



Utilisation of Plastifying and Fluxing Wastes of Plastics and Eggshell Powder in Manufacture of Eco-Friendly Floor Tiles

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Abstract: This study addresses the possibility of utilizing polypropylene plastics and eggshell wastes in the manufacture of eco-friendly floor tiles. Therefore, the research is part of the ongoing hunt for establishing sustainable alternatives for disposing off plastic and eggshell wastes around the globe. In this study polypropylene plastic wastes (PPW) are melted and used as a binder to eggshell powder (ESP) acting as a flux in the matrix. These are combined with fine aggregates. Three ternary mixes of PPW-ESP-Sand are made in the proportions of 50–0–50%, 55–10–35%, and 60–20–20%. Thirty six sample tiles of size 250 mm x 250 mm x 8 mm are cast. The physical properties of PPW, ESP, and sand are first established. Then, the effect of this PPW and ESP on the flexural strength, impact resistance, density, and water absorption of floor tiles made are investigated. Specifically, the bulk density of PPW, ESP and sand were 370, 1280, and 1700 Kg/m³ and specific gravities were 0.93, 2.54, and 2.64 respectively. Meanwhile, PPW–ESP–Sand mix of 60-20-20% had the lowest water absorption at 0.15% and also the lowest density of 1570Kg/m³, and the highest modulus of rupture of 11.7kN/mm² compared to conventional ceramic tile at 3.9KN/mm². The tile manufactured from the mix of 60-20-20% also exhibited the highest resistance to impact damage although all samples had a coefficient of restitution (e=0). In conclusion, the study presents a novel finding of combining two wastes replacing conventional non-renewable resources of clay and feldspar to produce eco-friendly tiles. Therefore, implementing the findings will facilitate achieving United Nations sustainable development goals (SDG), i.e. goal 12 of responsible consumption and production.

Keywords: Eggshell Powder, Floor Tiles, Polypropylene Plastic Wastes, Sustainable

1. Introduction

The ever-increasing population has led to mainly two problems i.e. continuous high production of wastes and depletion of existing natural resources. World over, production of plastics has been on an increase, for example, from the period of 2015 to 2016 alone, their demand shot up from 320 to 330 million tons [1]. Therefore, this trend is likely to greatly affect the ecological systems and their life. For instance, once these plastics are disposed of in the environment they take a very long time because of their durability. Once disposed of in water bodies they tend to float on the surface due to their low density [2]. These plastics are generally categorized under natural plastics, semi-synthetic plastics, synthetic plastics, and

thermoplastics [3]. Some of the dangers from plastic wastes are endangering aquatic life once thrown in water bodies [4], land pollution as a result of discharging toxic substances into the soil [5], air pollution experienced after burning of plastics which emits particulate emission and solid residue ash [6] among others.

Another environmental burden that has of recent seen a tremendous increase is eggshell waste i.e. in nations where the production of eggs for industrial use has increased. Food and Agricultural Organization (FAO) statistics show that globally egg production stands at 82.2 million tons as per the year 2019 [7]. Given that the eggshell approximates 11% of the egg's total weight [8, 9], therefore, this approximates to about 9.04 million tons of eggshell waste.

As a part solution to these challenges, plastic wastes could be utilised for very high value products in the construction industry [10]. This is mechanical recycling as suggested by [1, 11]. These plastics have demonstrated the potential of imparting strength in construction materials like creating plastic cement and serving as a binding agent [10, 12]. In other studies, it has demonstrated potential of equally increasing strength properties of tiles [13]. This reduces the ecological and health problems associated with them [14].

Similarly, eggshell wastes could also be utilized in the construction industry by taking advantage of its properties like a high content of CaCO_3 . This serves as a partial ingredient for cement [15]. Additionally, ESP has the potential to serve as a filler by partially replacing fine aggregates [16].

Therefore, as part of the global concern to finding sustainable solutions specifically to address environmental concerns to do with waste generation, the construction industry has been proven as a potential sector. Additionally, it also facilitates sustainable utilization of the world's scarce resources.

Traditionally, tiles have been known to come from a ternary blend of clay-quartz-feldspar [14]. These natural raw materials have had challenges of being non-renewable and given the merits of waste utilization in the construction industry, these need to be taken advantage of. This eco-friendly propensity has triggered a number of studies to utilize these wastes for high economic and eco-friendly uses.

Several studies have been conducted to assess the possibility of incorporating industrial by-products and agricultural wastes in making ceramic tiles. Thus, several wastes, e.g. plastic wastes [17, 18], eggshell powder [19, 20], rice husk ash [21], fly ash [22-24], Tiles wastes [25], glass waste [26] and blast furnace slag [27] have shown potentiality in being utilized in making ceramic tiles.

In many of these studies, there is a paucity of literature that can be traced on using a ternary blend of plastic and eggshell wastes for making floor and wall tiles. However, this ternary blend of plastic waste and eggshell waste has shown good results where these two were used to make roof tiles [28]. Increasing these wastes led to an increase in water absorption and also continuous addition of these wastes led to a reduction on the density. Eggshell wastes were proven to act as a filler in the manufacture of roof tiles [28].

The plastic wastes play the role of either plasticity provider allowing proper compaction or strength, plus acting as a flux offering body densification. It also embeds the filler through its vitreous phase [29]. Meanwhile, the eggshell powder acts a filler together with the sand filler because of its quartzous nature [30]. Eggshells consist of Calcium carbonate to about 95%, are resistant to water penetration and it is thus expected to increase on the strength of the tile sample. They have been successful used to partially replace fine aggregates, where 5% replacement of fine aggregates produced the best compressive strength [16].

Therefore, this study seeks to assess the possibility of utilizing plastic wastes and eggshell powder plastifying and fluxing behavior in making floor tiles [31].

The utilization of eggshell powder and plastic wastes aims at obtaining floor tiles that have low energy consumption during manufacture, outputting an eco-friendly building product, and promote zero-waste economy, cut on the demand for natural raw materials, and promoting 'waste to wealth' management practices.

2. Materials and Experimental Procedures

2.1. Plastic Wastes

Polypropylene (PP) plastic wastes (PPW) of the thermosetting plastic class was used in this study. These plastics have a density of about 0.94g/cm^3 , tensile strength 3200 – 5000Psi, water absorption 0.01%, melting point between 160 – 166°C, and softening point 140 – 150°C [32]. This PP was selected mainly because of its flexibility, widespread usage, and ease to soften, melt, shaped, or reshaped upon heating. It's able also to take on the shape of the mold upon cooling [4]. The PPW is to serve a plastifying function in the material mix, and binder effects. Plastics inform of polypropylene possess water-resistance properties, a relatively high bulk density that reduces the sample space.

The study samples were collected from one of the slum areas of Banda Kinawataka pits and drainage lines, Kampala city Uganda. They consisted mainly of basins, plates, cups jelly cans, food containers, and plastic screw top lids (Figure 1).



(a)



(b)

Figure 1. Polypropylene Plastic wastes a) after collection b) shredded samples.

The plastics were prepared by mechanical shredding in

small pieces of about 700mm (Figure 1b), thoroughly washed to remove glues plus all paper labels, dirt, and any possible remaining remnants. After washing, the sample was sun-dried and then tested for its physical properties (Table 1) before being melted for the production of floor tiles.

2.2. Eggshell Wastes 2.3 Fine Aggregates

Eggshell wastes (Figure 2) were collected from local bread makers “chapati” in Banda a Kampala city suburb in Uganda. They were prepared by washing them thoroughly in boiling water for about 5 – 10 minutes, soaking in water for 24 hours to facilitate easy removal of dirt and membranes.



Figure 2. Eggshell wastes being sundried after cleaning.

After they were sun-dried for 4 days, pounded using a motor and pestle, and finally pulverised to produce eggshell powder using a milling machine. The powdered eggshell wastes were sieved through a 1.18 mm sieve so as to obtain the appropriate size of ESP to use as a filler in the ternary mixture. This was done following ASTM C136-06 procedure (sieve no. 16) [33].

2.3. Fine Aggregates

Fine aggregates of sand that satisfy the required standards and passing through 600 microns were used. It was sieved through 0.15 - 10mm sieve. Sand was incorporated in the tile due to the quartz characteristics of SiO_2 . The sand is meant to provide the bulk of the tile. The test samples were first oven-dried at 105°C . It was characterised by performing sieve analysis following BS 882:1992 [34] and results represented in Figure 3. The particle size distribution of fine aggregates (sand) showed that it was well graded as about 75% passed the 600 microns.

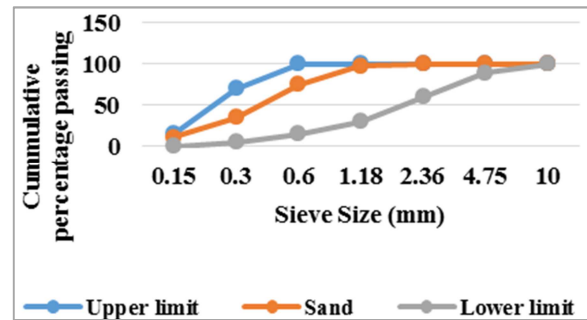


Figure 3. Sieve analysis curve for sand.

The specific gravity tests for the materials used were determined following procedures of ASTM D 854-00 standard test for the specific gravity of solids by water pycnometer [35] and IS-2720-Part-3-1980 [36]. Table 1 shows the bulk density and specific gravity of plastics, eggshell, and sand.

The bulk density as a measure to show the material effect on flow consistency and reflection of its packaging quantity was established following ASTM D1895B: standard test methods for apparent density and bulk factor [37].

Table 1. Physical properties of plastics, eggshells, and sand.

| Physical properties of materials used | Test values |
|---------------------------------------|------------------------|
| Bulk density of plastics | 1700 Kg/m ³ |
| Bulk density of sand | 1280 Kg/m ³ |
| Bulk density of egg shell | 370 Kg/m ³ |
| Specific gravity of sand | 2.64 |
| Specific gravity of eggshell | 2.54 |
| Specific gravity of plastics | 0.93 |

The bulk densities of filler materials (sand and eggshell powder) are slightly different however satisfying the required density of a plasticity-provider (fines). Whereas that of plastics is found to be 370Kg/m³ which is slightly lower than that recorded in the standard [32]. The bulk density is also lower than the bulk density of conventional materials that are normally used as a filler in construction.

The specific gravity of sand used falls in the range of 2.4-3.0 as specified by the ASTM C33 [38], while that of eggshell powder is found to be 2.54 which is within ASTM C33 range. However, other studies a slightly higher values are recorded at 3.37 like in [39]. Meanwhile, that of PPW was very close to the required standard of 0.9 as given by the

ASTM D792 [40].

2.4. Material Mix Matrix

The PPW-ESP-Sand ratio matrix adopted was as indicated in Table 1. Three mixes were made while varying plastic wastes from 50 – 60% maintaining a 10 – 60% as suggested in [31]. For the eggshell powder it was varied between 0 – 20% also keeping it less than a 20% mix ratio as proposed by [31].

Table 2. Material mix ratios used.

| Materials | Mix 1 (M1) | Mix 2 (M2) | Mix 3 (M3) |
|-----------------|------------|------------|------------|
| Plastic Waste | 50% | 55% | 60% |
| Eggshell powder | 0% | 10% | 20% |
| Sand | 50% | 35% | 20% |

2.5. Tile Specimen Preparation

For each mix after the dried plastics were measured in the proportion for each mix by weight, they were melted in a metallic reactor using gas as fuel to a melting at around (150°C – 170°C). After complete melting, well-sieved sand and eggshell powder were added little by little in the container while stirring. This mixture was stirred until a homogenous coloured mixture was attained. Thirty-six (36) sample tiles in total were manufactured of size 250mm x 250 mm x 8 mm (Figure 4).



Figure 4. a) Eggshell powder; b) PPW; c) Tiles in mould; d) Manufactured floor tiles.

2.6. Experimental Tests

2.6.1. Water Absorption

To establish the capacity of the manufactured tile in relation to water absorption, the porosity of the tiles made was determined. This is necessary also because it helps to establish performance characteristics and is also used as a criterion for classifying ceramic tiles in ISO 13006: 2012 [41]. The water absorption test on the sample tiles was carried out according to ASTM C 373 standard test methods [42] for determining

water absorption and BS EN ISO 10545-3: 1997 [43].

2.6.2. Density of Sample Tiles

This is the mass of the material per unit of its volume. It is an important factor the influences all strength properties of the tiles made. The density of the tiles made was computed, its weight measure accurately, and then its volume was computed from its measured dimension. The average density for each mixing ratio was then determined.

2.6.3. Flexural Strength

The bending strength of the tiles manufactured was determined on at least three samples of tiles for each sample mix and an average was obtained. This test was conducted in accordance with ASTM C 1505-01 [44] standard test method for determining of bend strength of tile using a three-point loading (Figure 5).



Figure 5. Performing flexural strength test using UTM.

2.6.4. Impact Resistance

Since building floors where tiles are used are more prone to impacts than walls, largely from falling object loads and point load characteristics experienced from footwear, impact resistance was established [45]. The measure of impact resistance helps to prove the durability of the tiles made under such circumstances. The impact resistance test was conducted following the American standard ASTM C648-84 [46] by measuring what is known as the restitution coefficient (e).

3. Results and Discussion

This section presents results and their discussion to give insight of the research in terms of engineering properties of plastic floor tiles. Tests include mechanical properties of flexural strength and impact resistance of sample tiles. Other investigations on the manufactured floor tile include density and water absorption following procedures given in the above section.

3.1. Physical Properties of Floor Tiles Made

3.1.1. Water Absorption

To determine the rate of permeability of the tile samples after 24 hours, water absorption was done on three (3) mix ratios, tile samples size 250 x 250 x 8mm by soaking them in

water. Once tiles absorb high water values it's likely to lead to cracking once they are put in areas prone to rainfall and freezing [47].

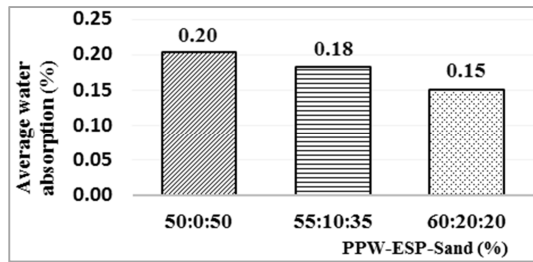


Figure 6. Water absorption of tiles made in PPW-ESP-Sand matrix.

Reduced water absorption was studied in relation to the addition of PPW and ESP. The water absorption rate reduced with the addition of the two wastes from 0.2% to 0.15%.

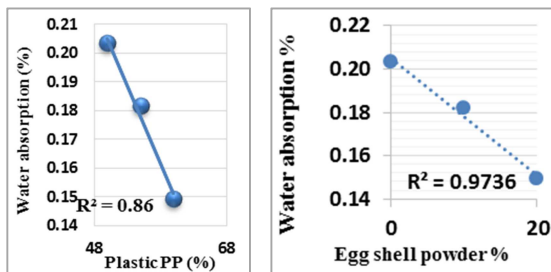


Figure 7. Statistical relationship of water absorption of tiles with PP and ESP.

As depicted in Figure 6 addition of PPW and ESP reduced on the permeability of floor tiles manufactured by 5% from 0.20% to 0.15%. This is in agreement with studies who also found out that the water absorption of tiles made with plastics reduced from 3.8% to 1.01% [48]. Addition of plastic wastes to sawdust led to tiles of no water absorbed after 24 hours of immersion [49]. The reduction in permeability of tiles manufactured could be attributed to the addition of high water-resistant materials of PPW [19]. The results of the manufactured tiles using plastics and eggshell wastes with natural sand conformed to the minimum requirements of ASTM test method C373 [42] on water absorption for ceramic tiles. The standard requires an average water absorption of less than 0.5% for flooring. Additionally, the reduction in permeability with an increase in ESP could be attributed to ESP acting as a filler and limiting any water seepages through tiny voids created by sand particles.

Table 3. The flexural strength of the manufactured floor tiles.

| PPW-ESP-Sand (%) | Average Maximum breaking load (kN) | Breaking strength (N) | Average flexural strength (N/mm ²) |
|----------------------------|------------------------------------|-----------------------|--|
| 50-0-50 | 0.667 | 400 | 9.4 |
| 55-10-40 | 0.800 | 480 | 11.3 |
| 60-20-20 | 0.833 | 500 | 11.7 |
| Conventional ceramic tile) | 0.250 | 167 | 3.9 |

It was observed that the flexural strength and breaking strength of the tile samples increased with an increase in PPW and ESP. The modulus of rupture improved by 25% when PPW and ESP were increased from 50 – 60% and 0 – 20%

There is a negative strong relationship (Figure 7) between eggshell powder and polypropylene plastics addition and water absorption of the tile samples up to 97.4% and 86%. This strong relationship is an indicator that this permeability reduction is mainly attributed to an increase in plastics and eggshell powder than any other factors.

3.1.2. Density of Manufactured Tiles

The density of tiles manufactured first increased by 8% with a reduction of sand and increase in PPW and ESP. Then this fell by 14.3% with continuous addition of the same. Tiles made from in matrix of PPW-ESP-Sand 55-10-35% had the highest density at 1,832 kg/m³ (Figure 8).

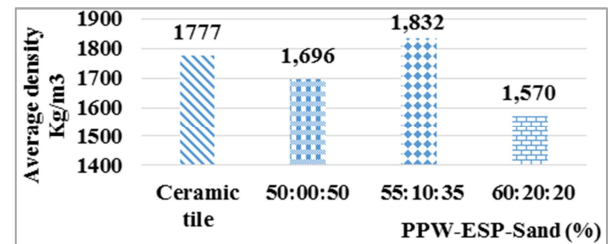


Figure 8. The average density of PPW-ESP-Sand manufactured and ceramic tiles.

A similar trend of results where the addition of plastics increased density and later reducing was obtained by [50]. However, this trend is generally attributed to the fact that when ESP was first introduced due to its high bulk density as a filler could have led to an increase in density of tiles made. However, when sand a high bulk density material of sand was continuously replaced by ESP, it led to a reduction in density by 14.3%. Therefore, there was a weight loss when the percentage of ESP increased and sand reduced [51].

3.2. Mechanical Properties of Floor Tiles Made

3.2.1. Flexural Strength

The flexural strength or bend strength was studied as a measure of the highest stress experienced within the material at the moment of yielding [28]. The test was performed on at least three samples of tiles. This test was done according to ASTM C 1505-01 [44] standard test method for determining of bend strength of tile by three-point loading. The values of breaking strength and flexural strength were represented in Table 3 below.

respectively (Table 3). These findings confirm with those of the previous researches where on the addition of more plastics led to an increase in flexural strength, like [48]. The strength improvement could be attributed to the stiffness properties of

polypropylene and this makes the floor tiles best suitable in high stress areas [49]. There is generally an increase in bond strength provided by plastics which contributed to the increase in this bending load. This improvement is seen higher i.e. 20% when ESP was first introduced at 10%. The subsequent addition of 20% ESP slightly increased the flexural strength by only 4.2%. Generally, the improvement in bend strength in relation to ESP addition is attributed to it acting as a filler and facilitating for more stiffness within the tile body [16]. The reduction in subsequent strength improvement rate could be because as more ESP replaced a much stiffer sand, the mix moved towards the optimum of 20% as obtained by [31].

The modulus of rupture for all the tiles made in the PPW-ESP-Sand matrix was way above the traditional convention ceramic tile by at least 58%.

However, the breaking strength and modulus of rupture of tiles made were below the minimum values as set ISO of 800 N and 18 MPa respectively (ISO 13006, 2012) [41].

3.2.2. Impact resistance

The impact damage was studied to establish the likely damage on the manufactured tiles as a result of falling objects and point-load sources like footwear, like stiletto heels plus hobnailed boots. To investigate this property, an impact resistance test was conducted using a spherical steel ball weighing 350 grams was dropped from a height of 1m from the tiles. The test was conducted on both the PPW-ESP-Sand manufacture tiles and onto the conventional ceramic tile.

This resistance to impact damage was assessed basing on two parameters i.e. coefficient of restitution, e and visual examination after impact. The impact damage by visual observation is as shown in Figure 9.

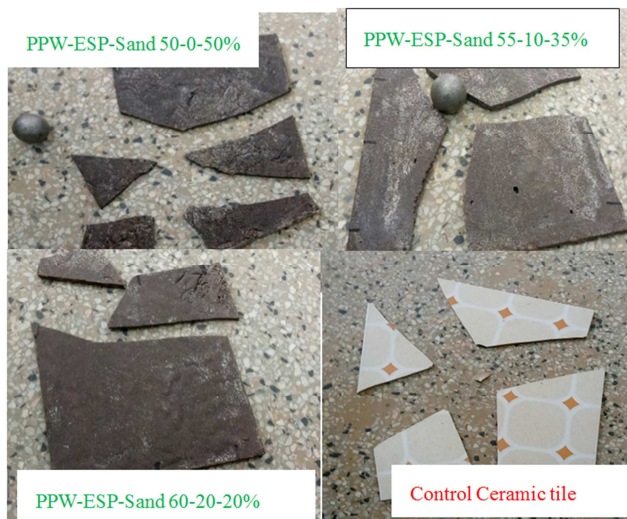


Figure 9. Visual observation of impact resistance test.

As a measure of good performance during service of the tiles made it was discovered that the damage reduced with an increase in PPW and ESP proportions in the tiles. The tile matrix of PPW-ESP-Sand 60-20-20% has the lowest observable shattering damage by the dropped steel ball. Therefore, the 60-20-20% matrix under service is expected to

offer some slight resistance under the impact. This could be attributed to the addition of more PPW that is said to have reduced the tile brittleness. Meanwhile, dropping the spherical steel ball onto ceramic tiles resulted in complete shattering into smaller pieces of the tile body (Figure 9). This implied that conventional ceramic tiles are also brittle.

For the coefficient of restitution (e), it was obtained as zero since for all tiles the still ball did not rebound to a measurable height after the first impact. This implies there was almost no elastic shock and the ball almost became embedded within the tile. Almost all the energy possessed by the ball before dropping was utilized in modifying the tile body, friction, and the steel ball [53].

4. Conclusions

The findings demonstrate that tiles seem to be a possible avenue to solve the environmental challenges posed by the plastics and eggshell wastes. This would reduce the pressure on the environment looking for landfills, additionally replace non-renewable natural resources of clay, feldspar and partially replacing sand.

A combination of PPW-ESP-Sand in proportions of 60-20-20% could produce tiles with better flexural strength, impact resistance, low permeability, lower impact damage, and low density.

This work has demonstrated a novel study with the tile matrix studied of PPW-ESP-Sand showing better results than plastics or eggshell only utilisation in making floor tiles as seen in previous studies.

The conventional matrix of clay-feldspar-quartz which are natural non-renewable resources could be substituted with the readily available wastes in the environment by about 80%.

Finally, this study demonstrates a very important finding in the search for sustainable solutions for our environment.

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