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Durability properties of bone china ceramic fine aggregate concrete

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HIGHLIGHTS

- Bone china ceramic waste as fine aggregate for concrete mix was evaluated.
- Pozzolanic behaviour of fine bone china ceramic aggregate lead to higher strength characteristics.
- Enhanced formation of CSH gel restricts the chloride ion diffusion.
- Upto 40% fine bone china ceramic aggregate is feasible for durable concrete.

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ABSTRACT

To suggest an alternative raw material for concrete, its role in the hydration mechanism and water durability characteristics is required to be understood. This article assesses the water based durability properties of concrete containing bone china ceramic fine aggregates (BCCFA). For this study, BCCFA was utilised as 0%, 20%, 40%, 60%, 80% and 100% partial replacement of fine aggregate. The hydration products were assessed by X-ray photoelectron spectroscopy. The water based properties of concrete such as percentage voids, apparent density, water absorption, water permeability (DIN) and chloride ion permeability were obtained for concrete samples. The results indicate that up to 40% BCCFA can be used for structural applications.

1. Introduction

The quantity of industrial production is increasing around the world and with it the challenge to recycle and reuse the waste generated in those production processes. Concrete industry being the highest consumer of natural resources and having a huge carbon footprint on the environment is turning over a new leaf towards green and sustainable materials by promoting waste exchange from other industries. Extractive river mining is a serious environmental issue which is being neutralised by using recycled fine aggregates procured from waste and by products of other industries [1]. In the past decade, the properties of ceramic aggregate concrete (sanitary, tile, insulator etc.) were extensively studied [2–9]. The pozzolanic behaviour of ceramic aggregates have been observed by many authors and a positive influence was found on microstructural and mechanical properties of concrete [3,10–14]. Both coarse and fine forms of ceramic aggregates have been tested for their influence on durability performance of concrete.

2. Literature review

2.1. Ceramic waste as coarse aggregate

Senthamarai et al. [15] reported a high permeability of ceramic concrete containing electrical insulators as coarse aggregate. They also reported that lower water cement ratio can slightly limit the permeability within acceptable ranges. Medina et al. [16] reported rise in porosity of concrete on replacement of natural aggregate by 20% and 25% sanitary ware based coarse aggregate. The authors also observed slight increase of 1.42% and 2.55% in oxygen permeability of concrete. Medina et al. [17] observed slightly high values of total porosity, water absorption, sorptivity and depth of water penetration on incorporation of 20% and 25% sanitary ware ceramic coarse aggregate. The higher values of the properties were still within the permissible limits for use in structural concrete. Medina et al. [18] observed that the higher porosity of sanitary ware based coarse aggregate concrete samples leads to higher chloride penetration in concrete matrix. Awoyera et al. [19] observed that on incorporation of 100% coarse tile ceramic aggregate, the mercury intrusion porosimetry (MIP) showed higher percentage of pore volume than the reference mix. They also observed that the angular

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nature of coarse aggregate led to macropores which caused the formation of voids.

2.2. Ceramic waste as fine aggregate

Higashiyama et al. [5] observed that incorporation of 15% GGBS (ground granulated blast slag) as supplementary cementitious material was sufficient to resist the chloride penetration in electrical insulator (fine aggregate) based cement mortar. Gonzalez-Corominas and Etxeberria [8] observed that the 28 day concrete resistance to chloride ion penetration decreased when ceramic wall rubble was introduced as fine aggregate. However, at 180 days of curing age, ceramic concrete exhibited better resistance to chloride penetration; a decrease of 52% and 70% was observed for samples containing 15% and 30% fine ceramic wall rubble aggregate. Higashiyama et al. [12] reported enhanced resistance to chloride ion penetration for mortar samples containing electrical insulator based fine aggregate than conventional mortar samples. Binici [20] reported that use of fine ceramic aggregate results in better resistance against chloride penetration. Vieira et al. [21] replaced natural fine aggregate by sanitary ware fine aggregate by 20%, 50% and 100%. They reported that with respect to reference concrete the mixes containing ceramic aggregate registered an increase in the water absorption by immersion and capillary and higher chloride ion migration. They concluded that higher water absorption of ceramic aggregate resulted in higher water to cement ratio causing formation of pores in concrete matrix. Zegardlo et al. [22] investigated the effect of ceramic fine aggregate procured from sanitary ware waste. They reported higher values of water absorption and lower degree of water resistance for ceramic concrete samples as compared to reference mix.

The durability of concrete containing various types of ceramic aggregates, investigated by various authors showed an increase in depth of water penetration, porosity and water absorption. However, no clear trend can be concluded regarding the resistance to chloride ion penetration. As per the knowledge of authors no study is available on the hydration products and durability of concrete containing bone china ceramics. The raw materials used in fine bone china tableware makes its chemical properties distinct and unique among other ceramic aggregates. In the present study, experimental investigations have been carried out to assess and draw suitable conclusions for the water based properties of bone china ceramic fine aggregate (BCCFA) concrete.

3. Materials

The ordinary Portland cement of 43 grade was used in this study. Basalt based aggregates were used as coarse aggregates of size 20 mm and 10 mm. River based natural sand was used as natural fine aggregate. Fine bone china ceramic waste was procured from a local tableware industry and then crushed to mimic the fine aggregate. The waste collected from the industry was biscuit fired discarded bone china ceramic products which is without the glossy finish. Both natural sand and BCCFA belonged to zone II grade of BIS 383 [23]. Table 1 presents the chemical composition of cement, natural sand, and BCCFA. Table 2 presents the physical properties of the aggregates. Fig. 1 shows the BCCFA used in this study. The grading curves for natural sand and BCCFA are presented in Figs. 2 and 3.

Potable water suitable for drinking was used as mixing water. High range water reducing superplasticiser was used to maintain a compaction factor of 0.90 or higher. The compaction factor is defined as the ratio of the weight of partially compacted concrete to the weight of fully compacted concrete.

Table 1
Chemical composition of cement, natural fine aggregate and fine bone china ceramic aggregate.

Chemical constituent	Ordinary Portland cement	Natural fine aggregate	BCCFA
CaO (%)	62.34	1.15	24.15
SiO_2 (%)	20.14	81.67	28.86
Al_2O_3 (%)	4.65	9.81	23.86
Fe_2O_3 (%)	3.29	2.11	5.41
SO_3 (%)	2.42	–	–
MgO (%)	2.23	0.75	2.86
K_2O (%)	0.72	2.52	1.58
LOI (%)	1.96	0.2	0.5

Table 2
Properties of aggregates used in the concrete mixes.

Property	Natural fine aggregate	BCCFA	Natural coarse aggregate
Specific gravity	2.67	2.40	2.74
Water absorption (%)	1.0	2.5	0.5

Fig. 1. Fine bone china ceramic aggregate.

4. Experimental programme

The concrete mix was designed as per Indian standard BIS 10262 [24]. The water to binder ratio was kept constant at 0.35. To compensate for water absorption characteristics of the aggregates, excess water was added in the mix to maintain uniform water to binder ratio. Six different concrete mixes were prepared for this study. CC refers to reference concrete and CCX stands for concrete containing BCCFA where X represents the percentage replacement of natural fine aggregate with BCCFA. Table 3 gives the mix proportion of concrete.

The testing regime followed was to determine X-ray photoelectron spectroscopy (XPS), compressive and splitting tensile strength, percentage voids, apparent density, water absorption, water penetration, sorptivity, chloride ion diffusion.

4.1. X-ray photoelectric spectroscopy (XPS)

A pellet sample (5mm $\times$ 5 mm $\times$ 1mm) was used for XPS measurements. The XPS analysis was carried out on an XPS system using monochromatic Al Kα radiation hv = 1486.7 eV. The samples were deposited on a carbon tape and degassed overnight in XPS chamber to minimise air contamination. Pass energy of 50 eV was maintained to carry out the survey analysis.