The effect of cement-waste mixes on the physical and strength properties of floor tiles

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Abstract

Industrial and agricultural systems often generate wastes such as plastics and egg shell wastes. Disposal of these wastes is usually a problem. The aim of this study was to investigate the feasibility of using plastic and egg shell wastes together with white cement in the production of floor tile materials. The waste was collected from kitchens and waste disposal facilities within Juja constituency, Kenya. The materials were cleaned and dried; and plastics were shredded while egg shells were crushed. Waste materials were then mixed with white cement in different proportions. Compressive strength tests were carried out to determine the suitability of using such solid wastes in making floor tiles. Crushed egg shells passing through the 1.2 mm sieve and shredded plastics with an average diameter of to 1 to 2 mm were used. Cubes were cast and cured for 28 days. The compressive strength of the cubes was tested using a universal testing machine. The study found that addition of up to 50% cement resulted in more than 10 fold increase in the compressive strength of the cast cubes. Addition of plastics decreased the compressive strength of the cubes while addition of egg shells had insignificant effect on compressive strength. Increasing the quantity of plastics and egg shells resulted in elevated water absorption, while larger quantities of cement resulted in reduced water absorption. With the presence of plastics, abrasion resistance increased and the tiles became less brittle. It is concluded that egg shells can be used as filler material in the manufacture of floor tiles. Because of the tendency of plastics to reduce the compressive strength of tiles, they should be used cautiously. The study has established that use of plastic and egg shell wastes in the manufacture of floor tiles is a viable waste reduction option. However, further studies are necessary to establish the chemical interactions involved in floor tile production systems where household and industrial wastes such as plastics and egg shells are used.

Key words: Construction materials, environment, egg shells, plastics, solid wastes

Introduction

Growth of population, increasing urbanization, and rising standards of living due to technological innovations have contributed to increase the quantity of a variety of solid wastes generated by industrial, mining, domestic and agricultural activities [1]. Globally, the estimated quantity of solid wastes generation was 12 billion tons in the year 2002[2]. Many authorities and investigators are lately working to have the privilege of reusing the wastes in environmentally and economically sustainable ways [3]. The utilization of solid wastes in construction materials is one of such innovative efforts. Previous study indicated that the egg shell waste samples were rich in CaO (50.7%) and may be used as an alternative raw material in the production of wall tile materials [4].

Use of floor tiles in construction is for decorative, protection and aesthetic purposes [5]. In India, Fiori and Brusa, (1983) [6], fabricated ceramic tiles the water absorption of which varied between with 0.1% to 2.5%. Their tiles were made using blast furnace slag. Water absorption capacity identifies the nature of the ceramic body in regard to internal structure, which is related to mechanical strength (measured by modulus of rupture and breaking strength) and also other characteristics that affect ceramic tile durability (particularly in unglazed tiles), such as resistance to deep abrasion, stain resistance, and resistance to frost/thaw cycles, as well as to dimensional quality (Sveda, 2003) [7].

Floor tiles are expected to sustain impact loads [8] and abrasion without breaking or losing their surface texture. According to Cheng and Wei-Ting, 2014 [9], the combination of silica fume and polyolefin fiber in cement-based composites improved the strength properties and abrasion resistance than only use of polyolefin fiber due to the pozzolanic and filler effect. Cengiz et al., 2009 [10], found that replacement of fly ash with cement reduced abrasion resistance of concrete and inclusion of the steel fiber improved the abrasion resistance of concrete. However, Using polypropylene fiber did not improve abrasion resistance of concrete made with or without fly ash. An investigation by Ramesh et al., (2013) [11], found that using steel fiber content of 1.5% and cement up to 30% by fly ash in concrete enhanced impact resistance.

For glazed tiles intended for flooring, European standard EN 14411 makes it compulsory to state the abrasion resistance class of the glazed surface as a whole (glazes and decorations), after performance of the standard test according to ISO 10545-7 (1999).

Floor tiles are usually made from clay which may be glazed to improve the tile properties [5]. The core material mostly used to produce interlocking tiles is granite particles, otherwise known as stone dust (pulverized granite). The word granite comes from the Latin granum, which means a grain, in reference to the coarse-grained structure of such a crystalline rock. Granite is a common and widely occurring type of intrusive, felsic, igneous rock [12]. The aggregated materials of interlocking tiles are usually bound together with cement. Cement is basically a binder which sets and hardens independently, and can bind other materials together when hydrated.

ASTM C 270 (13) focuses on the importance of lime and cement in defining the quality of mortar in relation to water retention, air content, and compressive strength. These parameters by themselves define the properties of good mortar using in masonry work, making of concrete and interlocking tiles. Brown and Robinson (1986) [14] wrote “The most rigorous mortar requirements are to provide adequate and uniform bond strength and to prevent wall leakage.” Other parameters, such as workability of the mortar and durability are also important. Two types of properties should be considered. Plastic mortar properties pertain to the mortar from the time of mixing until it chemically hardens in the wall. Hardened mortar properties develop as the mortar cures after the initial chemical set. Both types of properties are important in determining the quality of the masonry application. In an effort to eradicate solid waste this study focuses on using solid waste in form of egg shells and plastic as construction raw materials to develop floor building tiles.

This study was designed to establish the effect of cement, plastics and egg shell contents on the compressive strength of tiles; determine the effect of plastics on surface abrasion and impact resistance of tiles; and evaluate the effect of cement, plastics and egg shell contents on tile water absorption rate.

Materials and Methodology

Collection and preparation of the wastes

Egg shells were collected from kitchens and waste disposal facilities within Juja constituency, Kenya; Plastics were collected from disposal areas in hospitals and clinics and were shredded while egg shells were crushed. The materials were cleaned and dried. Crushed egg shells passing through the 1.2 mm sieve and shredded plastics with an average diameter of to 1 to 2 mm were used. Plastics and egg shells were used as filler materials to increase the bulk and reduce on the use of other materials like cement and egg shells. Cement was used mainly as a binder. The densities of plastics, white cement and egg shells were 400 kg/m^3, 1,440kg/m^3, and 1,290kg/m^3, respectively.

Waste materials were then mixed with white cement in different proportions. Cement, plastics and egg shells were mixed by volume in the ratios of 1:1:0; 1:1:0; 1:1:1; 1:1:2; 2:1:1; 1:2:1; 1:2:2; 2:1:2; 2:2:1; and 1:0:1. The mixture was poured into lubricated steel cube moulds with dimensions of 100x100x100mm. A porker vibrator was used to compact the mixture in the cubes. The cast cubes were left for twenty-four hours to set properly before they were removed from the moulds for curing. Cubes were cast and cured for 28 days. After curing, physical and mechanical tests were conducted on the cubes. The densities of the cubes were determined as a function of mass to volume where the volume of the cubes was 1,000,000mm^3. The compressive strength of the cubes was tested using a universal testing machine. Water absorption, impact resistance, abrasion resistance, were the other tests that were performed on the cubes. The cubes that gave the highest compressive strength were used to manufacture tiles. These tiles were dried at room temperature and were used to perform the impact resistance, water absorption and abrasion resistance tests.

Determination of water absorption of the cubes

Water absorption determined according to ASTM C373. Three Cubes from different mix ratios were oven dried at 100^{o}C until a constant mass was obtained and the dry weights were recorded. Thereafter the cubes were immersed into water for 24 hours and the wet weights recorded. The expression$\text{water absorption} = [(m_2 - m_1) * 100]/m_1$, was used to calculate the water absorption of the tiles, where m_1 = the mass of the dry cube and m_2 = the mass of the wet cube.

Determination of the compressive strength of cubes

After casting the cubes, they were cured for 28 days. Using the universal testing machine, the compressive strength of those cubes was determined at 7, 14 and 28 days. The cubes had to be surface dry before being tested for compressive strength.

Determination of the impact resistance of the tiles

After conducting the compressive strength test, cubes that give the maximum compressive strength were used to cast tiles on which impact resistance and abrasion test were performed.

Impact can be defined as the application of a high degree of instantaneous force on a minimal surface, and is generally negative for ceramic products. Heavy or pointed objects falling on tiles may damage or shatter the surface, depending on the type of object. The determination of impact resistance is addressed in the

European standard through measuring what is known as the restitution coefficient (BS EN ISO 10545-5: 1997).

A spherical steel ball weighing approximately 438g (see Plate 1) was dropped on to the sample tiles at a height of one meter (see Plate 2) and the degrees of damage to the sample tiles were recorded.

Plate 1: 438g spherical steel bearing

Plate 2: Spherical steel bearing dropped through one meter height

Determination of surface abrasion resistance of the tiles

A weight of 8.4kg was used together with abrasive sand to test for the abrasion of the tiles. The abrasive sand and the load are placed on top of the tiles and the abrasion of the tile surface was maintained for 10 minutes, after which the extent of the wear was assessed. Tiles from cement: plastics: egg shells ratios 2:1:1 and 2:0:1 respectively were made and used for abrasive resistance test. The sample tiles were weighed before undergoing the abrasion test and after the test. The two weights before and after abrasion were recorded. The abrasion effect was assessed on the basis of effective percentage weight loss.

Results and Discussion

The effect of cement, plastics and egg shell contents on compressive strength

The compressive strength of cubes increased with increasing quantities of cement. Compared to plastics and egg shells, cement contributes most significantly to the compressive strength (Figure 1).

The compressive strength of the cubes was negatively affected by the addition of plastics (Figure 2). This is consistent with the findings of Ghaly and Gill, (2004) [15]. The decrease in strength may be attributed to the weak bond between plastics and cement or the weak strength of the plastic. The effect of reducing the compressive strength of concrete by the plastic aggregates is due to the fact that plastic particles aggregates do not have the compression qualities of the conventional coarse aggregates.

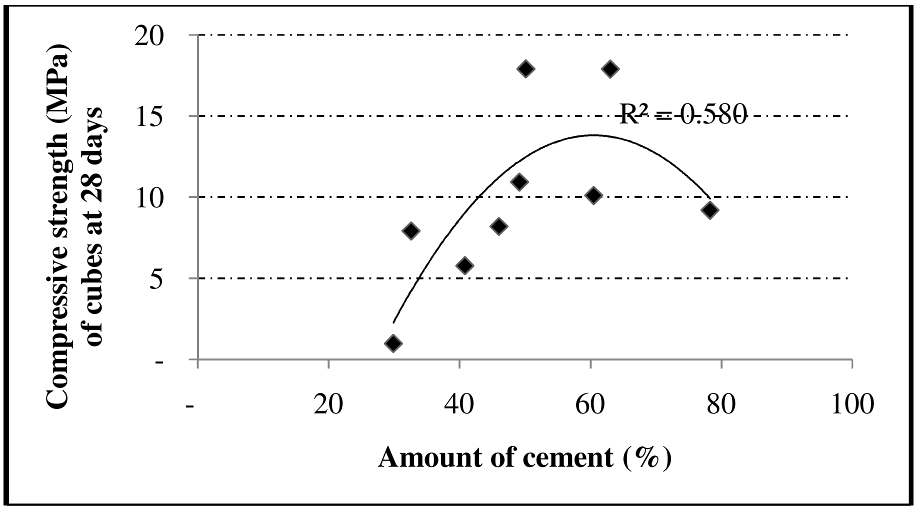

Figure 1: Effect of cement (%) on the compressive strength of cubes

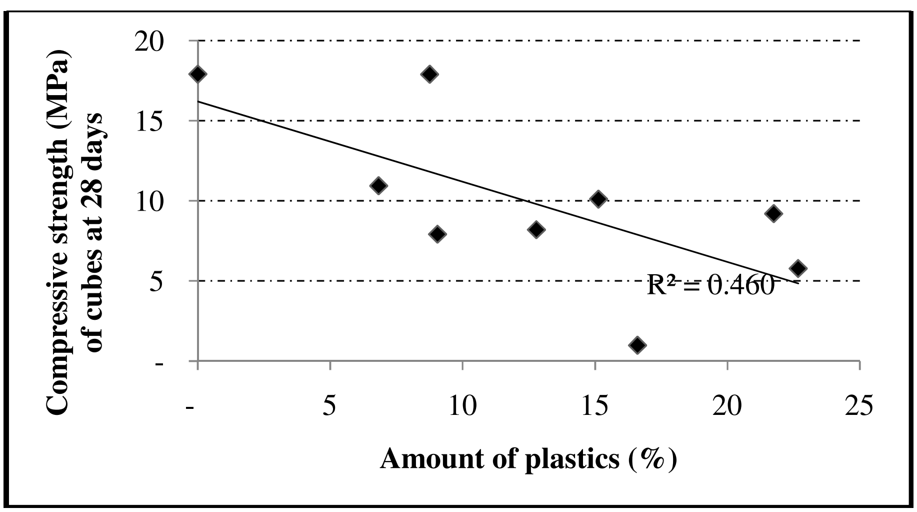

Figure 2: Effect of plastics (%) on the cube compressive strength

The effect of egg shells on the compressive strength of the cubes was insignificant (Figure 3). Egg shells consist of about 98% $CaCO_3$ [16]. They are used to increase the bulk of the mixture and reduce on the quantities of other mix ingredients.

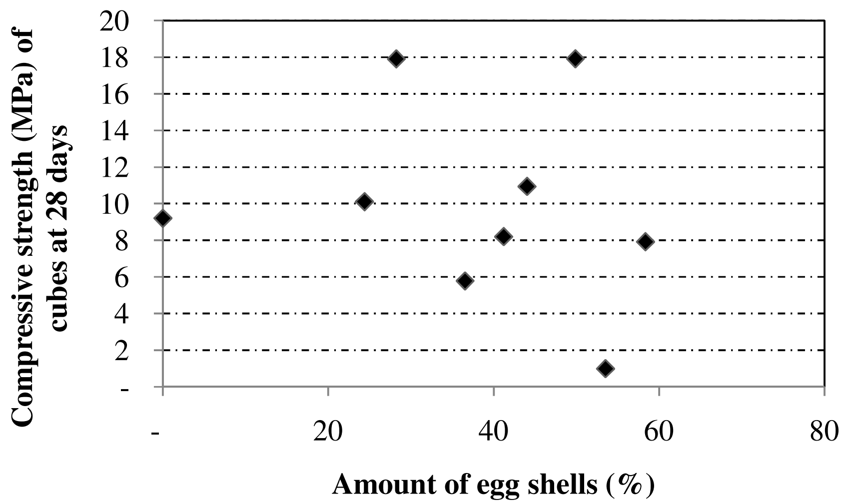

Figure 3: Effect of egg shells (%) on the cube compressive strength

The highest strength (21 N/mm2) was realized for a cement: plastic: egg shell ratio of 2:0:1 (Figure 4.4). A compressive strength of 17.9 N/mm2 after 28 days' curing was realized for ratios of 2:1:1 and 1:0:1. Ratio of 1:2:2 with the largest quantity of plastics resulted in cubes with the lowest (about 1 N/mm2) compressive strength (Figure 4.4). The compressive strength of the cubes made with a mixture of ratios 2:0:1 and 2:1:1 had the same strength as class 15 to class 20 concrete [17] (Figure 4.5). Cubes with the highest compressive strength were those with high cement content or without plastics.

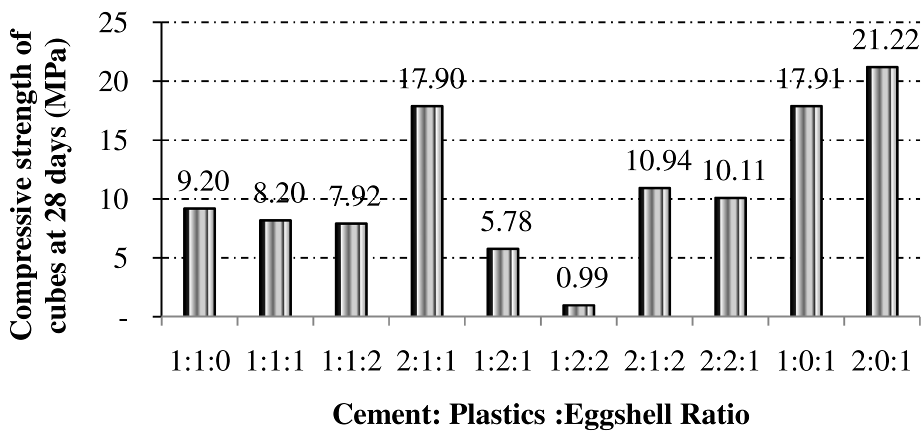

Figure 4: Effect of the different mix ratios on compressive strength of the cubes

In conclusion, the highest compressive strength (21.22 N/mm^2) was obtained without plastics. Since the major objective was to get rid of waste materials by making use of them in making construction floor tiles, the mix ratio containing cement, plastics and egg shells that gave a compressive strength of 17.9 N/mm^2 was considered the most appropriate. Tiles with both compressive strengths were manufactured to obtain impact and abrasion resistance results.

Effect of plastics on surface abrasion and impact resistance

Surface abrasion results show that tiles with cement, plastics and egg shells (2:1:1) wear at a rate lower than those made with cement and egg shells only (2:0:1). The absence of plastics makes the tiles weak and easily eroded by any rubbing object while presence of plastics makes the tiles more resistant to surface abrasion.

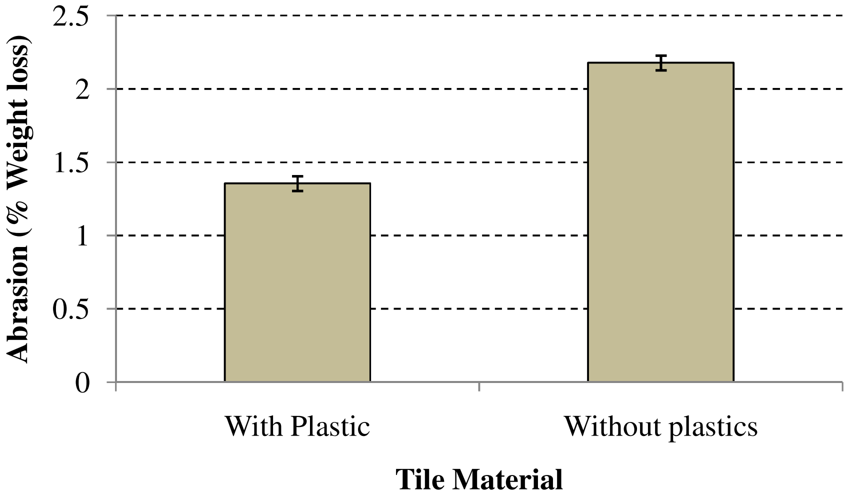

Figure 6: Effect of plastics on abrasion

Clearly, the presence of plastics protects the tile material from abrasion.

As for impact resistance, when the spherical steel ball was dropped on the tiles under study it only caused dents without shattering (see Plate 3). The inclusion of plastics reduced the brittleness of these tiles.
When the spherical steel ball was dropped onto tiles without plastics, the tiles shattered (see Plate 4), implying that they were brittle. When the test was conducted on the commercial ceramic industrial tiles, they shattered completely (see Plate 5). This implied that the industrial ceramic tiles are brittle in nature.

Plate 3: Indented tiles made with cement, plastics and egg shells

Plate 4: Shattered tile made with cement and egg shells without plastics

Plate 5: Shattered commercial ceramic tiles

In a nut shell, the presence of plastics in the tiles under study reduced their brittleness making them suitable for use as floor tiles.

The bending strength could not be measured because of the brittleness of the tiles. The weight of the apparatus caused failure of the tiles before any bending strength results could be recorded by the universal testing machine.

In conclusion, an appropriate combination of cement, plastics and egg shells (2:1:1) provided the highest impact and abrasion resistances, from which it was inferred that plastics were important in increasing impact and abrasion resistances of the tiles.

Water absorption results

Cubes with high quantities of cement had low water absorption rates while those with more plastics and egg shells had high water absorption rates (Figure 5). Cubes made from cement: plastics: egg shells ratio 1:2:2 had the highest water absorption rate (33.4%). This might have been due to more quantities of plastics and egg shells. Cubes made from cement: plastics: egg shell ratio of 2:1:1 had the lowest water absorption rate (11.4%).

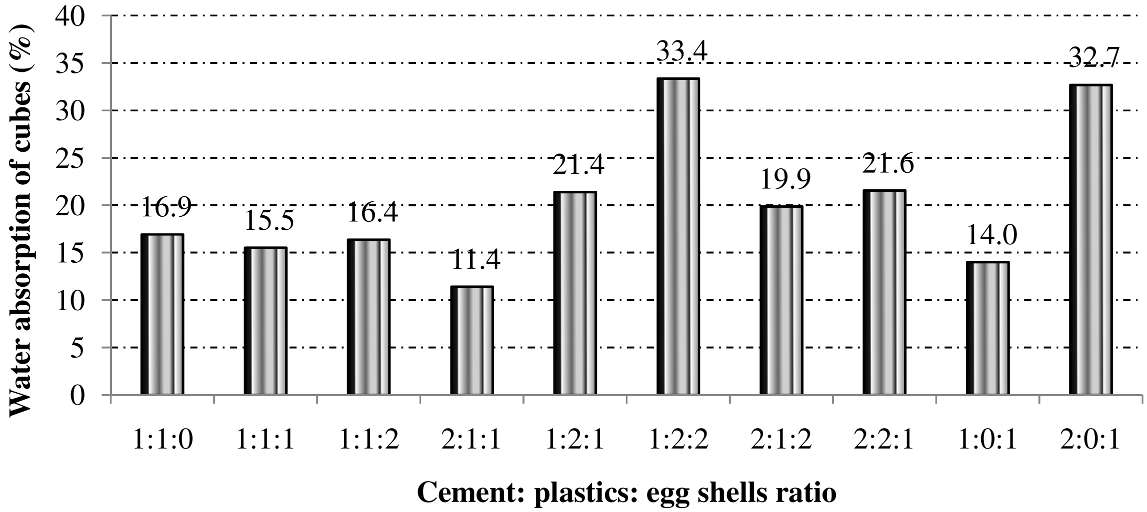

Figure 5: Effect of mix proportions on water absorption of the cubes

According to Kenya bureau of standards, floor tiles with water absorption rate in the range of 6-10% have an allowable maximum of 11% water absorption. Therefore, since these tiles have 11.4% water absorption rate, they can convincingly be used as floor finish materials.

The effect of cement, plastics and egg shell contents on the water absorption

Water absorption decreased with increasing cement content while increased water absorption was obtained with reduced cement content (Figure 6). Cement contributed most to reduced water absorption of the cubes.

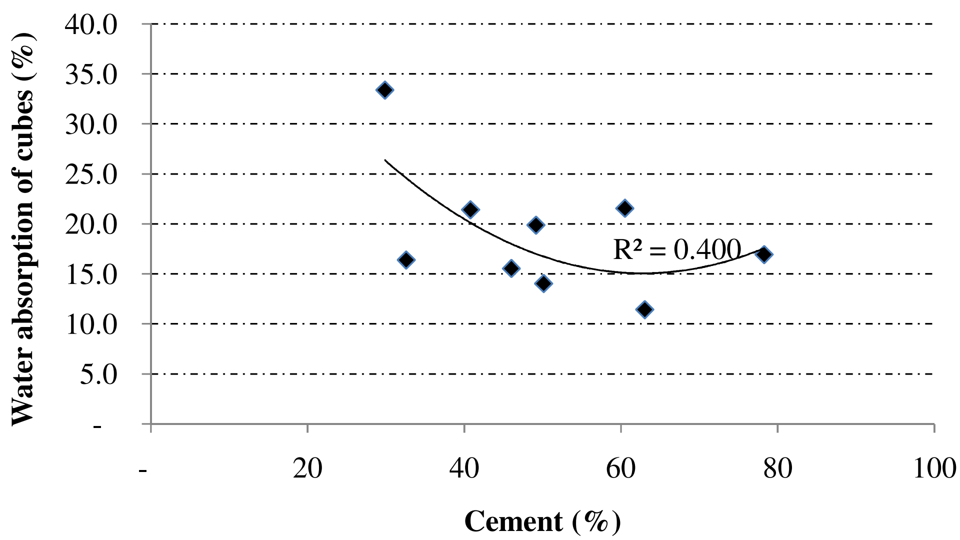

Figure 6: Effect of cement (%) on the water absorption of cubes

The contribution of plastics to water absorption is too minimal as shown by the weak relationship between them and the water absorption. Therefore, Plastics have a very insignificant effect on the water absorption of the cubes (Figure 7).

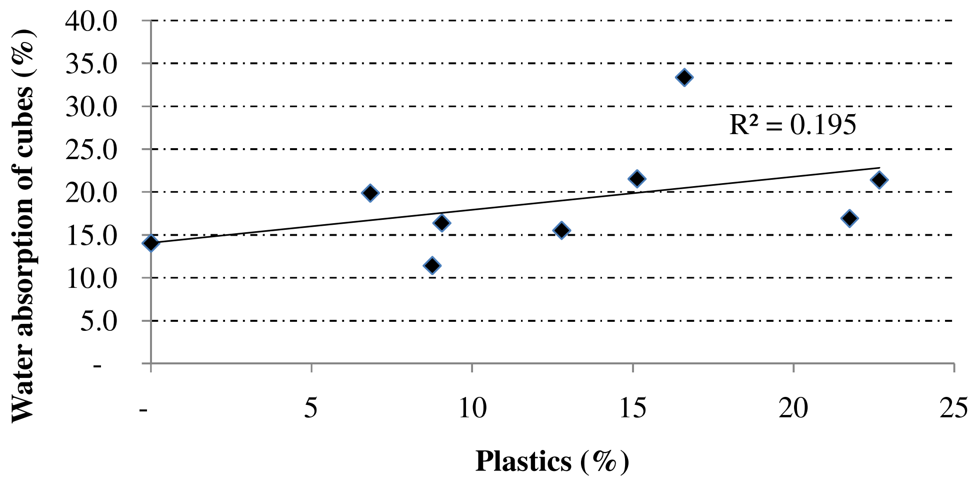

Figure 7: Effect of plastics (%) on the water absorption of cubes

Eggshells had a very insignificant effect on the water absorption of the cubes (Figure 8). This is shown by the very weak relationship between percentage egg shells and the percentage water absorption (5.7%) of the cubes.

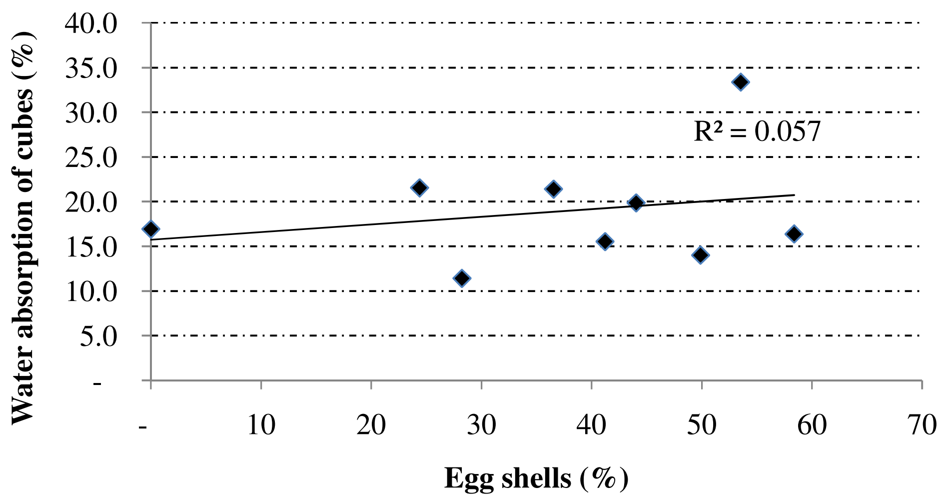

Figure 8: Effect of plastics (%) on the water absorption of cubes

In conclusion, water absorption was mainly influenced by the amount of cement. The contribution of plastics and egg shells to water absorption was minimal.

Conclusions

From this study the following conclusions can be made:

1) Compressive strength of tiles increases with increasing cement content. Compared to plastics and egg shells, cement contributes most significantly to the compressive strength of tiles, which decreases with increasing quantity of plastics.
2) Addition of egg shells does not significantly affect the compressive strength of tiles.
3) The presence of plastics seems to enhance abrasion resistance.
4) The presence of plastics in tiles under study enhanced impact resistance as they resisted impact due to a falling steel ball weighing 438g.

5) Water absorption decreased with increased amounts of cement. However, plastics and egg shells had no significant effect on water absorption of the tiles.
6) Plastics have a tendency to reduce the compressive strength of tiles. Hence, they should be used cautiously.
7) The most appropriate mix in the study was that which gave a compressive strength of 17.9 N/mm^2, a water absorption rate of 11.4% as well as tiles that are resistant to impact and abrasion.

Recommendation

The study has established that use of plastic and egg shell wastes in the manufacture of floor tiles is a viable waste reduction option. However, further studies are necessary to establish the chemical interactions involved in floor tile production systems where household and industrial wastes such as plastics and egg shells are used.

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