Journal of Biodiversity and Environmental Research
December, 2023 Editions
www.ssaapublications.com

JBER
Vol.2, No.2, E-ISSN 3027-1916
P-ISSN 3026-9466
Sahara African Academic

PRODUCTION OF INTERLOCKING FLOOR TILES USING WASTE PLASTICS

ANELE TRUST C.; MADUMERE EBENEZER & OKERE SAMUEL S.
Department of Materials and Metallurgical Engineering, Federal University of Technology Owerri.

Abstract
This study is aimed at the production of Interlocking tiles using waste plastics (Low-density polyethene and Polyethylene terephthalate) and sand. In this work, the tiles were produced by mixing sieved river sand with molten plastic. This was done in varying percentages of PET (10%, 20%, 30%, 40%, 50%), Sand (70%, 60%, 50%, 40%, 30%), with LDPE being constant at 20%. The tests performed to evaluate the physical and mechanical performance of the tile were weight, water absorption, compressive strength, and flexural strength. The samples were then compared with the control sample a conventional tile with 0% plastic. The result showed that for water absorption, sample B gives the best water absorption value at 1.07, sample D at 1.15, Sample C at 1.40, Sample E at 2.02, and Sample A at 3.32 with the control sample being 1.49. For compressive strength, Sample B has the best compressive strength value at 11.78 N/mm^2, Sample D 4.21 N/mm^2, Sample E 4.18 N/mm^2, sample C 4.11 N/mm^2, sample A 3.47 N/mm^2, with the control sample having a value of 4.24 N/mm^2.For flexural strength, sample B has the best flexural strength at 1.985 N/mm^2, sample A 1.718 N/mm^2, sample C 1.124 N/mm^2, sample D 0.579 N/mm^2, sample E 0.395 N/mm^2, with control sample possessing a value of 2.104 N/mm^2.

Keywords: Polymers, Interlocking, Floor Tiles, Waste Plastics, Production

Introduction
Plastics are one of the numerous materials used in production worldwide. Plastics are categorized either as thermoplastic or thermosetting plastic. These categories of polymer are differentiated based on their behaviour in the presence of heat. Thermoplastics have a low melting point and therefore can be recycled

or reformed by exposure to heat, while thermosetting plastics have a high melting point. (Shah, Garg, Gandhi, Patel, & Daftardar, 2017). Thermoplastics constitute about 80% of all plastic that is commonly used while thermosetting plastics constitute about 20% (Gawande, Zamare, Renge, Tayde & Bharsakale, 2012).

Plastic materials are used to make useful products such as bags, furniture, cups, basins, drinking and food containers etc. However, most of these, end up as waste material after use. It is estimated that 15–40% of waste plastic dumped into water bodies in these countries contributes to about 5.25 trillion estimated pieces of plastic debris in the oceans currently (Alexander, Danladi, Pierre, Mike, David, & Christopher, 2018). Low-density polyethylene is the type of plastic that is mostly used for various purposes such as packaging food and water. In most cases, after the consumption of the food items, the plastics are disposed of indiscriminately. Due to the extensive use of low-density polyethylene (LDPE) and polyethylene terephthalate (PET) plastics, and the indiscriminate and uncontrolled dumping of waste plastic into water bodies in developing countries, pollution has increased to such an extent that they are now a major environmental issue in many parts of Africa (Temitope, Abayomi, Ruth, & Adeola, 2015).

Plastic waste is hazardous and detrimental to the environment, human health and plant life. (Osarumwense, Okundaye, & Salokun, 2020). Therefore, the need for proper disposal, and if possible recycling of these wastes into useful products is necessary to curb the nuisance they cause to the environment. Recycling waste plastics has the benefit of reducing environmental impacts that may arise as a result of the indiscriminate burning of plastic materials. The recycling of waste plastic materials especially wastes generated from polyethylene in some developing countries can provide employment and means of livelihoods to the informal entrepreneurial sectors.

Building materials have experienced a considerable amount of innovation from the past till the present time. Building materials include clay, fine aggregates (sand), wood, coarse aggregates (rock), concrete reinforcement (steel), roofing tiles, floor tiles e.t.c among several others.

Tiles are usually thin, square or rectangular coverings manufactured from hardwearing material such as ceramic, stone, metal, baked clay, or even glass.

Interlocking tile blocks have been extensively used in several countries as a specialized problem-solving technique, for providing pavement in areas where conventional types of construction are less durable due to many operational and environmental constraints. Interlocking tile block technology is widely used in Nigeria for building and construction works such as footpaths, parking areas, minor roads, streets, etc. It is also adopted extensively in different uses where the conventional construction of pavement using hot bituminous mix or cement concrete technology is not feasible or desirable. Properly designed and constructed interlocking tile blocks give excellent performance when applied at locations where conventional systems have lower service life due to several geological, traffic, environmental and operational constraints. (Orhorhoro, Oyejide, & Atadious, 2018).

Research has shown that fibres from recycled PET can be used in the construction sector. Cement as the significant established binder is extremely costly. This is a direct result of a booming population, development and urbanization. The need to bridge the gap between demand and high cost has led to the search for the utilization of less expensive binders such as polyethene terephthalate (Bamigboye, Ngene, Ademola,& Jolayemi, 2019). (Nivetha, Rubiya, Shobana, and Vaijayanathi, 2016) showed that PET can be used as a binding material instead of cement in the manufacturing of paver blocks. It was found that the proportion of PET 30%, Fly-ash 25% and Quarry dust 45 % was the best. The measurements of physical and mechanical properties show that plastic waste paver blocks in these proportions have a higher compressive strength than concrete paver blocks.

This project is focused on the production of interlocking floor tiles from plastic waste as it is less expensive and environmentally friendly.

CONCEPTUALISATION

Polymers

A polymer is a large molecule, or macromolecule, composed of many repeated subunits; and because of their broad range of properties, both synthetic and natural polymers play an essential and ubiquitous role in everyday life. Polymers range from familiar synthetic plastics such as polystyrene to natural biopolymers such as DNA and proteins that are fundamental to biological structure and function. Polymers, both natural and synthetic, are created via the polymerization of many small molecules, known as monomers. Their consequently large molecular mass relative to small molecule compounds produces unique physical properties, including toughness, viscoelasticity, and a tendency to form glasses and semi-crystalline structures rather than crystals.

The term polymer was coined in 1833 by Jöns Jacob Berzelius, though with a definition distinct from the modern IUPAC definition. The modern concept of polymers as covalently bonded macromolecular structures was proposed in 1920 by Hermann Staudinger, who spent the next decade finding experimental evidence for this hypothesis. Polymers are studied in the fields of biophysics macromolecular science, and polymer science which include polymer chemistry and polymer physics.

Historically, products arising from the linkage of repeating units by covalent chemical bonds have been the primary focus of polymer science; emerging important areas of science now focus on non-covalent links. Polyisoprene of latex rubber and the polystyrene of styrofoam are examples of polymeric natural/biological and synthetic polymers, respectively. In biological contexts, essentially all biological macromolecules i.e proteins (polyamides), nucleic acids(polynucleotides), and polysaccharides are purely polymeric or are composed in large part of polymeric components e.g., isoprenylated lipid-modified glycoproteins, where small lipid molecule and oligosaccharide modifications occur on the polyamide backbone of the protein (Nuha, Mohammed, Mohamed, & Hamed, 2013).

Properties of Polymers

Introduction—Thermoset vs Thermoplastic

The primary difference between the two is that Thermoset is a material that strengthens when heated but cannot be remolded or heated after the initial forming, while thermoplastics can be reheated, remolded, and cooled as necessary without causing any chemical changes. As a result of these physical and chemical properties, thermoplastic materials have low melting points while thermoset products can withstand higher temperatures without loss of their structural integrity. Thermosets are unique and quite different from other plastic materials such as thermoplastics, so what's the difference between thermoplastic and thermosetting?

Unlike thermoplastic parts that melt and disfigure when exposed to excess heat, thermoset components as implied by their name become set in their physical and chemical properties after an initial heat treatment and therefore are no longer affected by additional heat exposure. After initial heat forming, thermoset material's ability to exhibit resistance to heat, corrosion, and mechanical creep makes them perfectly suitable for use in components that require tight tolerances and excellent strength-to-weight characteristics, while being exposed to elevated temperatures.

Thermoset Pros

i. Resistant against high temperature
ii. Hard and rigid
iii. Cost-effective

Thermoset Cons

i. Cannot be recycled.
ii. Much more difficult to surface finish.
iii. Cannot be remolded or reshaped.
iv. Poor thermal conductivity. (Thomasnet, 2022)

The rigidity of the material can result in material failure when used in high-vibrational applications.
Thermoplastic pellets soften when heated and become more fluid as more heat is administered. The curing process is 100% reversible as no chemical bonding takes place. This characteristic allows thermoplastics to be remolded and recycled without negatively affecting the material's physical properties. There are a variety of thermoplastic resins that offer various performance benefits, but the majority of materials commonly used offer high strength, shrink resistance, and easy flexibility. Depending on the resin, thermoplastics can serve low-stress applications such as plastic bags or can be used in high-stress mechanical parts.

Thermoplastic Properties

i. Extremely adhesive to metal
ii. Highly recyclable
iii. Superb impact resistance
iv. Can be remolded and reshaped
v. Excellent corrosion resistance
vi. Slip enhancement

Thermoplastic cons

i. May soften when reheated
ii. Can be more expensive than thermosets (Thomasnet, 2022)

Processing of Polymer

Due to the properties of polymers, it is possible to mold them and change their shape using several different repetitious manufacturing processes. The most important of these are extrusion, injection molding, blow molding, vacuum forming, extrusion blow molding, rotational molding, calendaring, foaming and compression molding.

1. **Extrusion:** Thermoplastic granules are forced through a heated barrel and the fused polymer is then squeezed through a die that is the profile of the extruded component. The extrusion is cooled by water or air as it leaves the die and is finally cut to the required length. The shape of the die can be varied from a simple hole with a centrally supported core to produce tubes such as pipes, to very complex sections for curtain tracks or hollow window frames (Muneeb 2022).
2. **Blow Molding:** It is a process for converting thermoplastics into hollow objects. Like injection molding, the process is discontinuous or batch-wise in nature, involving a sequence of operations that culminates in the production of a molding. This sequence or cycle is repeated automatically or semiautomatically to produce a stream of molded parts. The blow-molded parts are formed in a mold that defines the external shape only. As the name implies, the inner shape is defined by fluid pressure, normally compressed air. In this respect, blow molding differs radically from many molding processes where mold members determine both inner and outer forms. The major advantage is that the inner form is virtually free of constraints because there is no core to extract. The main drawback is that the inner form is only indirectly defined by the mold, so high precision and independent internal features are impossible. This has a bearing on wall thickness, which can never attain the consistency and accuracy of a full-mold process such as injection molding. (Ebnesajid, 2015).
3. **Injection Molding:** It is one of the most important processes for mass production of objects from thermoplastics, usually without additional finishing being required. Today, most injection molding machines are the universal types, which can accept all types of molds, within limits. The economics of this process are excellent for articles with complex geometry, giving this process an advantage over other techniques. Cost per molding improves with scale, despite the sizable initial cost of injection molding machines. The principle of injection molding is very simple. The plastic material is heated until it becomes a viscous melt. It is then forced into a

closed mold that defines the shape of the article to be produced. There the material is cooled until it reverts to a solid, then the mould is opened and the finished part is extracted (Ebnesajid, 2015).

4. **Calendaring:** It is used to produce plastic sheeting and products such as floor tiles, coated fabrics and covering for car interiors. Fused thermoplastic is extruded onto heated rotating rollers that squeeze the material into a continuous sheet or film. The film is cooled by jets of air or water, before being cut to suitable lengths or loaded onto rolls (Evan M., Nickolas, P., Savvas, H., 2022)

Plastics

Leo Hendrik Baekeland seems to have been the first person to use the term "plastic materials" to describe products made from macromolecules (resins, elastomers and artificial fibres). The main inventions in the world of plastics occurred between the two World Wars: cellophane in 1913, then polyvinyl chloride in 1927, polystyrene and nylon in 1938, and polyethylene in 1942. In a 2018 study, the International Energy Agency predicted production of around 600 million metric tons by the middle of the century. (Philippe, 2019).

Key Dates in the History of Plastic

1907 – Bakelite, 1913 – Cellophane, 1924 - PMMA (Plexiglas), 1933 - Polyethylene (PE, PE-HD, PE-MD, PE-LD, PE-LLD), Polyurethane (PUR), Nylon (Polyamide 6.6), 1944 - Polystyrene (PS, PS-E) and 1954 - Polypropylene (PP). (Phillips, 2019)

Plastic Waste and the Impacts

Plastic accounts significantly for a larger proportion of human waste across the globe despite the deliberate policies enacted to curb its rise; as part of SDG Goal 3,6, 7 and 13 which emphasizes health, clean water, sanitation, clean energy and climate action (Shen, Huang, Chen, Song, Zeng, & Zhang, 2020). Recent estimates suggest that as much as 300 million tonnes of plastic waste are produced annually on a global scale, while approximately 90 per cent of such waste is neither recycled nor incinerated, but majorly disposed of as single use (Sofi, Manzoor, Bhat, &Munvar, 2020). In perspective, this equals 6,000 shiploads of waste ending its journey in our seas and ecosystem. In this light, it has been suggested that in millions of years to come, plastic wastes may serve as the geological indicator of the current Anthropocene era (Bigalke, &Filella, 2019). In Nigeria, clear statistical data on plastic waste generation is missing (Abubakar, Umaru, & David, 2019). This means that plastics alone may account for as much as 34% of Nigeria's total solid waste. Plastic pollution is associated with a wide range of undesirable consequences. It poses a threat to the marine ecosystem (Dumbili, & Henderson, 2020), threatens global food security, and is associated with several health challenges in humans. Recent studies by (Barboza, Lopes, Oliveira, Bessa, Otero, Henriques, & Guilhermino, 2020) have found the presence of microplastics in the human diet

Plastic Recycling and the Issues

However, in turning plastic waste into a viable source of economic growth and development in Nigeria, certain challenges are expected and will need to be addressed. First, there will be a need to address Nigeria's problem of indiscriminate solid waste disposal. Illegal dumping of solid waste in undesignated areas is identified as a major challenge facing Nigeria's waste management regime (Alumona, &Onwuanabile, 2019). Particularly, the indiscriminate dumping of solid wastes makes it difficult for recyclers to gain access to sufficient feedstock for their recycling plants. According to Adeleke (2018), the spate of indiscriminate waste disposal in southwestern Nigeria is so alarming that it already constitutes adverse public health consequences. Similarly, Abubakar et al (2019) stress that in North Central Nigeria, the indiscriminate disposal of domestic and industrial waste is so rampant that even waste management companies have begun to indulge in such illicit activities. Therefore, the point to stress is that while indiscriminate dumping of wastes poses a series of adverse environmental and health consequences, it also makes it difficult for recyclers to collect the plastic wastes needed as raw materials for the production of bio-oil. As such, it is necessary for efforts aimed at addressing the problem of plastic pollution in Nigeria through pyrolysis, to begin with, mass sensitization on the need to avoid indiscriminate waste disposal. A strong senate-backed policy/legal framework with very strong sanctions must be instituted to curb this waywardness. Widespread illiteracy and poor public awareness of the environmental impact of indiscriminate waste disposal is widely considered one of the main challenges facing Nigeria's waste management regime, and this can be adequately addressed through mass
sensitization, public education, and provision of collection units across cities.

Building Construction Works

Concrete is the most widely used building material due to its durability, resistance to fire and compressive strength characteristics when compared to other materials such as steel and wood. Constituents of concrete include cement, fine aggregate, coarse aggregate and water. Admixtures such as superplasticizers may be added for strength enhancement. The use of concrete in the construction industry has increased drastically in the last decades, consequently, the cost of its constituent material has increased. Besides the rise in the cost of concrete production, continuous mining of granite may result in the depletion of aggregate deposits, environmental degradation and ecological imbalance (Ofonime, & Ifiok, 2016).

The production of concrete involves the mixing of sand, cement, granite (or gravel, as the case may be) and water in certain pre-defined proportions and under a carefully controlled environment to achieve the properties necessary for good performance in service.

Concrete however has many disadvantages. Some of them include:

- Compared to other binding materials, the tensile strength of concrete is relatively low.
- Concrete is less ductile.
- The weight of concrete is high compared to its strength.
- Concrete may contain soluble salts. Soluble salts cause efflorescence.

(Civil Today, 2022)

Polyethylene is used worldwide for diverse plastic products and possesses the following attractive characteristics

- High mechanical strength that exceeds the strength of wood, glass and ceramic.
- High thermal properties.
- High chemical stability and resistance;
- Excellent electrical insulation properties over a wide range of frequencies;
- High toughness and moderate tensile strength;
- High flexibility and good processability;
- Low cost.

(RamaDevi, Vinodh,& Kumar,2020)

Tiles produced with plastic also have the following advantages:

i. Less weight.

ii. Reduced water absorption rate.
iii. Ability to carry more loads.
iv. More economical.
v. More water resistant.
vi. Less sensitive to weathering effect.

(Sourabh, Ravindra, Sujeet, Pramod, & Rachana,2022)

Tiles

Interlocking floor tiles are tiles that interlock together to form a floating floor. Most types of interlocking floor tiles are not glued down. They are essentially interlocked together with some type of interlocking floor system over a flat surface. They are held down by gravity and their weight. Properly designed interlocking tiles will not come apart during normal usage.

Fig. 1.1 Interlocking floor tile *(Vincenzofoto, 2023).*

Types of Floor Tiles

a. High Impact Polymer Interlocking Floor Tiles:

ModuTile specializes in this type of interlocking floor tile made out of high-impact polymer (impact plastic tiles). They have a wide range of usage including, but not limited to, garage flooring, basement flooring, home gym flooring, patio flooring, trade show flooring, showroom flooring and much more. The high-impact polymer interlocking tiles are considered rigid and strong enough to support large amounts of weight from vehicles, furniture or walking traffic (modutile, 2023).

b. Rubber Interlocking Floor Tiles:

Other common interlocking floor tiles are made out of flexible PVC (aka rubber floor tiles) and are normally used in environments where they need to support rollover weights exceeding 40,000 lbs. per sq. inch. One good example of rubber interlocking floor tiles used is in a warehouse where a forklift is used. Another would be on a gym floor where free weights are commonly dropped on the ground. These tiles are harder to clean, so they are not as common in garage floor environments. They also tend to be more expensive because they are heavier and more difficult to produce (modutile, 2023)

c. Foam Interlocking Floor Tiles:

These types of tiles are usually made from EVA (Ethylene-vinyl acetate) foam. They are usually used as a gym mat because they are soft to land on. Gymnasts and wrestlers often use these types of tiles to prevent injury. They are not as durable for normal walking traffic where shoes are used (modutile, 2023).

Use of Plastic Waste in Building Construction and Tile Making

(Osarumwense, Salokun, & Okundaye, 2020) found that a ratio of 1:3 is the optimum mixture for LDPE-based tile, and the plastic-sand bonded tiles could replace the sand-cement composite for engineering constructions. In their work, waste LDPE plastics were utilized in the production of paving tiles. The tiles were produced by mixing sharp sand with molten plastics in varying ratios of 1:1, 1:2, 1:3 and 1:4 plastic-to-sand. The mixture was allowed to cure for 28 days and characterized using standard procedures. The results showed that the compressive strength increases from 1.099 N/mm^2 to 1.787 N/mm^2 as the sand component of the ratio increases from 1 to 3. Further increase of sand in the ratio results in a decrease in compressive strength, to 1.581 N/mm^2. At this ratio, the tile (sample) could withstand up to a maximum load of 39 KN before failure occurs as against 29 KN for a conventional sand-cement composite (control). Furthermore, the average frictional coefficient of the sample and control were 0.372 N/kg and 0.289 N/Kg respectively.

(Puttaraj, Basavaraj, Gagan, Shivu & Manjunath,2020) carried out an investigation aimed at manufacturing floor tiles using waste plastic in different properties with Fly ash, without the use of cement and comparing it with normal cement tiles. To evaluate different physical and mechanical properties, tests like water absorption test, transverse resistance, resistance of impact and abrasion resistance tests were carried out as per IS specifications on the plastic tile and these test results were compared with normal cement tiles. Water absorption of the oven-dried and cooled specimens were tested for water absorption. After 24 hours of saturation difference in weight is 3.8%. For a normal tile transverse strength is 22.75 N/mm^2, as per the results they obtained a transverse strength was 10.80 N/mm^2.The abrasion strength of the tile was 0.6.

Test results include compressive, tensile and impact strengths, stress-strain response, fire resistance, water absorption and permeability of sand plast. The optimum mix ratio for the compressive, tensile and impact strength was 1:2. The compressive and tensile strength of sand plast blocks ranged from 4.8 to 7.4N/mm2 and 3.3 to 7.2N/mm2 respectively. These are greater than the respective values for sand Crete blocks produced in Ghana generally varying from 1.4 to 3.5N/mm2 and 0.1 to 0.3N/mm2. The static modulus of elasticity of sand plast averaged approximately 89.0, 311.5 and 197.7 N/mm2 for mix proportions of 1:1, 1:2 and 1:3. At temperatures below 80 ^{0}C the strength properties and stability of sandplast blocks remained unchanged. When immersed in water, sandblast blocks were found to be insoluble in water. The coefficient of permeability of sandblast averaged 4.6 x 10-4, 8.2 x 10-4 and 21.8 x 10-4 cm/sec for mix proportions 1:1, 1:2 and 1:3 respectively.

Materials and Methods

Materials

Materials required for this research work were sourced locally. The plastic materials were collected from trenches, drainage, streets, dump sites, and eateries around the FUTO Ihiagwa metropolis. Lubricating oil was obtained from a mechanical shop around Obinze, Ihiagwa. The sand was collected at Otamiri River in FUTO.

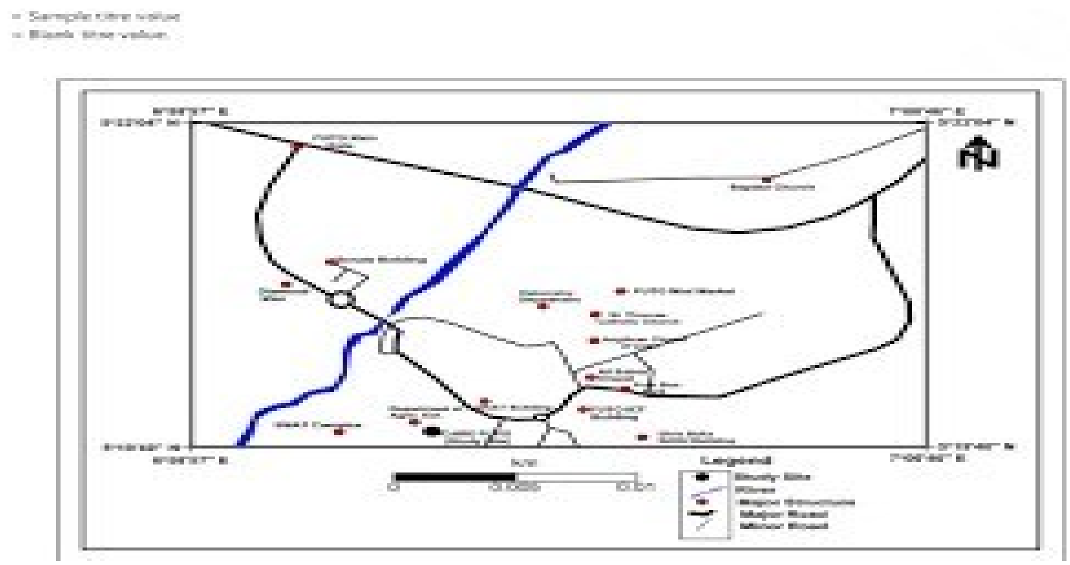

Fig3.1 Map of FUTO (case study)

The interlocking floor tile was produced with shredded water sachets (LDPE), plastic bottles (PET) and sand. Other materials include charcoal, firewood and matches.

The equipment used in this work is listed below:

i. Weighing Scale
ii. Metallic mold
iii. Digital Pen thermometer
iv. Hand Trowel
v. Sieve
vi. Hand glove
vii. Wood Stirrer
viii. Cooking pot
ix. Mouth mask
x. Scissors
xi. Knives

METHODOLOGY

The following methods were used to achieve the production of interlocking tile.

Collection and manual sorting

This involves the separation of plastic materials into categories (PET & LDPE)

Washing: Detergent and water were used to wash the already sorted plastic to get rid of contaminants and also to remove the label attached and allow it to dry.

Shredding: The sorted plastics were then cut into smaller pieces using scissors and knives.

Collection of Sand: Sand was collected and sieved to a size of 1180microns

Making of the Mold: To give the molten plastic the final shape of the tile, a mould was made, the mold was manufactured by welding plates together having a geometric dimension measuring 19cm x 10x 9cm and a density of 7860kgm, alongside a top cover fabricated to apply vertical force and compress the molten plastic to make it compact.

Weighing: Weighing was done to get the desired weight per cent that was used in each specimen

Melting: It involves the addition of the weighed plastic in the desired proportion to the cooking pot with a good source of heat. When there was a significant amount of plastic body formation, the desired composition of sand was added to the molten state plastic to play the role of a binder.

Shaping: As the plastic became soft enough to undergo deformation, it was then transferred to the mold and compressed to get the desired thickness.
It was repeated until the interlocking tile with all the compositions was obtained.

Conclusion

1. The waste LDPE and PET plastic were locally collected and used.
2. The plastics were well shredded and the sand sieved using an 1180micron sieve
 size.
3. The interlocking tiles were produced and the sample with the composition of 20% LDPE, 20% PET, and 60% Sand was the most optimal from the result of the tests carried out with a water absorption value of 1.07, flexural strength of
 1.985 N/mm^2, and an average compressive strength of 11.78N/mm^2.

Recommendation

1. Laboratories in the Federal University of Technology Owerri should be improved to enable students to carry out tests without incurring exorbitant costs.
2. Students should be given enough time to complete their research.
3. Further work should be done with river sand of varying sizes.

Microanalysis can be carried out on the produced composite tiles to understand the level of interactions of the individual constituents.

References

Abubakar, A., Umaru, K., & David, S. S. (2019). An appraisal of solid waste management in Minna, Niger state: policy and planning implication to Nigerian cities. au-journal of interdisciplinary research (ISSN: 2408-1906), 4(2).

Adeleke, M. A. (2018). Indiscriminate Solid Waste Dumping Sites and Its Public Health Implications in Osogbo, Southwestern Nigeria. Annales of West University of Timisoara.Series of Biology, 21(2), 143.

Alexander, K., Danladi, Y., Pierre, K., Mike, W., David, C.W. & Christopher C. (2018) Recycling Waste Plastic in Developing Countries: Use of LowDensity Polyethylene Water Sachets to form Plastic Bonded Sand Blocks. Waste Management, 80(8)112-118.

Alumona, I. M., & Onwuanabile, K. M. (2019). Environmental Insecurity in Nigeria. In Internal Security Management in Nigeria (pp. 181-213). Singapore: Palgrave Macmillan

Barboza, L. G. A., Lopes, C., Oliveira, P., Bessa, F., Otero, V., Henriques, B., & Guilhermino, L. (2020). Microplastics in wild fish from North East Atlantic Ocean and its potential for causing neurotoxic effects, lipid oxidative damage, and human health risks associated with ingestion exposure. Science of the Total Environment, 717, 134625.

Bamigboye, G.O., Ngene,B.U., Ademola,D.,,Jolayemi,J.K.(2019).International Conference on Engineering for Sustainable World Journal of Physics: Conference Series 1378. https://doi.org/doi:10.1088/1742-6596/1378/4/042105

Bigalke, M., & Filella, M. (2019). Foreword to the research front on "Microplastics in Soils". Environmental chemistry, 16(1), 1-2.

Civil Today. (2022). Retrieved From https://civiltoday.com/civil-engineeringmaterials/concrete/15-advantages-and-disadvantages-of-concrete

Dumbili, E., & Henderson, L. (2020). The challenge of plastic pollution in Nigeria. In Plastic Waste and Recycling. Academic Press. (pp. 569-583)

Ebnesajjad, S. (2015). Fluoroplastics, Volume 2: Melt processible Fluoropolymers the definitive user's guide and data book. William Andrew.

Evan M., Nickolas,P. ,Savvas,H.(2022). Calendering of thermoplastics: models and computations. International Polymer Processing Journal of the Polymer Processing Society.https://doi.org/10.1515/ipp-2021-4214

Gawande, A., Zamare,G.,Renge,V.C.,Tayde,S.,& Bharsakale,G. (2012).An Overview on Waste Plastic Utilization in Asphalting of Roads. Journal of Engineering Research and Studies.3(2).

Modutile. (2023). Interlocking Floor Tile Questions.Retrieved from https://modutile.com/help/interlocking-floor

Muneeb Ahmed.(2022). Processing of polymers. Retrieved from https://www.scribd.com/document/516287135/MCE313-Processing-of-Polymers

Nivetha, C. Rubiya, M. Shobana, S. Vaijayanathi, G. (2016). Production of Plastic Paver Block from the Solid Waste. ARPN Journal of Engineering and Applied Science. 11(2)

Nuha, M., Mohammed, O., Mohamed, G., & Hamed A. (2013). Reviewing of General Polymer Types, Properties and Application in Medical Field.International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064. DOI:10.21275/ART2016772|

Ofonime, A. H & Ifiok, E. E. (2016). International Journal of Engineering Sciences & research technology 2016 ISSN: 2277-9655 Compressive strength characteristics of tile waste concrete. DOI: 10.5281/zenodo.59631

Orhorhoro, E.K., Oyejide, J.O., & Atadious, D. (2018).Performance Evaluation of a Designed Simple Interlocking Tile Blocks Machine.Innovative Systems Design and Engineering.9(2).

Osarumwense, J.O, Okundaye,A.O, & Salokun,O. (2020).Utilization of Low Density Polyethylene (LDPE) Plastic wastes in the Production of Paving Tiles. Journal of Materials and Environmental Science,11(12),2052-2060.

Philippe Chalmin. (2019). The history of plastics: from the Capitol to the Tarpeian Rock, Retrieved from URL : http://journals.openedition.org/factsreports/5071

Puttaraj, M., Basavaraj, P., Gagan, M., Shivu, S., Manjunath, S.(2020).Journal of Seybold report Volume 15 issue 8.

Rama Devi,D.,Vinodh P.,Vinodh R.(2020).International Journal of Engineering Applied Sciences and Technology,Vol. 4, Issue 12, ISSN No. 2455-2143, Pages 512-516

Shen, M., Huang, W., Chen, M., Song, B., Zeng, G., & Zhang, Y. (2020). (Micro) plastic crisis: Un-ignorable contribution to global greenhouse gas emissions and climate change. Journal of Cleaner Production, 120138.

Sofi, I. R., Manzoor, J., Bhat, R. A., &Munvar, R. (2020). Plastic Pollution and the Ecological Impact on the Aquatic Ecosystem. In Handbook of Research on Environmental and Human Health Impacts of Plastic Pollution (pp. 80-93). IGI Global.

Sourabh, J., Ravindra, S., Sujeet, G., Pramod, P., Rachana, V. (2022). Making Of Economical Plastic Tiles Using Plastic Waste.International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 Volume: 09 Issue: 06

Temitope, A.K., Abayomi, O.O., Ruth, A.O, & Adeola, A.P. (2015). A Pilot Recycling Pure Water Sachets/Bottles into Composite Floor Tiles: A Case Study from Selected Dumping Site, Ogbomoso. Journal of Material Science and Engineering 4(6) 201-220. doi:10.4172/2169 0022.1000201

Thomasnet. (2022).Comparison of Thermoset Versus Thermoplastic Materials. Retrieved from https://www.thomasnet.com/articles/plastics-rubber/thermoset

Vincenzofoto, (2023). Granite outdoor floor tile diagonal. Shutterstock.com. https://www.shutterstock.com/image-photo/granite-outdoor-floor-tile-diagonal-1248469144.