A REVIEW ON MECHANICAL CHARACTERISTICS OF NORMAL CONCRETE PARTIALLY REPLACED WITH RECYCLED CERAMICS AGGREGATES

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Abstract
The quantities of ceramic wastes in our nation have been on the increase significantly (approx. 45.9 tonnes annually in Nairobi) without consideration for potential reuse or recycling, increasing the risk to public health due to the scarcity of land area. This growing problem can be alleviated if new disposal options other than landfill can be found. In addition, increased construction activity and continuous dependence on conventional materials of concrete are also leading to scarcity of these materials resulting to increased construction cost. This study aims at reviewing the past research work on the use of ceramic waste aggregate as possible partial substitute for conventional coarse aggregate in concrete. From the review, an optimum mechanical strength of recycled ceramics in concrete was identified. Recycled ceramics originates mostly from broken or leftover tiles, sanitary and kitchenware. Two different ceramics were considered as partial substitute for coarse aggregate in concrete under this review, i.e. crushed clay bricks and tiles. The replacement proportions varied from 0%, 17%, 33%, 50%, and 67% by weight for natural aggregates, while other components kept constant. A detailed analysis of the results of previous work is presented for concrete design mixes. Final tests results of this work are of importance in assessing the mechanical properties determined through splitting tensile tests, flexural tests, compressive tests and bond strength development tests at 7, 14, and 28 days. Tests results showed positive response for mechanical properties of the new concrete. The review indicates that considerable knowledge and expertise has been accumulated on the use of waste ceramic products as partial occupant of natural aggregates in concrete technology. This therefore provides better and efficient recycling and utilization of waste ceramics in our environment.

Key words: Ceramic waste, concrete, aggregates, replacement, recycling, mechanical strength

1.0 Introduction
Cement and aggregate, which are the most important constituents used in concrete production, are the vital materials needed for the construction industry. This inevitably led to a continuous and increasing demand of natural materials used for their production. Parallel to the need for the utilization of the natural resources emerges a growing concern for protecting the environment and a need to preserve natural resources, such as aggregate, by using alternative materials that are either recycled or discarded as a waste.

Ceramics are often used in the manufacture of wall and floor tiles, and bricks and roofing tiles. Sanitary ceramics, as with all other ceramic products, are produced from natural materials which generally contain kaolin, china clay, feldspar, potassium, and quartz (F. Pacheco and S. Jalali, 2010). Ceramics industry includes the following sectors: ceramic flooring and wall coverings (ceramic floor and wall tiles, respectively), ceramic sanitary ware, bricks and roofing tiles, refractory materials, ceramics for technological applications (insulators, etc.), and ceramic objects for domestic and decorative purposes (tableware and ornaments).

Construction industry as the end user of almost all the ceramic materials, is well poised to solve this environmental problem which is partly its own. The use of waste products in concrete not only economical but also solves some of the disposal issues. Crushed ceramic aggregate can be used to produce lightweight concrete, without affecting strength (Kanaka sabai *et al.,* 1992).

The high consumption of raw materials by construction sector, results in chronic shortage of building materials and the associated environmental damage. In the last decade, construction industry has seen various researches conducted on the utilization of waste products in concrete in order to reduce the utilization of natural resources. T. Sekar *et al*., (2011), found out through experimentation that the compressive strength of concrete cubes made with ceramic insulator and glass insulator were found to be 16% and 26.34% lesser respectively than that of conventional concrete (T. Sekar *et al*., 2011). Veera Reddy (2010), concluded that replacement of coarse aggregate by ceramic scrap in excess of 20%, leads to reduction of strength below conventional mix (MC) (Veera Reddy, 2010). P. Turgut *et al.,* (2009) suggested that the replacement of fine aggregate by fine glass (FG) at level of 20% by weight had a significant effect on the compression, tension and flexure properties of concrete paving block samples as compared with the control sample (P. Turgut and E. Yahlizade, 2009).

Lopez *et al.,* (2007), observed that this substitution process would increase slightly the compressive strength (De Brito *et al*., 2005), nevertheless, researches carried out so far by reusing ceramic wastes in concrete are scarce and do not fully evaluated mechanical properties of the new concrete, which are key issues. This therefore forms part of a study area that needs to be fully looked into. Above studies suggest that there is a strong need to use recycled ceramic aggregates materials in concrete in an environmental friendly way.

2.0 Study Objective

Through experimental review, study mechanical properties of ceramic waste aggregates as partial replacement in concrete.

3.0 Literature Overview

3.1 Ceramic Materials Properties

3.1.1 Composition of a Ceramics

Ceramic tiles are building materials used as finishing products and designed to cover floors and walls. A very ancient manufactured product, ceramic tiles are still used today in the most modern and advanced applications. Ceramic tiles are slabs of various formats and variable dimensions (sides of lengths from a few centimetres to a metre and beyond, thicknesses from 5 to over 25mm), made mixtures of clay, sand and other natural substances fired at high temperatures. This mixture of materials establishes the ceramic nature of the tiles. These mixtures are then moulded into the required shapes through special shaping processes, and finally fired in kilns at extremely high temperatures (between 1000 and 1250°C).

3.2 Classification of Ceramic Wastes

Ceramic wastes can be separated in two categories in accordance with the source of raw materials. The first, being fired wastes generated by the structural ceramic factories that use only red pastes to manufacture their products, such as brick, blocks and roof tiles. The second one is all fired waste produced in stoneware ceramic such as wall, floor tiles and sanitary ware.

In each category the fired ceramic waste are classified according to the production process. This classification is reported in the following diagram, Figure 1 (F. P.Torgal and S. Jalali, 2010).

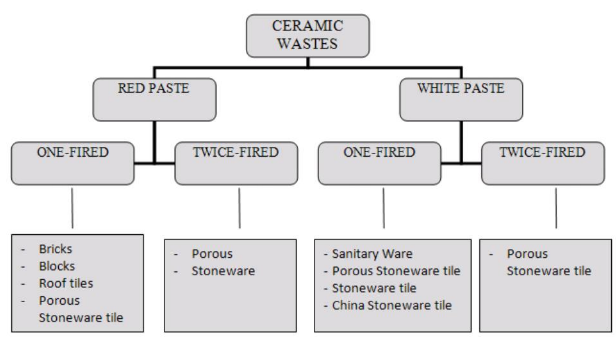

Figure 1: Classification of ceramic wastes by type and production process

3.3 Chemical Composition

The chemical compositions of ceramic pastes are reported in Table 1. The silica and alumina are the most significant oxides present in the ceramic pastes. The variation of proportion of the silica and alumina is due to the clay used. It should be noted that the red paste shows high proportion of iron oxide responsible for the red colour of the products. Ceramic wastes were crushed to make the ceramic aggregate.

Table 1: Chemical composition of ceramic pastes (F.Pacheco and S. Jalali, 2010)

Type	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2
Red paste twice fired ceramic	51.7	18.2	6.1	6.1	2.4	0.2	4.6	0.8
White paste once-fired ceramic	58.0	18.0	1.0	8.3	0.6	0.2	1.2	0.8
White paste for twice - fired ceramic	59.8	18.6	1.7	5.5	3.5	1.6	2.5	0.4
Red paste for stoneware tile	29.1	20.3	7.7	1.2	1.1	0.4	4.2	0.9
White paste for stoneware tile	65.0	21.3	1.3	0.2	0.3	2.5	3.7	0.2
White paste for sanitary ware	65.8	22.2	0.6	0.1	0.1	1.0	3.5	0.3

3.4 Ceramic Materials in Concrete

Khaloo (1995), investigated the use of crushed tile as a source of coarse aggregate in concrete. The crushed tile had a lower density and a much higher water absorption value compared to those of natural crushed stones. The resulting concrete made with 100% crushed tile as the coarse aggregate had a lower density and higher compressive (+2%), tensile (+70%) and flexural (+29%) strengths. Ay and Unal (2000), studied the possibility of using ground waste ceramic tile as a cement replacement in concrete. It was found that ground waste tile possessed pozzolanic properties and it was possible to use ground waste tile as a 35% by weight replacement of cement.

Akhtaruzzaman and Hasnat (1988), used manually crushed, well burnt clay bricks as coarse aggregates and tested four grades of concrete made with crushed brick as aggregate to determine their physical and mechanical properties. Normal compressive strength ranged from 13.8 to 34.5 MPa. In general, for the same grade of concrete, the modulus of elasticity of the concrete produced with crushed brick aggregates was about 30% lower, the tensile strength was about 11% higher and the unit weight was about 17% less than that of natural aggregate normal concrete. Empirical equations predicting the modulus of elasticity and the tensile strength of brick aggregate concrete have been derived. However, the modulus of elasticity was 30% less than that of normal concrete.

Padmini *et al*., (2001), who used a fractional factorial experimental design method, studied the relative influence of different parameters on the strength of concrete using low-strength (6-13 MPa) bricks as aggregates. It was found that the strength of brick concrete was most influenced by the cement content, the aggregate conditions (i.e. pre-wet or dry before mixing) and the strength of brick from which the aggregates were derived.

Kibriya and Speare (1996), used three different types of brick aggregates to assess their impacts on the strengths and the long-term durability of concrete. The brick concrete had comparable compressive, tensile and flexural strengths to those of normal concrete but the modulus of elasticity was drastically reduced. Mansur *et al.,* (1999), studied the suitability of crushed clay bricks as coarse aggregate for concrete, comparing its basic properties with those of conventional concrete, produced with granite aggregates. Four basic mixes were used corresponding to grades ranging from 30 to 60 MPa.

For identical mix proportions, the use of crushed brick aggregates resulted in higher compressive and tensile strengths, lower drying shrinkage, and an almost identical specific creep. However, and in parallel with the previously described study, the use of crushed brick led to a significant reduction in the modulus of elasticity and a substantial loss in the workability of the fresh concrete. A stress-strain curve equation for brick-aggregate concrete was proposed.

Devenny and Khalaf (1999), also studied the possibility of using crushed brick as coarse aggregate in concrete, comparing the compressive strength of normal concrete manufactured with granite aggregates with that of concrete made with crushed brick aggregates, obtained from four types of bricks, with compressive strengths varying from 39 to 81 MPa. They concluded that the use of crushed brick aggregates may exceed the compressive strengths reached using granite aggregate, even allowing for the production of high strength concrete, with a simultaneous lower density, which is suitable for low dead-weight applications. The authors observed that concrete compressive strength consistently increases with the brick compressive strength and with the concrete density.

Khatib (2005), used fine recycled aggregates obtained from crushed bricks to replace increasing fractions of the sand of a conventional concrete. For a 50% replacement fraction, no compressive strength reduction was observed and for an integral replacement, the reduction in strength was only 10%.

3.5 Mechanical Properties

3.5.1 Compressive Strength

Compressive strength is the capacity of a material to withstand axially directed pushing forces. However, the strength of the concrete with recycled brick as an aggregate depends on the strength of the original brick. For instance, the use of crushed brick aggregates, obtained from brick with higher initial strength, may exceed the compressive strengths reached using granite aggregate, even allowing for the production of high strength concrete (Gomes and De Brito, 2009).

Generally, it is possible to estimate the strength of the concrete with the brick as the coarse aggregate from the strength of the original brick (Gomes and De Brito, 2009). This estimation of the compressive strength could be important when recycled bricks from a construction waste are used as an aggregate for a new concrete. On this way it would be possible to determine whether or not that brick type, in a particular condition, is suitable for use as the aggregate for a new concrete with demanded strength.

3.5.2 Flexural Strength

Flexural strength is the stress at which a material breaks or permanently deforms. The angular shape of the crushed brick and its surface roughness are generally beneficial for a good bond between the aggregates and the cement paste which could hence increase the flexural strength performances. In spite of that assumption, flexural strength of the concrete with crushed brick as an aggregate is about 8% - 15% lower than the one of the ordinary concrete (Gomes and De Brito, 2009). During the studies of correlation between flexural and compressive strength of concrete with recycled crushed brick aggregate, it was observed that a decrease in flexural strength has a similar pattern as the one observed for compressive strength (Guerra *et al*., 2009).

3.5.3 Tensile Strength

The splitting test is rather simple to perform, does not require other equipment than that needed for the compression test, and gives an approximately similar value of the “true” tensile strength of concrete (Neville, 1971). This estimation gives an indication of the strength of concrete in a structure, which is dependent on the adequacy of compaction and curing. Some aspects regarding the tensile strength of lightweight concrete and aggregates were studied by Holm, (1994). He showed that shear, bond strength between aggregate and cement paste, and crack resistance are related to tensile strength that is, in turn, dependent upon tensile strength of the coarse aggregate and cement paste phases and the degree to which the two phases are securely bonded.

Investigations involving the splitting tensile strength of very high-strength concrete (f_c>50MPa) for penetration-resistant structures were carried out by O’Neil *et al.,* (2002). Due to the addition of silica fume, high-range water reducing admixtures and special curing conditions provided, the tensile strength of the concrete was higher than that of conventional concrete.

3.6 Modulus of Elasticity

The modulus of elasticity of concrete is a function of the modulus of elasticity of the aggregates and the cement matrix and their relative proportions. The moduli of elasticity of concrete with crushed brick as an aggregate is about 30-40% lower than that of normal concrete (Hansen, 1992). With the increasing of a percentage of substitution of natural aggregate with crushed brick aggregate, the modulus of elasticity decreases. It is also concluded that the modulus of elasticity of fine and both fine and coarse crushed bricks concrete is lower up to 30%, 40% and 50% in a comparison with the modulus of elasticity of a natural aggregates concrete (Guerra *et al.,* 2009). By using recycled brick for concrete aggregate an increasing of deformation has to be taken into account. Replacing 100% of the natural aggregate with recycled brick increases the deformations about 30% (Holm, 1994). That means that in constructions, in which deformations should be considered, the smaller elasticity modulus resulted from the use of recycled brick aggregate.

3.7 Water Absorption

The main problem of using the recycled brick as an aggregate for concrete is its high water absorption. The water absorption of recycled crushed brick aggregate concrete is significantly greater than the one of the natural aggregate concrete (Guerra *et al*., 2009). Water is necessary for the corrosion of embedded steel, as it can carry chlorides and sulphates as well as other harmful ions. The presence of water can also cause freeze thaw damage to concrete.

The durability of concrete with recycled brick aggregate may turn to be its major insufficiency, since the water absorption increases very significantly with the proportion of the crushed brick aggregate on the concrete mix. The use of a plasticizer admixture has a positive effect by decreasing the water absorption. The high water absorption problem may be partially solved by using a pre-saturation method of the aggregates (Hansen, 1992).

4.0 Experimental Investigations

Density of crushed brick aggregate micro-concrete was found to be lower by 16.4%, and the density of crushed tiles aggregate micro-concrete was found to be lower by 12.7% than the one of control micro-concrete (Ivana *et al*., 2008). Test results of flexural and compressive strength of 28days old specimens of recycled crushed brick, crushed tiles and river aggregate micro-concrete are presented in Table 2. After 28 days, the compressive strength of micro-concrete with recycled crushed brick aggregate was about 23.8%, and with crushed tiles about 32.7% lower than the one of river aggregate micro-concrete. Micro-concrete produced with these aggregates does not perform as well as concrete produced with regular river aggregates in terms of strength. However, the concrete still has a strength that would make it suitable for some applications, with the added benefit that density values are much lower; making it suitable in situations where self-weight is a problem (Ivana *et al.,* 2008).

	Compressive strength, MPa	Flexural strength, MPa
Control mixture MC1	46.88	10.1
Mixture MC2	35.73	6.63
Mixture MC3	31.56	6.01

Table 2: Properties of hardened (Ivana et al., 2008)

After 28 days, the flexural strength of micro-concrete with recycled crushed brick aggregate was about 34.4%, and with crushed tiles about 40.5% lower than the one of river aggregate micro-concrete. From these preliminary results it could be concluded that there was a reduction in flexural strength when crushed brick or tiles aggregates was used instead of river aggregate (Ivana *et al*., 2008).

On the whole, it can be said that the concretes having tile can be similarly use with conventional ones (Tavakoli, 2013). Table 3 reveals the results of substation of as a coarse aggregate. Besides, Figure 2 represents the samples compressive strength diagrammatically. It shows that using tile as a coarse aggregate not only cause no reduction in the strength of concrete, but also increase the compressive strength of it up to 30% and in higher percent (up to 40%) bear no negative impact on compressive strength. The strength of the samples which include tile has been reported to be very similar to each other (Tavakoli, 2013).

Further, the highest reported strength belonged to the sample which included 10% tile whose compressive strength has increased about 5.1%. On the contrary, the least reported strength was related to the samples including 40% tile whose strength was somehow similar to the control sample. One reason for decreasing the strength of samples as a result of enhancing the amount of tile may be the increase in the flaky aggregate (Tavakoli, 2013).

Table 3: Physical and mechanical properties of concrete mixes (Tavakoli, 2013)

Sample	Slump (mm)	Specific Weght (kg/m3)	Water absorption (%)	Average strength (MPa)	
				7 days	28 days
C	60	2441	5.05	26.9	33.1
CG10	50	2427	4.9	28.2	34.8
CG20	50	2407	5.2	27	34.3
CG30	45	2397	5.45	27.2	34.1
CG40	40	2385	5.7	25.7	33

Changes in the unit weight have been represented in Figure 3. The unit weight decreases as the amount of tile increases. In other work, in the samples which contain 40% of tile, this decrease about 2.3%. As a whole, it can be asserted that using tile causes a decrease in unit weight and hence it helps the load bearing capacity of structures.

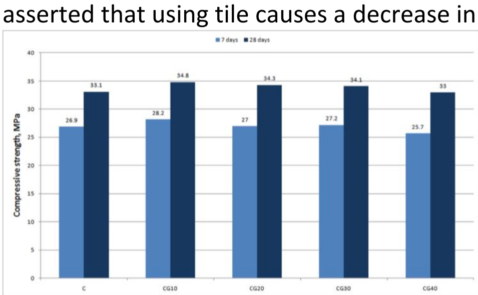

Figure 2: Compressive strength

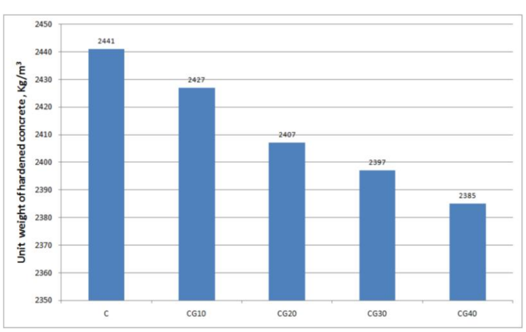

Figure 3: Unit weight of hardened concrete

From the findings above for this study, it can be inferred that using ceramics can not only bear fruitful effects in concrete but also can have a positive effect on environment. As it was previously mentioned, the bulk of ceramics production in the world is about 8500 million square meters per year. This amount, supposing that thickness and weight are expressed in weight unit, shows that about 120 billion ton ceramic wastage is produced which can be used simply in concrete production. Consequently, this would bear positive effects both in concrete production and environment and decrease the excessive use of raw materials in concrete (Tavakoli, 2013).

5.0 Conclusion and Future Work

An overview of important properties of concrete made with crushed clay brick and tiles as an aggregate is presented in this paper. The overview shows that concrete can be successfully produced using waste ceramics aggregates. The following conclusions may be drawn from the study:

(i) Regarding the mechanical performance, in terms of compressive and tensile strength, the use of ceramic recycled aggregates for concrete is suitable.

(ii) According to results of experimental investigation that are presented in this paper. The compressive and flexural strengths of the crushed brick micro-concrete and crushed tiles micro-concrete are lower than the strengths of river aggregate microconcrete. The concrete with recycled crushed brick aggregate still has a strength that would make it suitable for applications in which the high strength is not necessary.

(iii) Using tile wastage in concrete leads to removal of those materials from environment. Besides, decreasing the use of raw materials, using the wastage is considered positive economically.

The aim of experimental investigation presented in this paper was the investigation of possibilities of utilization of waste brick and tiles as an aggregate in micro-concrete. However, sufficient research has not yet been done on the effects of shapes and sizes of waste ceramics aggregates on physical and mechanical properties of the new concrete. And the use of plastic fibres to improve strength properties of ceramic concrete.

This investigation is preliminary and the future work will address extensive investigation of physical and mechanical properties of normal concrete with coarse aggregate partially replaced with recycled clay products in order to obtain final conclusions.

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