FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 9 No. 1, January, 2025, pp 211 - 217
DOI: https://doi.org/10.33003/fjs-2025-0901-3032

MECHANICAL AND VISCOELASTIC PROPERTIES OF COCONUT COIR FIBRE REINFORCED HIGH-DENSITY POLYETHYLENE COMPOSITE FOR APPLICATION AS WALL TILE

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ABSTRACT

In the effort to clean up the environment and transform plastic waste into valuable resources, the mechanical and thermal properties of a composite made from High- Density Polyethylene (HDPE) and Coconut Coir Fiber (CCF) were examined to determine the optimal blending ratio for producing wall tiles. The Coconut Coir Fiber was treated with 10% w/v sodium hydroxide and mixed with waste HDPE using a roll melt mixing compression molding technique. The study assessed tensile strength, flexural strength, and hardness. While the addition of coconut coir fiber improved the hardness of recycled HDPE, it did not enhance flexural or tensile strengths. The viscoelastic properties, evaluated using a 242E dynamic mechanical analyzer over a temperature range of 30°C to 130°C at frequencies of 2 Hz, 5 Hz, and 10 Hz, revealed that the composite exhibited better thermal stability at higher temperatures than waste HDPE.

Keywords: Waste high-density polyethylene, Coconut coir fibre, Composite, Dynamic mechanical analysis

INTRODUCTION

Polyethylene, often known as polyethene (PE), is a homopolymer as it is made up of just one monomer, ethylene ($CH_2{=}CH_2$). It is a flexible and lightweight synthetic resin made from the polymerization of ethylene, a byproduct of refining natural gas or crude oil (Cardoso & Fisch, 2016). High-Density Polyethylene (HDPE) is a polymer that falls under the category of thermoplastics whose monomer unit is ethylene (Gonzales *et al.*, 2024). HDPE has a resin identification code of 2. The chemical resistance, lightweight, flexibility, hardness, ability to tolerate high and low temperatures, and high impact tolerance are some notable qualities of HDPE *(*Jacob *et al.*, 2018).

Natural fibres can be derived from plants, animal bodies, or geological formations. Depending on the source and species, natural fibres can compete with other conventional fibres due to their excellent mechanical and physical qualities. Natural fibres are classified as either plant, animal, or mineral fibres (John & Thomas, 2008). Coconut fibre, which consists mainly of cellulose, lignin, and hemicellulose, is utilized across different industries, including in the production of composite materials (Yi *et al.*, 2022).

A polymer matrix with natural fibre reinforcement deposited in it makes up natural polymer composites (Lakshmikanthan *et al.*, 2022). Due to the advantages polymers offer over conventional materials, plastics have supplanted many materials in various applications (Karina *et al.*, 2008). However, plastics have contaminated the environment because they are not biodegradable. Therefore, it is imperative that plastic waste be eliminated from the environment. Reusing plastic is not a desirable option because of contamination, and its combustion releases harmful fumes. Recycling to other items is a more alluring option because of these factors. To produce load-bearing composite materials, reclaimed plastics can be strengthened with either synthetic or natural fibres (Negasi & Rotich, 2020).The following is a brief overview of some reports on the manufacture and characterization of polymeric composites: The thermo-mechanical characteristics of bamboo- reinforced HDPE composite were examined by Widiastuti *et al.*, (2022). They observed that the composites outperformed the unreinforced waste high-density polyethylene regarding load-bearing capacity and thermal stability, as evaluated through Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC). The physical, mechanical, and thermal characteristics of composite produced from banana fibre and high-density polyethylene have been investigated by Neher *et al.*, (2020). They observed that as the weight percentage of fibre in the composites increased, so did the BF-HDPE composites' capacity to absorb water and their tensile strength. Flexural strength initially improved for composites containing 5% BF-HDPE; for other higher com- positions, the value was reduced. The more fibre added, the lower the Leeb's rebound hardness. Using a thermogravimetric analyzer, thermal characteristics were examined; the composite with 20% fibre content demonstrated greater thermal stability. The thermo-mechanical characteristics of plantain particle-reinforced HDPE waste (wHDPE) were examined by Jacob *et al.*, (2019). They observed that the best mechanical properties were achieved when plantain particles and wHDPE formulation were 20% and 80%, respectively. According to dynamic mechanical study curves, the composite exceeds HDPE in terms of stiffness stability and glass transition temperature.

This research aims to determine the optimal blending ratio of CCF fibre and waste High-Density Polyethylene for possible use as wall tiles by analyzing the tensile strength, flexural strength, hardness, and viscoelasticity of recycled HDPE combined with 5%, 10%, 15%, and 20% coconut fibres.

MATERIALS AND METHODS

Sample Collection and Preparation

The waste HDPE vegetable oil bottles (Devon Kings oil bottles) were collected from dumpsites and the coconut coir fibre was collected in Barnawa environment within Kaduna South Local Government Area of Kaduna State, Nigeria.

Sample Preparation

To prepare the collected waste HDPE bottles for recycling, the waste HDPE bottles were washed to remove contaminants and sun-dried to eliminate any remaining moisture. Subsequently, a razor was used to shred them into tiny pieces (Worku & Wubieneh, 2021)

Coconut coir fibre was extracted from coconut shells by soaking the collected coconut husks in water for 72 hours to soften their husks. The fibre was then removed from the husk using a knife, rinsed with distilled water, and left to dry at room temperature. A milling machine was used to pulverize the coconut sheath fibres into a powder, which was then sieved through a 100 μm sieve (Yi *et al.*, 2022).

Chemical Treatment

The coconut fibre was macerated in a 10% sodium hydroxide solution for two (2) hours. It was repeatedly washed with distilled water to remove residual sodium hydroxide until the solution was neutral and then dried in an oven at 60 °C for 24 hours (Ofem & Ubi, 2020)

Fibre -OH + NaOH → Fibre- O- Na^+ + H_2O (1)

Preparation of Composite

Compression moulding was used to develop composites weighing 100 grams. The waste high-density polyethylene (wHDPE) was reinforced with treated natural fibre (0%, 5%, 10%, 15%, and 20% by weight). A counter-rotating two-roll open mill was used for the compounding process. The wHDPE was masticated for four minutes, after which the natural fibres in the various weight percentages were added. Once well combined and masticated, the composite was placed in a preheated mould and cured at 100 °C for 10 minutes using an electrically heated hydraulic press. The developed composite was cooled at room temperature under a pressure of 3 bar and carefully packed for analysis (Medupin *et al.*, 2018).

Mechanical Properties include:

Tensile Strength

A universal tensile tester measured the force required to fracture the test sample. The prepared composite was cut into the shape of a dog bone or dumbbell with a 45 mm gauge length. The specimen was fixed between the two jaws of the universal testing machine, with the cross-head speed set at 50 mm/min and the temperature at 25 °C. The specimen was gradually stretched until fracture occurred (ASTM, 2014; Yi *et al.*, 2022).

Hardness

A hardness test measures how well a surface resists indentation under a specific load. Using a micro Vickers hardness tester, composite samples of dimensions 30 mm × 30 mm× 5 mm were subjected to a stress of 0.3 kgf. The sample was indented beneath the tester, and hardness was calculated using the load and the indentation area (Jacob & Mamza, 2021).

Flexural Strength

The maximum force required to bend a beam was determined via a flexural test. A universal testing machine measured the flexural strength using a three-point bending method. The composite sample was inserted into a three-point bending machine, and force was applied until the sample's maximum deflection was achieved. Flexural strength (σ) was calculated using Equation 2:

$$\sigma = \frac{3Pl}{2bt^2} \quad (2)$$

Where: σ = flexural strength (MPa); l = length of specimen span between supports (mm); P = maximum deflection force (N); b = width of specimen (mm); t = thickness of specimen (mm) (ASTM, 2015b; Jacob & Mamza, 2021).

Dynamic Mechanical Analysis

Polymers respond to motion energy in two ways: through a viscous response, which dis- tributes mechanical energy and prevents breakage, and through an elastic response, which facilitates shape recovery. These responses were analyzed using Dynamic Mechanical Analysis (DMA). A dynamic mechanical analyzer conducted DMA following the ASTM D7028 standard (ASTM, 2015a). The setup included a sample holder for three-point bending, a furnace temperature range of 30–110 °C, a dynamic load of 4 N, a frequency range of 2–10 Hz, and a heating rate of 3 K/min. Composite samples measuring 60 mm × 12 mm × 5 mm were prepared for testing. Each sample was placed in the machine using a three-point bending configuration and secured in the furnace (Jacob & Mamza, 2021).

RESULTS AND DISCUSSION

Mechanical Properties

Tensile Strength

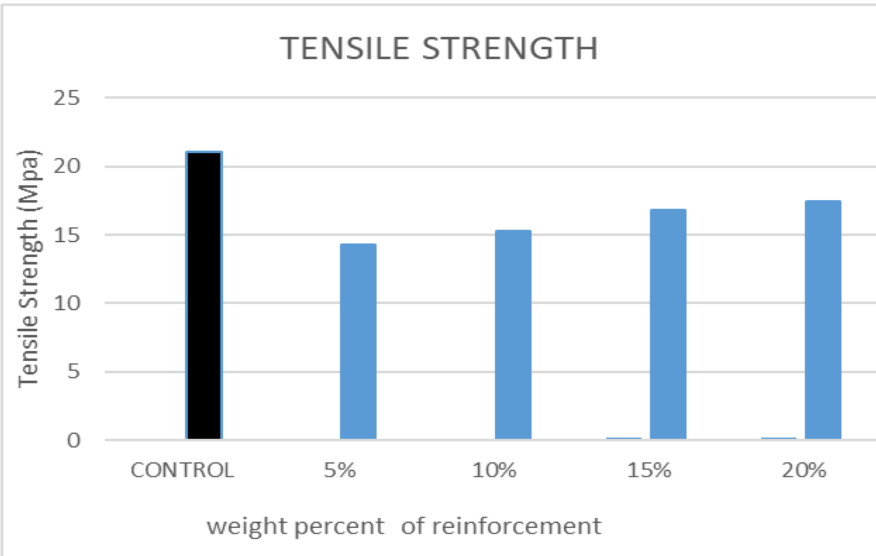

Figure 1: Impact of CCF on the Tensile Strength of Recycled HDPE Composites

Figure 1 shows the tensile strength results of the composites made from coconut coir fibre (CCF) samples and the waste HDPE (control sample).

Adding 5%, CCF decreased the tensile strength, but a subsequent increase in the weight percent of the CCF increased the tensile strength of the composite with 20% CCF composite showing the highest tensile strength among the composites. This outcome aligns with those reported by Yi *et al.* (2022), Charoenvai (2014) and Widiastuti *et al.*, (2022) who observed that increasing natural fibre content decreased tensile strength.

Hardness

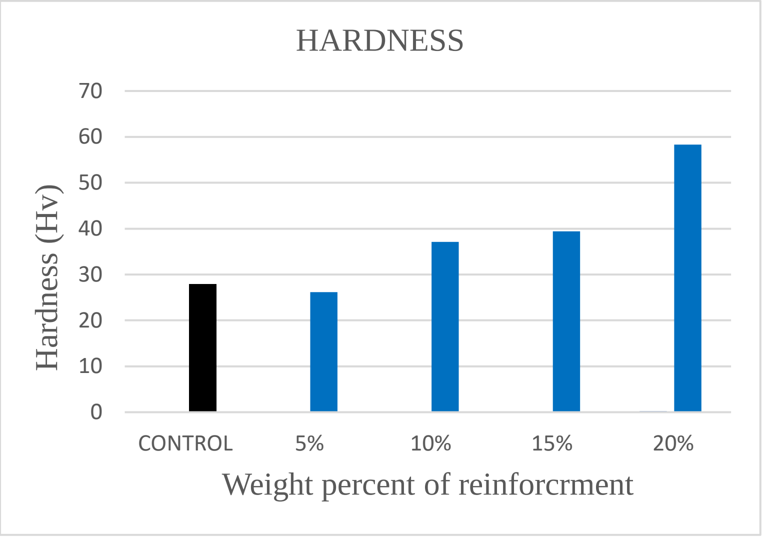

Figure 2: Impact of CCF on the Hardness of Recycled HDPE Composite

Figure 2 presents the Vickers hardness values for the waste HDPE (control sample) and CCF composites. The composites' hardness increased as the weight proportion of the CCF increased. The cause of the hardness increase could be as a result of the strengthening effect of the fibers integrated into the polymer matrix. This finding corroborates the results of Jacob *et al.*, (2019), Daramola *et al.*, 2019) Medupin *et al.*, (2018), Bahra *et al.*,(2017) , Yi *et al.*, (2022) and Adah *et al.*, (2024).

Flexural Strength

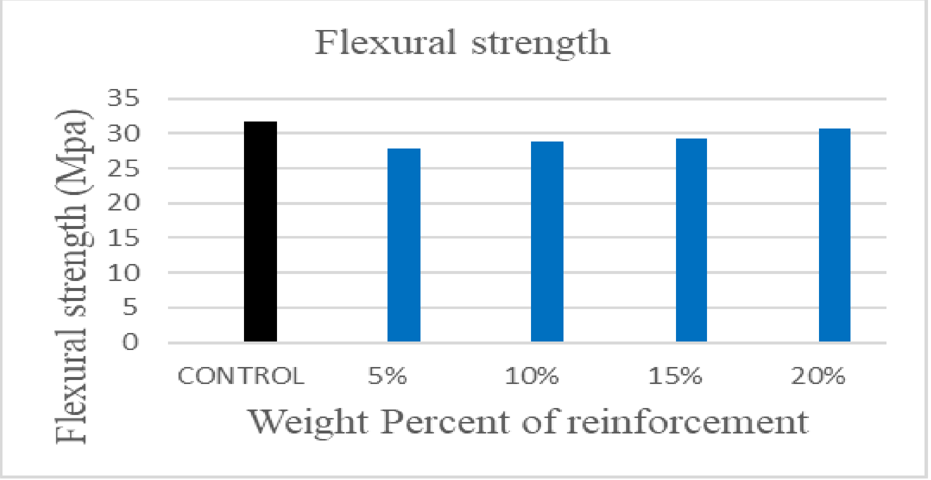

Figure 3: Impact of CCF on the Bending Strength of Recycled HDPE Composites

Figure 3 displays the flexural strength results for the CCF composites and the waste HDPE (control samples). Adding 5%, CCF decreased the flexural strength, but a subsequent increase in the weight percent of the CCF increased the flexural strength of the composite with 20% CCF composite showing the highest flexural strength among the composites. These results are consistent with findings by Yi *et al.*, (2022) and Neher *et al.*, (2020).

Viscoelastic Properties

Storage Modulus (E′)

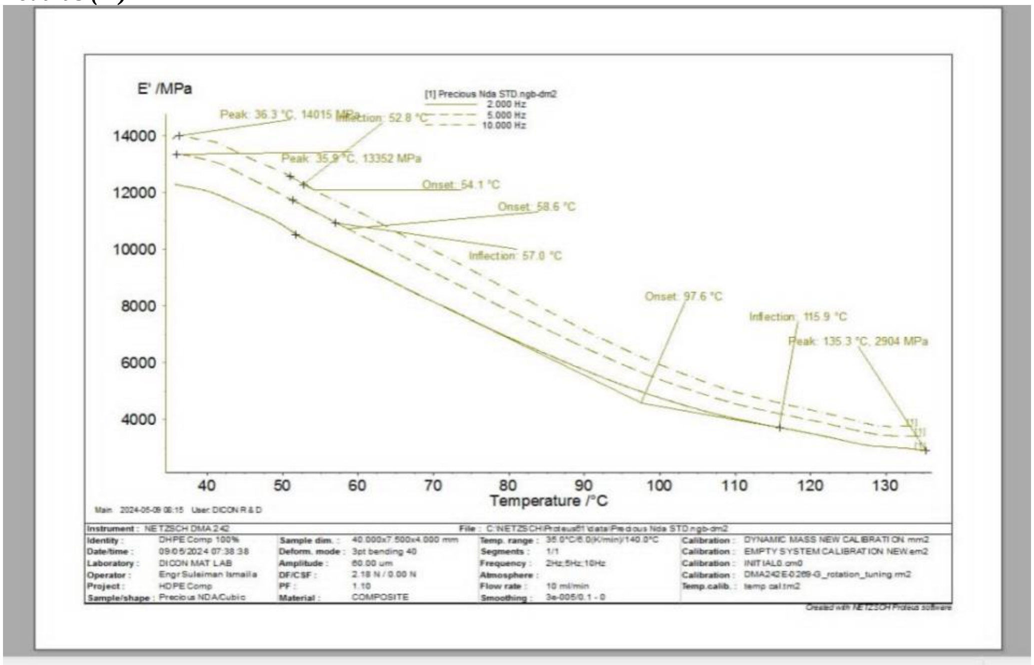

Figure 4: Storage modulus curve of waste HDPE composite at 2, 5, and 10 Hz

The stiffness of polymeric materials is indicated by their storage modulus (E') (Gupta, 2017; Jacob et al., 2018). In other terms, it represents the energy retained within the system, denoted by the elastic component. Figure 4 illustrates the storage modulus of waste HDPE at frequencies of 2, 5, and 10 Hz. The curve at 2 Hz indicates that the composite remains stable under dynamic loads as the temperature rises up to 97.6 °C, before reaching an inflection point at 115.9 °C. Additionally, the storage modulus decreases with increasing temperature, attributed to the reduction in fiber stiffness at higher temperatures. This finding aligns with the studies by Jacob *et al.,* (2019), Satapathy and Kothapalli, (2018), and Jacob and Mamza, (2021). Similar results were observed at 5 and 10 Hz frequencies but with lower inflection values of 57.0 °C and 52.8 °C, respectively. The storage modulus increased with an increase in frequency from 2,904 MPa at 2 Hz to 13,352 MPa at 5 Hz and 14,015 MPa at 10 Hz. This result indicates that an increase in frequencies increases the stiffness of the waste HDPE. A similar result has been reported by Jacob, (2023).

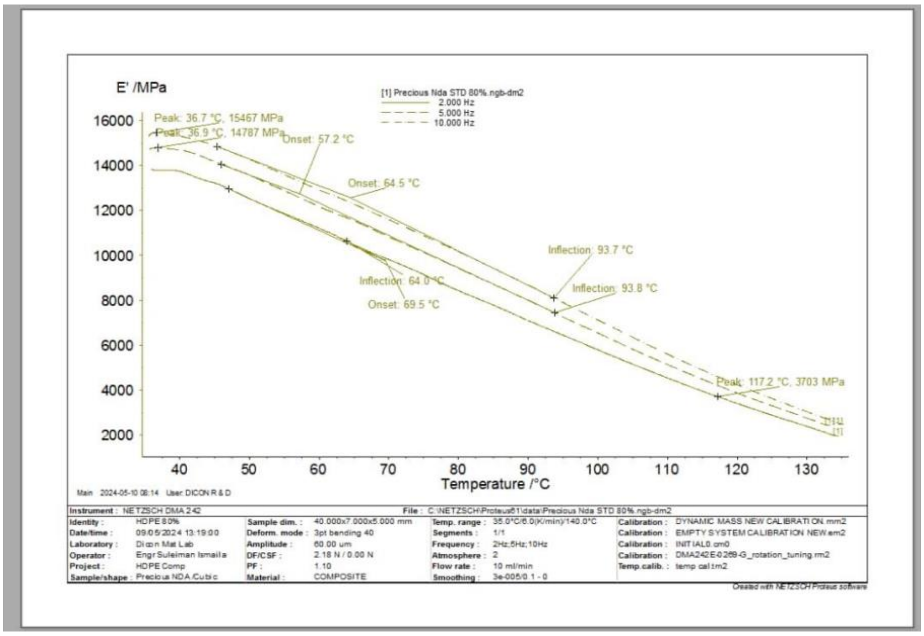

Figure 5: Storage modulus curve of waste HDPE and 20% CCF at 2, 5, and 10 Hz

Figure 5 illustrates the storage modulus of 80% waste HDPE and 20% CCF. At 2 Hz,stability was observed as the temperature increased to 64.0 °C, reaching an inflection point at 69.5 °C. These findings are consistent with the study by Jacob *et al.*, (2019), Satapathy and Kothapalli (2018), and that made by Jacob and Mamza (2021). Similar results were observed at 5 and 10 Hz frequencies with inflection values of 93.8 °C and 93.7 °C, respectively. These results also indicate that with an increase in frequencies, the inflection values of the composite did not follow a regular pattern of continuous increase or decrease. The storage modulus increased with frequency from 3,708 MPa at 2 Hz to 14,787 MPa at 5 Hz and 15,467 MPa at 10 Hz. A similar result has been reported by Jacob (2023). A comparison of this result with that of the waste HDPE at 2 Hz shows that the CCF composite has a higher storage modulus than the waste HDPE, which indicates that the incorporation of the CCF increased the stiffness of the waste HDPE.

Damping Parameter

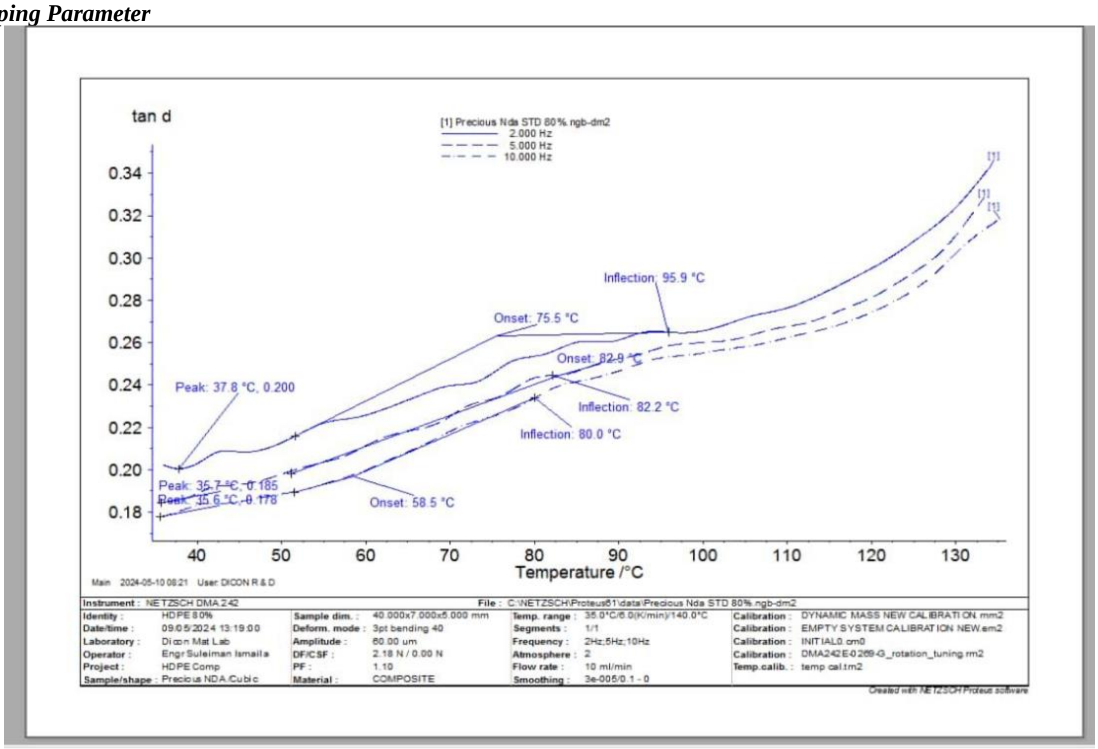

Figure 6: Damping curve of 80% waste HDPE and 20% CCF

According to Gupta (2017), damping, also known as Tan delta (Tan δ), is the ratio of storage modulus to loss modulus. This measures the viscoelasticity of materials. A low damping value indicates that the material is more elastic, whereas a high damping value indicates greater non-elastic strain behavior (Jacob *et al.,* 2018).

Figure 6 shows the damping (Tan δ) of 80% waste HDPE and 20% CCF. The viscoelasticity of the waste HDPE and 20% CCF is eminent at a tan delta value of 0.200 at 95.9 °C. Jacob and Mamza (2021) have reported a similar result. At frequencies of 5 and 10 Hz, damping values of 0.185 and 0.187, respectively, were observed. This result indicates that with increased frequencies, the tan delta value of the 80% recycled HDPE and 20% CCF followed a regular pattern of continuous decrease.

CONCLUSION

Lightweight, inexpensive, and readily available materials were used to develop the composites. Various filler ratios were examined under the same conditions. Adding natural fibre improved the composite's hardness, tensile and flexural strengths . The ideal mechanical properties, including a tensile strength of 17.47 MPa, flexural strength of 30.67 MPa, and hardness of 58.33 Hv, were observed at 20% coconut coir fibre and 80% waste HDPE. The hardness of the composite 20% coconut coir fibre and 80% waste HDPE was higher than that of the control sample and the tensile and flexural strengths of the 20% coconut coir fibre and 80% waste HDPE were found to be lower than that of the control sample. Dynamic mechanical analysis revealed that the composite outperforms waste HDPE in stiffness stability under dynamic loading at higher temperatures. Large- scale production of wall tiles from HDPE plastic waste and HDPE composites can reduce pollution and mitigate environmental harm caused by HDPE waste

Figure 7: Some of the developed potential composite wall tiles

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