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The Effects of Plastic Waste Materials on the Physical and Strength Properties of Floor Tiles

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ABSTRACT

Human activities often generate solid waste, such as plastics. The disposal of this waste is usually a setback. This paper aimed to examine the viability of using plastic waste and white cement to produce floor tiles. Waste was collected from waste disposal facilities within Benson Idahosa University. The materials were cleaned and dried, and plastics were shredded. Waste materials were then mixed with white cement in different ratios. Compressive strength tests were performed to verify the suitability of utilising these solid wastes to make floor tiles. Shred plastics that were passed through a sieve with an average diameter of 1 to 2 mm were utilised. The cubes were cast and cured for 7, 14, and 28 days. The compressive strength of the cubes was tested using a universal testing machine. The study found that the addition of up to 50 % of cement resulted in a more than a 10-fold increase in the compressive strength of the cast cubes. On the other hand, the inclusion of plastics reduced the compressive strength of the cubes. Furthermore, increasing the number of plastics increased water absorption, whereas larger amounts of cement reduced water absorption. Plastics are a common waste produced by man; hence, they are easily accessible and a very economical material to produce floor tiles.

1. Introduction

Growth in population, rising urbanisation, and increasing living standards owing to technological advancement have contributed to an increase in the quantity of a variety of solid wastes generated by agricultural, domestic, mining, and industrial activities [1]. On a global scale, the estimated quantity of solid waste generation was 12 billion tons as of 2002 [2]. Many experts and researchers have been working to have the privilege of reusing the wastes in economically and environmentally sustainable manners [3]. The utilisation of solid wastes in construction materials is one such novel effort. For example, floor tiles in construction are for aesthetic, decorative, and protection purposes [4]. The main material commonly utilised to produce floor tiles is clay which could be glazed to enhance the tile properties. For example, the fabrication of ceramic tiles utilising blast furnace slag with 0.1-2.5% water absorption has been investigated in India [5].

Tiles must have some degree of impact resistance. The impact resistance of ceramic tiles is essential for their service life. Floor tiles are expected to support several types of loads, some of which may be static, but impact

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loads also occur. For example, impact loads provide the most common way for walls to break [6]. The effect of water absorption on the frost resistance of clay roofing tiles was examined by Sveda [7]. The relation between water absorption and the frost resistance of brick products was stated to be impossible to define precisely. However, water absorption capacity identifies the nature of the ceramic body regarding internal structure, which is related to mechanical strength as well as other characteristics that affect ceramic tile durability (especially in unglazed tiles), such as resistance to deep abrasion, stain resistance, and resistance to frost/thaw cycles, as well as to dimensional quality.

For glazed tiles intended for flooring, European standard EN 14411 makes it compulsory to state the abrasion resistance class of the glazed surface (glazes and decorations) after performing the standard test according to ISO 10545-7 [8]. This study aims at using solid waste plastic as construction raw materials to develop floor building tiles to eradicate solid waste. Solid wastes including plastics, once used and dumped, can accumulate without decomposing, resulting in unsightly sceneries, blocking water channels, reducing soil fertility by preventing moisture penetration into the soils, and widespread diseases like malaria and cholera as a result of the creation of breeding grounds [9]. However, these materials can be useful for the construction industry.

Plastics can refer to materials comprising several elements: carbon, nitrogen, oxygen, hydrogen, chlorine, and sulphur. Plastics are formed through polymerisation, which can be either condensation or addition polymerisation. Based on their physical properties, plastics can be classified either as thermosetting or thermoplastics plastic materials. Thermoplastic materials are plastic that can be formed into desired shapes under heat and pressure and become solid on cooling. In contrast, thermosetting plastics materials, once shaped, cannot be remoulded by applying heat [10]. Plastic wastes cause eternal drawbacks as products synthesised from petroleum are non-biodegradable; that is the main reason why plastic wastes remain in landfills without breaking down or changing composition. Some of the difficulties linked with improper disposal of plastic waste include littering landscapes, polluting beaches and oceans, the generation of toxic fumes when burnt, and bags made up of plastics killing animals [11]. There is a broad range of utilisation of plastic. Food packaging plastics, for example, become waste quickly after being purchased and used. In contrast, other plastic items are re-used several times before being thrown into the environment as waste. Plastics are easily reusable compared to recycling, as the process of recycling consumes a huge amount of capital, energy, and resources. According to EPA [12], in the United States, the portion of post-consumer plastic waste sent to landfills is 80 %, incinerated (8 %), and recycled (7%). Plastic re-use significantly helps in reducing the amount of plastic waste that necessitates disposal, and recycling plastic can have several other advantages comprising reduced energy consumption, conservation of non-renewable fossil fuels (plastic production uses 8% of the global oil production, 4% during manufacture, and 4% as feedstock), reduced amounts of solid waste going to landfill and reduced emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2), and nitrogen oxide (NO). According to a recent study [13], a material that comprises one or more organic polymers of large molecular weight solid in its finished state and some form while processing into finished articles can be shaped by its flow is plastic wastes. Prabir Das [14] suggested the use of plastic waste in the construction industry at various places. Notwithstanding, proper selection of material/grade and practical design consideration can help to replace many more applications. Design flexibility, low system cost, lighter weight, part integration, very high productivity, and enhanced product appearances are the main features of plastic waste engineering [9].

2. Materials and Method

The plastic waste will be gotten and gathered from different locations (dumpsite areas) for adequate quantity, and the needed ones will be selected and separated for use. The fine aggregate used will be purchased from dealers near Benson Idahosa University, Benin City. Those particles passing through the 4.75 mm sieve and restrained on the 75 mm (micro) sieve are called fine aggregates ranging from 0.06 – 0.2 mm in size; and will be used in the project. The water used to cure the mortar cubes will be free of impurities if the water is not potable. The tools used include opened metal drum, aluminium mould, shovel, hand trowel, and Head pan.

The plastic waste materials to be used in this project work will be obtained from the Benson Idahosa University (BIU) waste dumpsite on the Legacy campus in two months. Therefore, an adequate quantity of plastic waste should be obtained. The plastic waste is washed to remove dirt and some foreign bodies. The drying of the washed plastic waste to remove water was carried out under normal atmospheric conditions.

Sharp sand will be purchased from a nearby dealer, and unwanted debris should be sorted out and removed from the sand. 6 kg of dried plastic and 4 kg of sand were measured for use. The measured sharp sand should be added gradually while mixing with an iron rod. The mixing is thoroughly carried out until the ground plastic and sand have produced a good constituent.

The moulds for casting the blocks will be cleaned, and 18 cubes will be released, 9 using grounded plastic as a binder in the ratio of 60 % plastic to 40 % sand and the other nine (9) in the ratio of 80 % plastic to 20 % sand. A hand trowel is used to settle and vibrate the mixture in the mould, so there are no air pockets (voids). The blocks are allowed to cool and set, after which they are removed from the moulds and cured for 7 days, 14 days, and 28 days. Finally, a compressive strength test will be performed for the curing ages and recorded results will be carried out.

The production of the waste plastic floor tiles will be carried out in the laboratory of the civil engineering department of the Levant construction company, Benin City, using the mixing ratio of 60 % plastic to 40 % sand and 80 % plastic to 20 % sand (that is 6 kg and 7.5 kg of plastic to 4 kg and 2.5 kg of sand) respectively.

2.1. Plastics Collection and Processing

Plastics will be collected, especially from dumping sites, washed and shredded into pieces of 1 mm average diameter. Plastic is a strong material, and it is resistant to both chemical and physical attacks making it hard to disintegrate [15]. It is also resistant to the penetration of water which is why it is considered one of the major threats to the fertility of our soils. This has made it a suitable component in this material because it increases the water penetration resistance of the material. Plastics also increase bonding in the composite material. Plastics are mainly used as fill materials to increase the bulk and reduce other materials like cement [9].

2.2. White Cement as a Binder

This is a third component, which binds the plastics to make a material that is resistant to water penetration [9]. In this case, white cement is utilised to bring out the colours of plastics respectively. White hydraulic cement is a good ingredient since it is resistant to water infiltration and will boost the strength of the material. White cement was used for aesthetic properties. Nonetheless, ordinary common Portland cement can be used. Potable water will be used to mix the ingredients.

2.3. Mixing Plastics and Cement

The densities of plastics and white cements are 400 kg / m^3 and 1,290 kg/m^3, respectively**.** Therefore, crushed plastics and white cement will be mixed in different amounts (Table 1). Thus, the commercial production of these tiles should aim to minimize the cost of production. The porker vibrator, spades, trough, trowel, and steel float are used in casting the cubes. The ingredients (cement, plastics, and water) are weighed using the measuring scale and then mixed in a trough and then cast in already prepared moulds and vibrated using a vibrator, and then left in the mould for 24 hours, after which they will be demoulded and cured for 28 days. Finally, the cubes are subjected to testing in a compressive strength testing machine, and the results will be obtained and recorded.

2.4. Making of Tiles

After obtaining the ratio (2:1) that gave the maximum strength, the making of the tiles began. Moulds of 300x300x10 mm size will be employed to make these tiles. First, the mixture of white cement and plastics is hand compacted into the moulds, and the surface is smoothed using a steel float; then, the tiles are left to set and dry in the moulds for 24-48 h before they are removed and left to dry at room temperature. The mixture was made of plastic to allow proper compaction manually.

Table 1 Quantities of Different Materials.

Cement (kg)	Plastics (kg)
0.94	0.26
0.62	0.17
0.47	0.13
0.94	0.13
0.47	0.26
0.37	0.21
0.75	0.10
0.75	0.19
0.84	0.00
1.25	0.00

2.5. Water Absorption Rate ASTM Test Method C37, EN99

The capacity of ceramic material to absorb water is correlated to its porosity. Fully vitrified stoneware, compact material with low porosity, has water absorption values below 0.5%. The strength of any building material will be severely reduced if allowed to absorb excessive moisture. This is the main reason for restricting the application of materials without a protective measure such as DPC and DPM coverings, which are more resistant materials to weather. The water absorption value will directly bear other performance characteristics such as mechanical resistance, frost resistance, and resistance to sudden temperature changes. It also gives us an idea of the fired product's degree of internal cohesion and compaction. The open porosity of a wall or floor tile depends on the ceramic body's composition. This may vary considerably from one product to another (porcelain floor tiles have low porosity; wall tiles are very porous). Other determining factors include the compaction of an un-fired piece or piece-forming (which in turn depends on such other factors as grain size, distribution of the spray-dried powder, moisture, etc.) and finally, the firing process. Water absorption is also used as a criterion for classifying ceramic wall and floor tiles in ISO 13006:1998 [9]. The glazed layer has zero water absorption since it is fully vitrified. The procedure comprised the following steps:

(a) Random selection of cubes of each mixing ratio.
(b) Drying the cubes in an oven for 24 h at 60 °C to remove all water.
(c) Weighing and recording of the dried cubes as M_1.
(d) Immersion of the cubes in water for 24 h.
(e) Precise measurement of immersed cubes weights specified as M_2.

Then, the formula expressed in equation (1) will be used to obtain the moisture content of floor tiles.

$$\gamma_{MC} = [(M_2 - M_1) \times 100]/M_1 \tag{1}$$

Where, γ_{MC} is the per cent moisture content, M_1 is the mass of the dry tile, and M_2 is the mass of the wet tile.

The average absorption of water from the sample was determined by the arithmetic average of the individual results, and the results will be rounded to a single decimal place. The impact can be defined as applying a high degree of instantaneous force on a minimal surface and is generally negative for ceramic products. Heavy or pointed objects that fall on tiles can damage or shatter the surface, depending on the object type. The determination of impact resistance is addressed in the American standard by measuring what is known as the restitution coefficient (ASTM C648-84) [16]. Aspherical steel bearing weighing approximately 438 g is dropped from a height of one meter above the surface of the tile samples, and the degree of shuttering or indention will be recorded.

2.6. Surface Abrasion Resistance Test ASTM C1027

Porcelanosa [17] believes that the degree of ceramic tiles' resistance to abrasion on their glazed surface is the factor that will determine their durability essentially. Therefore, an in-house method has been developed to give a clearer idea of how tile samples withstand wear and loss of appearance. The test reproduces and exaggerates the real abrasion conditions of any floor tile. Used as an abrasive agent is a quantity of sand with a high silica content (with a hardness of 7 on the Mohs scale) placed on the sample. This abrasion of the tile surface is maintained for 10 minutes, after which the extent of the wear is assessed. For this study, a weight of 8.4kg will be used alongside abrasive sand to test for the abrasion of the tiles. The sample tiles are weighed before undergoing the abrasion and after the test. The two weights before and after abrasion will be recorded. The abrasion effect is assessed based on effective percentage weight loss.

3. Results and Discussion

3.1. Result of Mix Ratio (60% Plastic to 40% Sand)

The compression test results for a plastic waste block made with a mix design of 60% plastic to 40% sand (plastic waste 6 kg and sand 4kg) for 7, 14, and 28 days, respectively, are presented (Tables 2 – 4, and Figs. 1 – 3). The results (Table 2 and Fig. 1) show that the lower the weight of the plastics blocks, the lower the compressive strength. Whereas, Table 3 and Fig. 2 show that the higher the weight of the plastic block, the more increased the compressive strength is. The graph (Fig. 4) shows that as the curing days increase, the compressive strength of the plastics block also increases.

Table 2 Compressive Strength for 7 Days (60% Plastic to 40% Sand).

Sample (Plastic Waste Moulds)	Weight of Mould Samples (kg)	Average Weight	Crushing Load (kg)	Compressive Strength (N/mm^2)	Average Compressive (N/mm^2)
A	3.35	3.34	772	30.82	27.47
B	3.34		669	26.71	
C	3.32		623	24.81	

Table 3 Compressive Strength for 14 Days (60% Plastic to 40% Sand)

Sample (Plastic Waste Moulds)	Weight of Mould Samples (kg)	Average Weight	Crushing Load (kg)	Compressive Strength (N/mm^2)	Average Compressive (N/mm^2)
A	3.41	3.46	829	33.09	34.39
B	3.48		801	34.98	
C	3.49		879	35.09	

Table 4 Compressive Strength for 28 Days (60% Plastic to 40% Sand).

Sample (Plastic Waste Moulds)	Weight of Mould Samples (kg)	Average Weight	Crushing Load (kg)	Compressive Strength (N/mm^2)	Average Compressive (N/mm^2)
A	3.45	3.50	1094	43.67	39.69
B	3.47		914	36.49	
C	3.59		975	38.92	

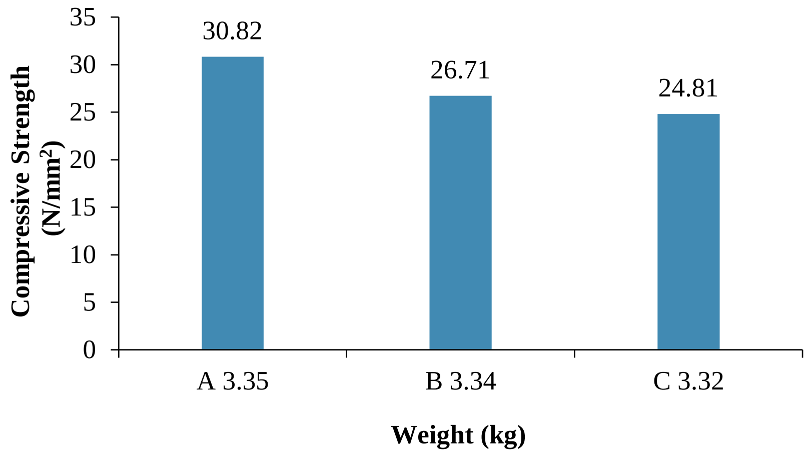

Fig. 1: Graph of 7-Day Compressive Strength (60% Plastic to 40% Sand).

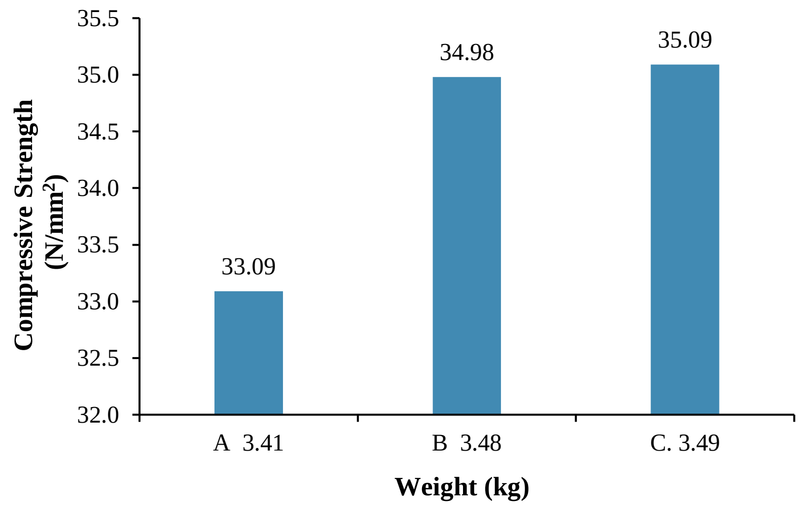

Fig. 2 Graph of 14-Day Compressive Strength (60% Plastic to 40% Sand).

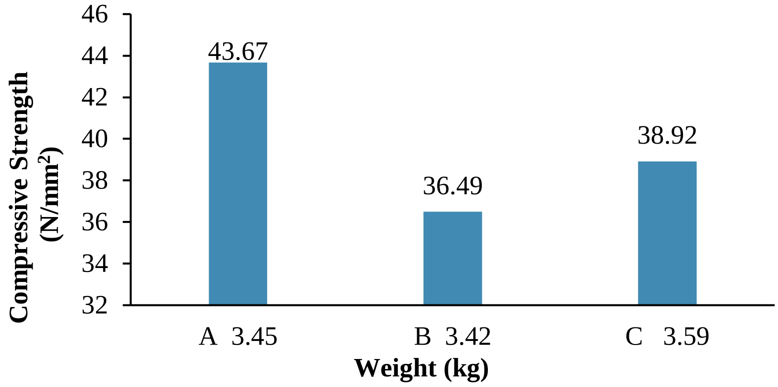

Fig. 3 Graph of 28-Day Compressive Strength (60% Plastic to 40% Sand).

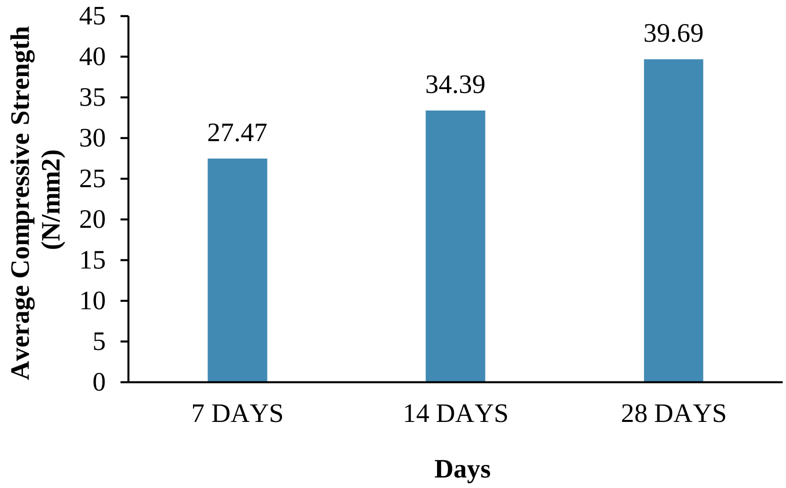

Fig. 4 Average Compressive Strength Graph (60% Plastic to 40% Sand).

3.2. Result of Mix Ratio (80% Plastic to 20% Sand)

The results of the compression test for a plastic waste block made with a mixture of 80% plastic to 20% sand (plastic waste 7.5 kg and 2.5 kg) for 7, 14, and 28 days, respectively (Tables 5 – 7, and Figs. 5 – 7).

Table 5 Compressive Strength for 7 Days (80% Plastic to 20% Sand).

Sample (Plastic Waste Moulds)	Weight of Mould Samples (kg)	Average Weight	Crushing Load (kg)	Compressive Strength (N/mm^2)	Average Compressive (N/mm^2)
A	3.17	3.26	312	12.46	13.56
B	3.29		335	13.37	
C	3.31		372	14.87	

Table 6 Compressive Strength for 14 Days (80% Plastic to 20% Sand).

Sample (Plastic Waste Moulds)	Weight of Mould Samples (kg)	Average Weight	Crushing Load (kg)	Compressive Strength (N/mm^2)	Average Compressive (N/mm^2)
A	3.21	3.20	353	14.09	13.29
B	3.20		327	13.09	
C	3.18		401	12.69	

Table 7 Compressive Strength for 28 Days (80% Plastic to 20% Sand).

Sample (Plastic Waste Moulds)	Weight of Mould Samples (kg)	Average Weight	Crushing Load (kg)	Compressive Strength (N/mm^2)	Average Compressive (N/mm^2)
A	3.21	3.22	364	14.53	16.30
B	3.20		315	12.57	
C	3.26		322	21.82	

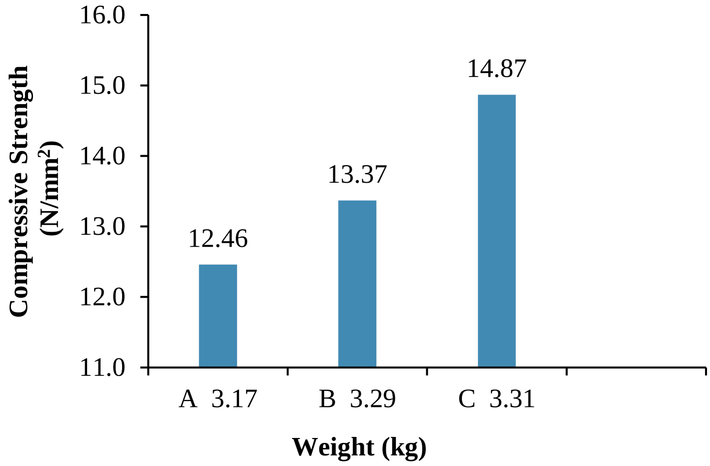

Fig. 5 Graph of 7 Days Compressive Strength (80% Plastic to 20% Sand).

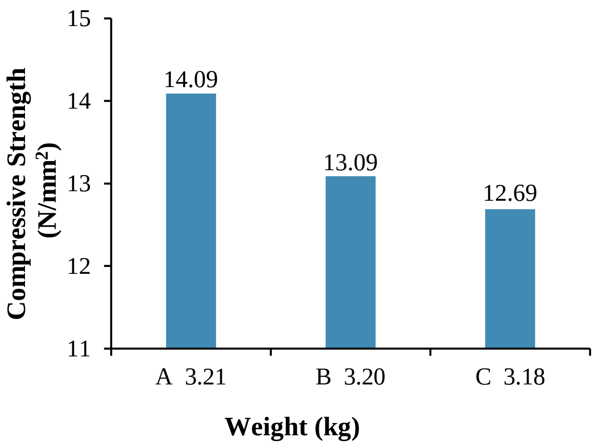

Fig. 6 Graph of 14 Days Compressive Strength (80% Plastic to 20% Sand).

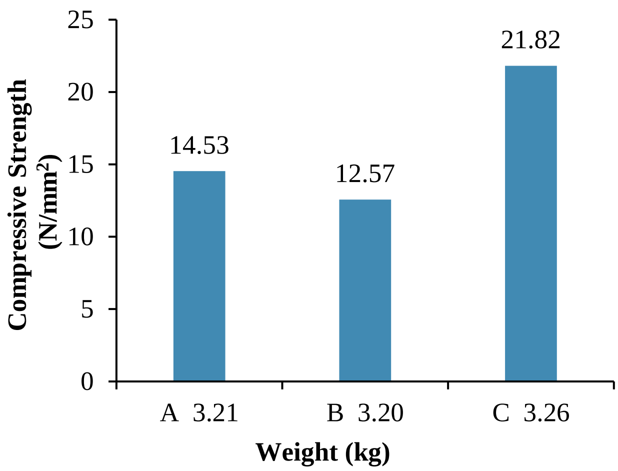

Fig. 7 Graph of 28 Days Compressive Strength (80% Plastic to 20% Sand).

Fig. 5 shows that the higher the weight of the plastic block, the lower the compressive strength. Whereas, Fig. 6 shows that the higher the weight of the plastic block, the higher the compressive strength of the block. Conversely, Fig. 7 shows that the lower the weight of the plastic block, the lower the compressive strength of the block. From Fig. 8, it was noticed from the first sample there is an increase in weight and also a rise in compressive strength, and there was a drop in the weight, which led to a decline in the compressive strength of the plastic.

Tables 8 – 9 give a comparative analysis of the compressive strength tests and standard compressive strength at different curing ages. The results (Table 8) show that the increase in curing (days) of the plastic block led to a rise in the compressive strength of the plastic block. Whereas Table 9 shows the increase in curing age led to an increase in compressive strength of the plastic block, and the compressive strength of plastic block has lower compressive strength compared to that of standard compressive strength of cement block.

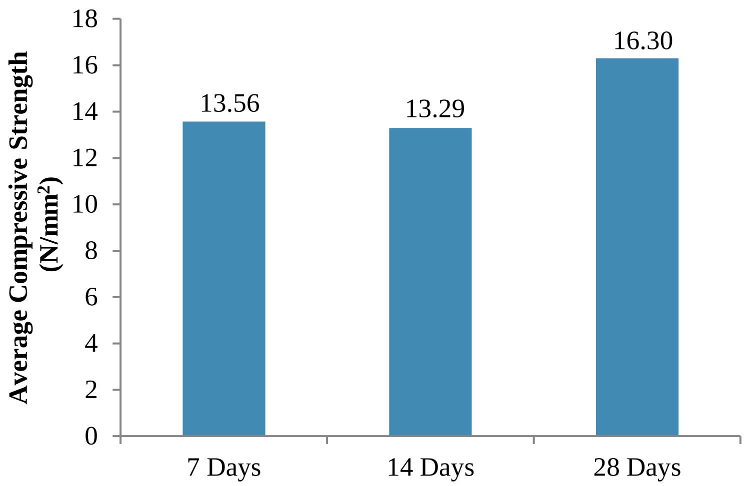

Fig. 8 Graph of Average Compressive Strength for 80% Plastic to 20% Sand Mix.

Table 8 Average Compressive Strength for (80% Plastic to 20% Sand) and (60% Plastic to 40% Sand).

Curing (Days)	Compressive Strength for the Melted Plastic Waste Block (N/mm^2) Mix Ratio (60% Plastic to 40% Sand)	Standard Compressive Strength Cement Block (N/mm^2) Mix Ratio (80% Plastic to 20% Sand)
7	27.47	13.56
14	34.39	13.29
28	39.69	16.30

Table 9 Per cent Reduction in the Compressive Strength of the Plastic Block.

Mix Ratio	7 Days	14 Days	28 Days
60% Plastic to 40% Sand	$\frac{28.94-27.47}{28.94}\times 100$ $= 5\%$	$\frac{35.09-34.39}{35.09}\times 100$ $= 2\%$	$\frac{42.57-39.69}{42.57}\times 100$ $= 6.8\%$

4. Conclusion and Recommendations

4.1. Conclusion

The following conclusions can be made from this study.

(a) The compressive strength of the tiles increases with increasing cement content. Compared to plastic waste, cement contributes most significantly to the compressive strength of tiles, which decreases with the rising quantity of plastics.

(b) The presence of plastics appeared to improve abrasion resistance. The presence of plastics in the tiles studied improved the resistance to impact as they endured impact due to a falling steel ball weighing 438 g. Water absorption is reduced with increasing amounts of plastic. The most appropriate mix in the study gave a compressive strength of 17.9 N/mm^2, a water absorption rate of 11.4 %, and tiles resistant to impact and abrasion. The density of tiles improved with increasing cement quantity.

(c) The tiles made using cement and plastics waste mixture are affordable for ceramic tiles and commercially viable. The production process is cheap since it does not involve more expensive industrial equipment. Waste (plastics) are the primary materials needed to manufacture these tiles.

(d) Increasing the number of plastics resulted in reduced density. In addition, with the presence of plastics, abrasion resistance increased, and the tiles became less brittle. Due to the tendency of plastics to reduce the compressive strength of tiles, they should be used with caution. The study has established that the use of plastic waste in the manufacture of floor tiles is a viable waste reduction option.

4.2. Recommendations

This study can be very important in conserving the environment, particularly in areas with poor waste disposal facilities, by making good use of these wastes in the manufacture of floor tiles for use in the construction industry. Notwithstanding, the physical and mechanical properties comprising freeze/thaw resistance, chemical resistance, crazing resistance, deep abrasion resistance, stain resistance, thermal shock resistance, wedging, warpage, breaking strength, bond strength, thermal expansion, and moisture expansion were not performed on the tiles understudy. Therefore, more research should be carried out regarding tiles' properties to determine their viability for usage in different environments and determine the viability of plastic waste in the manufacture of floor tiles.

Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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