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Permeability resistance of concrete incorporating recycled ceramic tile as fine aggregate †

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Abstract: Several researches have proposed that incorporation of ceramic wastes into concrete production will be of immense benefits to both ceramic and concrete industries. However, while mechanical properties of ceramic waste concretes have been extensively investigated, there are very limited data on their durability performance. This ongoing study addresses this critical gap by focusing on the durability aspects, specifically the permeability, of concrete enhanced with recycled ceramic tiles (RCT) as a fine aggregate. The assessment of permeability encompasses two key facets: resistance to water absorption and resistance to chloride ion penetration. Water absorption tests were carried out on concrete specimens with varying percentage replacement of sand with RCT (0%, 33.3%, 66.6% and 100%) while chloride ion penetration tests were conducted using silver nitrate colouration technique on similar specimens immersed in 3% NaCl solution for 14, 28 and 56 days. Results of preliminary tests on RCT shows that it is a suitable fine aggregate material for concrete production and a lighter material than sand. Moreover, while samples with RCT out-performed control samples in terms of resistance to water absorption, resistance to chloride ion penetration was directly proportional to percentage replacement of sand with RCT. This improved performance has been attributed to the refined microstructure of RCT concrete at cement paste-aggregate interface due to the pozzolanic property of RCT

Keywords: concrete; chloride ion penetration; recycled ceramic waste; water absorption

1. Introduction

Ceramic wastes are generally generated by industries manufacturing ceramic products like sanitary wares, electrical insulators, bricks, tiles, porcelains, etc. due to cracks, off-standard products, size discrepancy, glazing fault, production error, etc. They are also generated during transportation and distribution of these products and as construction and demolition wastes. These amount to millions of tonnes of ceramic wastes which are presently not reused in any significant quantity, but are rather disposed in landfills all over the world [1]. Ceramic wastes are classified as non-biodegradable [2-3]. Hence, their disposal in landfills constitutes to huge environmental problems. As a remedy, several researchers have proposed that incorporation of these wastes into concrete production will be of immense benefits to both ceramic and concrete industries [4-6]. However, while compressive strength and other mechanical properties of these ceramic waste concretes have been extensively investigated [2, 5, 7-9], there are very limited data on their durability performance. Nevertheless, the few studies on durability properties of concrete incorporating ceramic waste as aggregate have reported comparable and improved performances, but these studies are on few ceramic waste materials.

In a study by Siddique et al. [10] on concrete incorporating bone China ceramics as fine aggregate, ceramic aggregate-based specimens outperformed control specimens in

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terms of resistance to capillary water absorption and chloride ion ingress. However, they exhibited slightly higher porosity and water absorption than control specimens. This was attributed to the fact that bone China ceramic fine aggregates are angular in shape and hence lead to the formation of voids in concrete mass. In a related study, Pacheco-Torgal and Jalali [11] investigated permeability related characteristics of concrete with ceramic sand as complete replacement for river sand and reported similar improved results in terms of resistance to chloride ingress, capillary water absorption and oxygen permeability. Nevertheless, a few studies have reported slight deduction in durability performance of concrete with ceramic waste aggrege [3, 12].

The available literature on the subject of durability properties of ceramic aggregate concrete shows that there is scarcity of data on concrete incorporating ceramic waste tiles as fine aggregate. In this on-going study, water absorption resistance and chloride ingress resistance of concrete into which recycled ceramic tile (RCT) is incorporated as a fine aggregate have been investigated.

2. Materials and Methods

The laboratory tests in this study utilized concrete specimens produced from the five materials listed in Table 1. Specifically, Portland limestone cement (CEM II) belonging to strength class 32.5R was employed. River sand and RCT were used as fine aggregate, while granite chippings was used as coarse aggregate. RCT was derived from waste ceramic floor and wall tiles obtained from a ceramic tile dealer in Uyo, Akwa Ibom State, Nigeria (see Figure 1a). They were broken into smaller pieces and crushed into the required size with the help of a hammer mill (see Figure 1b). 100mm concrete cube specimens with varying percentage replacement of sand with RCT (0%, 33.3%, 66.6% and 100%) were produced. Specimens were designated as M_0, M_{33}, M_{66} and M_{100}, corresponding to their respective percentage replacement of sand with RCT.

Table 1. Mix constituents and proportions for production of concrete test specimens.

Mix Composition	Dry Batch Weight (kg/m³)			
	M_0	M_{33}	M_{66}	M_{100}
CEM II 32.5	443	443	443	443
Sand	607.6	405.2	202.8	0
RCT	0	202.4	404.8	607.6
Coarse Aggregate	1214	1214	1214	1214
Water	235	235	235	257
w/c	0.53	0.53	0.53	0.58
% Replacement of sand with RCT	0	33.3	66.6	100

Figure 1. Recycled ceramic tile (RCT) (a) before crushing and (b) after crushing.

Water absorption tests were carried out in compliance with BS 1881-122. After 28 days of curing, specimens were oven dried for 72 hours, then allowed to cool under air. They were then immersed in water for durations of 10, 20, 30, 60, 120 and 180 minutes.

Water absorption (***W_a***) was therefore calculated using Equation 1, where ***M_t*** is the initial mass of specimen before immersion and ***M_d*** is the mass of specimen after each duration of immersion. Chloride ion penetration test was carried out using silver nitrate colouration technique as used elsewhere [13, 14]. This involved immersing concrete specimens in 3% NaCl solution for a period of 14, 28 and 56 days after an initial 28 days wet curing. On each test day, specimens were split into two and sprayed with 0.1M $AgNO_3$ solution which formed white precipitate of AgCl that was used to measure the depth of penetration of chloride ion (see Figure 2).

$$W_a = \frac{M_t - M_d}{M_d} \times 100 \quad (1)$$

Figure 2. Extent of chloride ion penetration (into concrete specimens exposed to 3% NaCl) indicated by white precipitate of AgCl on outer layers of specimen**.**

3. Results and Discussions

3.1. Suitability of RCT as Fine Aggregate

Results of selected physical properties of aggregates used are presented in Table 2. Specific gravity of RCT was within the range of 2.4 – 3.0 which is typical of different rock materials used as normal weight aggregate [15]. Specific gravity and bulk density of RCT were observed to be lower than that of sand. This has been reported elsewhere [16, 17] and is an indication that RCT is capable of producing lighter weight concrete compared to sand. From the values of gradation coefficient (C_c) and uniformity coefficient (C_u), RCT can be classified as well graded since its C_u is greater than 6 and its C_c is between 1 and 3 [18].

Table 2. Physical properties of aggregates used.

Property	Sand	RCT	Coarse Aggregate
Specific gravity	2.61	2.40	2.39
Bulk density (kg/m^3)	1635	1373	1386
Uniformity coefficient (C_u)	2.85	17	1.84
Gradation coefficient (C_c)	0.73	1.78	0.87

3.2. Water Absorption

Water absorption curves of test specimens are presented in Figure 3. From the curves in the figure, it is obvious that the incorporation of RCT as fine aggregate does not reduce concrete's resistance to water absorption. Although all specimens exhibited similar water absorption at early stage of immersion, it is clear that after 180 minutes of immersion, ***M_{66}*** specimens recorded the least water absorption, followed by ***M_{100}*** and then ***M_{33}*****.** This indicated that RCT based concrete specimens possessed higher resistance to water absorption than conventional concrete. Similar trend has been reported before [11]

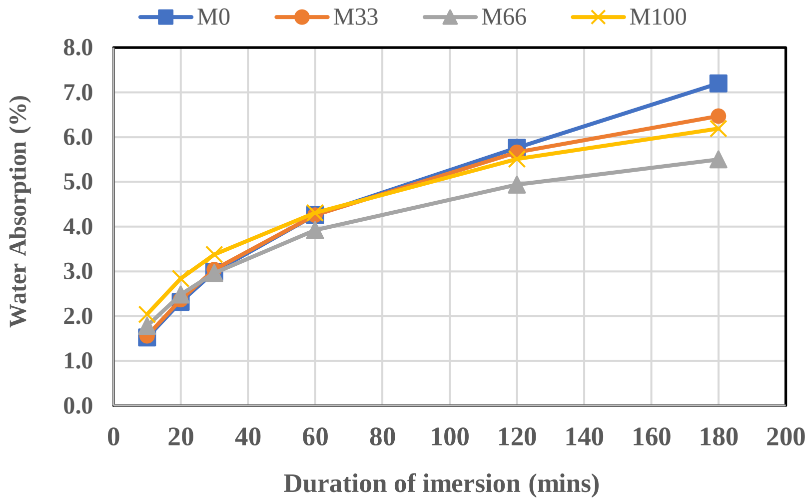

Figure 3. Water absorption of concrete specimens with different replacement level.

3.3. Chloride Ingress

Figure 4 presents depth of chloride ion penetration for specimens immersed in 3% NaCl solution for 14, 28 and 56 days after initial 28 days wet curing. Resistance to chloride ion penetration was found to be directly proportional to percentage replacement of sand with RCT. It has been reported that ceramic waste aggregates do not interfere with hydration process, neither do they affect the morphology of hydration products; rather that their incorporation refines the microstructure of concrete at cement paste-aggregate interface [19]. This refinement of microstructure results in a more compact pore structure with reduced permeability and is likely to be the explanation for the improved resistance to water absorption and chloride ion penetration.

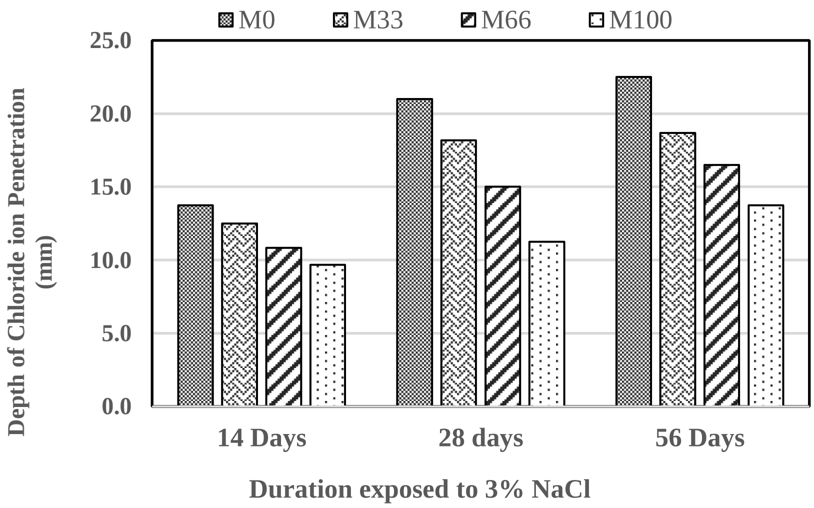

Figure 4. Depth of chloride ion penetration after exposure to 3% NaCl for 14, 28 and 56 days.

4. Conclusion

In this study permeability characteristics of concrete incorporating RCT as fine aggregate were investigated in terms of resistance to water absorption and chloride ion transport. From experimental results, RCT has been found to be a suitable fine aggregate material, capable of producing lighter weight concrete compared to river sand. Specimens with RCT contents were found to have higher resistance to water absorption and chloride ion ingress than control specimens. This improved performance of RCT concrete has been attributed to its compact and refined microstructure. The use of RCT as fine aggregate in concrete production is therefore strongly recommended.

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