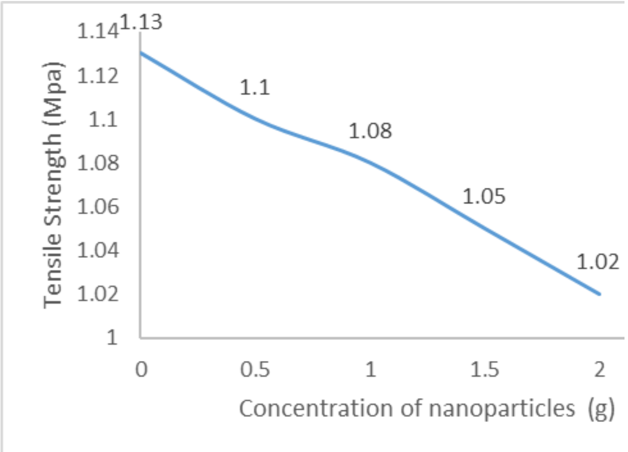

Figure 3: Effect of increase in the concentration of Fe nanoparticles on the tensile strength waste polyethylene.

The result shows that the tensile strength of control waste polyethylene was shown at 1.13 Mpa. It can be observed that the incorporation of the green Fe synthesized nanoparticles at different concentrations of 0.5 to 2 g decreases the tensile strength of the nanocomposites from 1.1 to 1.02 Mpa. The addition of the nanoparticles Fe generally decreases the tensile strength of the waste polyethylene nanocomposites. This is because of the nature of particle size and the on-unform dispersion of metal nanoparticles. The metal nanoparticles are made of different sizes some are large while others are small. This particle may easily be accumulated at the interface between the nanoparticles and the polymer matrix without bond formation which opens a space for the growth of dislocation movement due to multiple creation of cavities during stress leading to a decrease in the tensile strength of the polymer composites. The lack of bond formation between the nanoparticles and polymer matrix may also lead to phase separation with different mechanical and chemical properties. This may result in to a non-uniform microstructure within the polymer matrix which may lead to stress concentration at the boundaries of the two different phases leading to a decrease in the overall tensile strength of the polymer composites.

During particle dispersion, the distribution of the particles in a polymer matrix may be affected by the size and shape of the particles. The larger particles act as a barrier causing stress concentration and weakening the tensile strength of the polymer composites. Also, smaller particles agglomerated together by the formation of strong clusters surrounded by a void gap. This void gaps and cluster particles concentrate stress which causes the tensile stress of the material to drop.

Comparing the result with another report, it can be seen that the current result slightly agrees with a report from Chang *et al*. (2013) where an increase in filler loadings of zinc oxide nanoparticles to reinforce an ultra-high molecular weight polyethylene decreases the tensile strength from 100 to 30 Mpa. The value was higher than the result obtained from this work this is because of the age of the polymer involved in this work. Another reported Zhou et al. (2018) addition of Zn nanofiller to polypropylene decreases the tensile strength for polypropylene/Zn nanocomposites from 23.7 pure PP to 21.6. The result obtained from this work is lower than the reported result because of the aging factor of the waste polymer and also the inability of the nanoparticles to occupy the submicroscopic cracks in the waste polyethylene nanocomposites. A further report from Tripathi and Dey (2019) stated that the incorporation of NiO nanoparticles into low-density polyethylene (LDPE) decreases the tensile strength from 9.5 to 8.3 Mpa LDPE/NiO nanocomposites. The result agrees with the present result but the value obtained from the present work was lower than the result reported due to more agglomeration of the nanoparticles which lead to the formation of void gaps resulting in more dislocated movement.

However, Aguilar *et al*. (2014) Loading of inorganic nanofiler $CaCO_3$ nanoparticles to polypropylene increases the tensile modulus from 1.17 pure pp to 1.44 Gpa PP/CaCO3. The result obtained from this work slightly opposes the reported result due to the difference in the chemical composition of the nanoparticles used. Another report by Maleki *et al*. (2022) showed that the addition of Fe_2O_3 microparticle to polypropylene (PP) increases the tensile strength from 23.0 to 37.5 Mpa of the PP/Fe_2O_3 composite. However, the result obtained from this work was lower than the result reported. This is because the increase in tensile strength reported was due to the reinforcing effects of Fe_2O_3 microparticles, which strengthen its matrix and divert the crack growth path (Maleki *et al*., 2022). Also, Dimitrios *et al*. (2010) reported that the addition of carbon tubes (CNT) to polypropylene increases the tensile strength from 28 to 35 Mpa polymer/nanotube composites (PP/CNT). The result opposes the result obtained from this current. This research this is because nanotubes act as reinforcement agents (Dimitrios *et al*., 2010). Further work by Emamifar and Mohammadizadeh (2015) revealed that addition of ZnO nanoparticles to pure low-density polyethylene (LDPE) films the tensile strength significantly increased from 10.07 to 23.7 MPa LDPE/ZnO nanocomposites. The result obtained from this work also opposed the reported result because in this work the nanoparticles agglomerated which introduced defects to the polymer matrix which led to stress concentration hence reducing the tensile stress of the polymer composites.

Effect of green synthesized Fe nanoparticles on the Young modulus of waste polyethylene

The effect of an increase in the concentration of green synthesized Fe nanoparticles on the Young modulus (elastic modulus) of waste polyethylene (sachet water leather) was observed in Figure 4.

The Young's modulus of control waste polyethylene was shown at 1.76 Mpa. It can be observed that Young's modulus waste polyethylene/green synthesized Fe nanocomposite decreases from 1.53 to 1.25 Mpa with increased dosage of the nanoparticles.

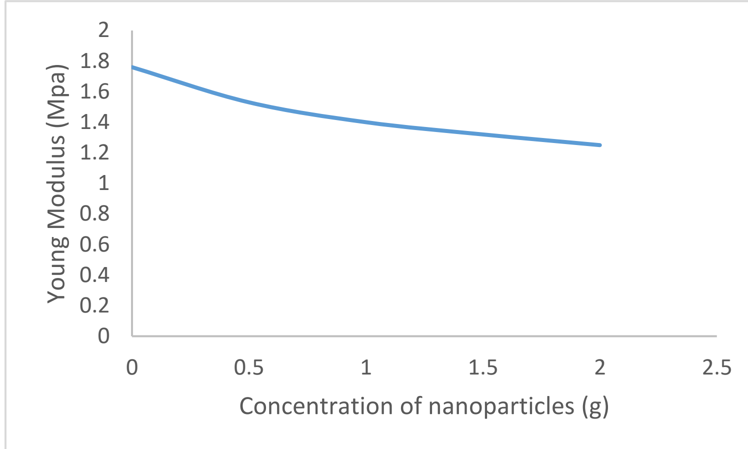

Figure 4: Effect of increase in the concentration of Fe nanoparticles on the Young Modulus of waste polyethylene

The result suggests that the addition of green synthesized Fe nanoparticles waste decreases the elastic modulus of waste polyethylene nanoparticles. This is because the nanoparticles act as a barrier to the movement of dislocation which is responsible for plastic deformation. This defect prevents the movement of the dislocation which leads to a decrease in the elastic modulus of the polymer composites. The nanoparticles also create a void gap in the polymer matrix these gaps create a porous microstructure which promotes stress concentration making the material deform faster leading to reduced elastic modulus.

The result obtained from this work agrees with the result reported by Anžlovar *et al*. (2019) where it was shown that the incorporation of different loading of ZnO nanoparticles to high-density polyethylene (HDPE) decreased the young modulus from 11.7 to 10 Gpa HDPE/ZnO nanocomposites. However, the result obtained was higher than the value reported. Nayeemuddin *et al*. (2022) also reported loading of low-density polyethylene (LDPE) with an increase in the concentration of $NiFe_2O_4$ decreases Young's modulus than LDPE/$NiFe_2O_4$ nanocomposites from 8.20 Mpa neat LDPE to 6.20 Mpa. The report agrees with the result reported however the value was higher than the reported result because, in this work, the nanoparticles poorly interact with the polymer matrix due to agglomeration. The result observed from this work was similar to the result reported by Maurice *et al*. (2013) which indicated that the addition of SiO_2 nanoparticles to polymethylmethacrylate (PMMA) decreases Young's modulus of PMMA/SiO_2 composite from 4.28 control PMMA to 4.22 Mpa composite as the concentration of the nanoparticles increases. The result reported was also slightly above the result observed from this research due to the type of polymer and nanoparticles present.

However. Chee *et al*. (2012) reported that Young's modulus increased from 70 to 100 Mpa with the addition of alumina nanoparticles into low-density polyethylene (LDPE). The result obtained from this work opposes this report because the reported result suggests that the incorporation of alumina nanoparticles would improve the stiffness of LDPE. This was due to strong interfacial interaction which enable the load to be transferred easily across the nanoparticles-matrix interface (Chee *et al*., 2012). In another report by Abbas *et al*. (2019) loading of ZnO nanoparticles to poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) increased the young modulus from 43% to 57% ZnO/PHBV nanocomposites. The result of this current work opposed the result reported due to the poor interfacial adhesion between the present polymer matrix and the nanoparticle which interact by hydrogen bonding.

A further report by Srikanth *et al*. (2019) also showed the addition of Cadmium oxide doped zinc oxide (CdO–ZnO) to polyvinyl alcohol (PVA) films increases the elastic modulus 16.2 to 34.6 Mpa. The reported result was higher than the result obtained from this work due to the reduction in the strain component which has led to a drastic increase in the film elasticity (Srikanth *et al*., 2019).

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Effect of green synthesized Fe on the elongation at break of waste polyethylene

Figure 5 shows the effect increase in the concentration of green synthesized Fe nanoparticles on the percentage elongation at the break of waste polyethylene.

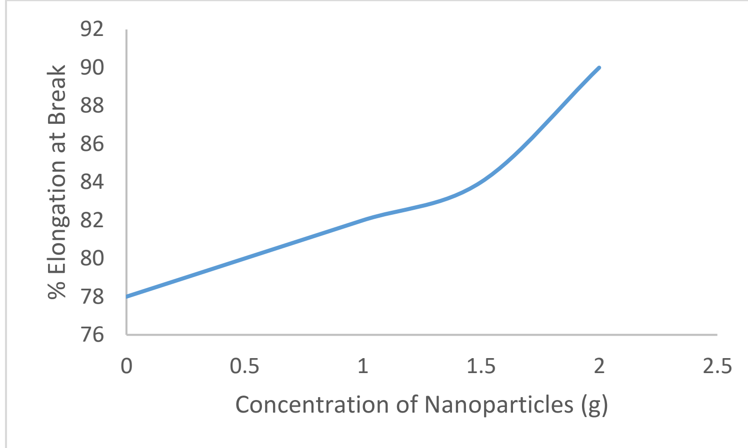

Figure 5: Effect of increase in the concentration of Fe nanoparticles on the percentage elongation of waste polyethylene.

From the above result, it can be observed that control waste polyethylene recorded a % elongation at a break of 78.0 %. The percentage elongation of waste polyethylene/green synthesized nanocomposites increases from 80 to 90% as the concentration of the nanoparticles increases from 0.5 to 2 g.

The result suggested that the incorporation of green synthesized nanoparticles increases the percentage elongation at break of waste polymer composites. This is because the metal nanoparticles are ductile materials which increase the ability of the polymer composites to deform under stress without being fractured. This occurs by the ability of the metal to dissipate energy around allowing the material to resist high stains before failure during deformation. Additionally, the metal nanoparticles absorb energy and behave like plastic by acting as a barrier to dislocation motion promoting plastic deformation thereby increasing the percentage elongation of the polymer composites.

Yadav *et al*. (2019) showed incorporation of $NiFe_2O_4$ nanoparticles into polypropylene increases the elongation at a percentage break from 247.70 to 391.08 % as the concentration of the nanoparticles decreases. the result agrees with the result obtained from this however the percentage was higher than in this work due to the nature of the nanoparticles and the formation of clusters during dispersion. Another work by Sabo *et al*. (2021) reported that loading of NiO nanoparticles into polystyrene increases

the percentage elongation by 46.67 to 50.00% that of PS/NiO nanocomposite. The percentage elongation of the reported result was lower than the result obtained from this study due to the type of polymer used and the homogeneous dispersion of the nanoparticles. Also, Shirinova *et al*. (2016) reported a dissimilar result that showed that the addition of Fe_3O_4 nanoparticles to polypropylene PP increased the percentage elongation at break from 281.04 to 402.50 % as the nanoparticles concentration was increased. The result was higher than the percentage obtained from the current work this was due to the non-homogeneous dispersion of the nanoparticles within the polymer matrix (Shirinova *et al*., 2016). A further report by Juan. (2020) showed that an increase in the dosage of graphene added to polypropylene increased the elongation at break of the nanocomposites obviously from 29 to 39%. The result reported was lower than the result obtained because of the nanoparticles and the propagation of crack hence improving the percentage elongation.
However, Ginting *et al*. (2016) also reported that the incorporation of Fe_3O_4 into polyethylene-grafted maleic anhydride PE-g-MA decreases the elongation at the break of the nanocomposite from 17 to 12%. The reported result was similar to the result obtained from this work but the value obtained was lower than the result obtained due to the percentage elongation at break depending on the degree of grafting MA and also by the distribution of maleic anhydride (MA) within the molecular chain polyethylene (PE) (Ginting *et al*., 2016). Another report by Awang and Mohd *et al*. (2018) showed that the addition of rice husk and ZnO nanoparticles to polypropylene decreases the percentage of elongation at break from 5 to 15 %. The result reported was lower than the percentage obtained from this work this was due to the presence of the rice husk which increases the stiffness and transforms the polymer into a brittle composite. Further reported by Prasert *et al*. (2020) also revealed that the addition of ZnO nanoparticles to polypropylene decreases percentage elongation from 245 to 135 % polypropylene/ZnO nanocomposites. The result was higher than the percentage observed from this research because the increase in stiffness reduces the ductility of the polymer composites (Prasert *et al*., 2020)

CONCLUSION

The waste polyethylene/green synthesized nanocomposites synthesized, and the effect of green synthesized Fe nanoparticles on the mechanical properties were investigated. The incorporation of the green synthesized Fe nanoparticle increases the mechanical properties such as hardness, flexural strength, and percentage elongation at break. However, decreases tensile strength and Young's modulus properties.

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