Construction and Building Materials 169 (2018) 289–298

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Strength and impact resistance properties of concrete containing fine bone china ceramic aggregate

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HIGHLIGHTS

- Ceramic aggregate from fine bone china ceramic waste was evaluated.
- River sand of concrete mixes was replaced by fine bone china ceramic aggregate.
- Fine bone china ceramic aggregate is mechanically feasible for concrete.

ARTICLE INFO

Article history:
Received 23 October 2017
Received in revised form 26 February 2018
Accepted 28 February 2018

Keywords:
Ceramic waste
Fine bone china ceramic aggregate
Impact resistance
Drop weight test
Modulus of elasticity

ABSTRACT

This article examines the mechanical and impact resistance properties of concrete incorporating fine bone china ceramic aggregate. Three different concrete mixes with varying water-to-binder ratios containing different substitutions (0%, 20%, 40%, 60%, 80% and 100%) of fine bone china ceramic aggregate as fine aggregate were prepared. The mechanical properties such as compressive strength, split tensile strength, flexure strength and modulus of elasticity were evaluated. The impact resistance of concrete containing 40% fine bone china ceramic aggregate was measured by a drop weight test and rebound test. The microstructure of the concrete mixes was examined via a scanning electron microscope. The inclusion of fine bone china ceramic aggregate in concrete leads to enhanced mechanical strength and impact resistance properties. The microstructure of the fine bone china ceramic aggregate concrete showed enhanced formation of hydration products.

1. Introduction

The higher rigidity of concrete classifies it as a brittle material. To recommend a suitable concrete mix for structural applications satisfying its serviceability criteria, evaluation of the modulus of elasticity is an important parameter to consider. Similarly, for non-structural applications such as pavement blocks the impact resistance of concrete should be thoroughly evaluated. In the past few decades the concrete and construction industry has pushed towards the effective utilisation of recycled materials and by-products as concrete-making material [1–9]. Among the various recycled or waste materials, the use of different types of ceramic waste as aggregate has been extensively researched due to their ability to be manufactured into any form of aggregate [10–14].

Ceramic waste aggregate is available worldwide and has varying physical and chemical properties depending on the locally available raw material and production processes. The studies carried out by various researchers have considered fine or coarse forms of ceramic aggregate.

Senthamarai and Manoharan [11] evaluated the effect of electrical insulator based ceramic coarse aggregate on the compressive strength, flexure strength, split tensile strength and modulus of elasticity of concrete. They observed that on incorporation of 100% ceramic aggregate the mechanical properties are negatively affected. Correia et al. [14] reported that the inclusion of 100% coarse recycled ceramic aggregate resulted in inferior compressive and flexural strength of concrete. Medina et al. [10] concluded that up to 25% coarse sanitary-ware aggregate provided enhanced compressive and split tensile strength of concrete. The pozzolanic behaviour of sanitary-ware aggregate was concluded as the major strength-gaining factor. Alves et al. [13] demonstrated that concrete samples containing 20%, 50% and 100% fine sanitary-ware ceramic aggregate exhibited a loss in compressive strength and split tensile strength. The modulus of elasticity for ceramic aggregate concrete was found to be lower than that of control concrete.

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https://doi.org/10.1016/j.conbuildmat.2018.02.213
0950-0618/

The poor physical characteristics of ceramic aggregate were one of the primary reasons for the inferior mechanical performance of ceramic concrete. Gonzalez-Corominas and Etxeberria [12] observed slightly increased strength properties of concrete such as compressive and split tensile in concrete samples containing fine ceramic aggregate. The modulus of elasticity observed for the same mix considerations was slightly inferior to that of the control concrete.

The tableware industry of India is growing, with future planned investments. The potential drawback that the fine bone china ceramic tableware industry is facing is the waste disposal system for rejected products. The waste generation amounts to nearly 15–20% of total production units and more than 50,000 tonnes per annum [15,16].

For tableware ceramics, especially bone china ceramic, the authors have carried out studies covering the fresh properties and microstructure properties of fine bone china ceramic aggregate concrete [17,18]. It was reported that the introduction of fine bone china ceramic aggregate provides higher strength characteristics and superior microstructure compared with control concrete. To the best knowledge of the authors, no previous studies have been carried out on the modulus of elasticity and impact resistance properties of ceramic aggregate concrete.

The aim of this study is to evaluate the potential factors affecting the mechanical properties of fine bone china ceramic aggregate concrete. For this purpose, the physical and chemical characteristics of raw fine bone china ceramic aggregate have been evaluated. Various concrete mixes have been investigated for their compressive strength, split tensile strength, flexural strength, modulus of elasticity and impact resistance. Microscopic images have also been obtained to evaluate the microstructure of concrete specimens.

2. Materials and methods

2.1. Materials

Ordinary Portland cement of 43 grade was used in the study. River sand satisfying the specifications of BIS 383 [19] having the specific gravity of 2.67 and water absorption of 1% was used as fine aggregate. Naturally available crushed stone aggregate having the specific gravity of 2.74 and water absorption of 0.5% was used as coarse aggregate. For the fine bone china ceramic aggregate, the waste products of a local tableware production unit were crushed to obtain the form of fine aggregate (Fig. 1). Table 1 presents the physical and chemical properties of the fine bone china ceramic aggregate. The grading curves for the natural sand and fine bone china ceramic aggregate are presented in Figs. 2–3. Fig. 4 shows the gradation curve for all-in-aggregates.

Fig. 1. Fine bone china ceramic aggregate.

Table 1
Physical and chemical characteristics of fine bone china ceramic aggregate.

Analysis	Values obtained
Physical characteristics	
Specific gravity	2.40
Water absorption (%)	2.5
Chemical characteristics	
CaO (%)	24.15
SiO_2 (%)	28.86
Al_2O_3 (%)	23.86
Fe_2O_3 (%)	5.41
MgO (%)	2.86
K_2O (%)	1.58
LOI (%)	0.5

Tap water was used for mixing the ingredients of the concrete. A high range water reducer superplasticizer was used to obtain a compaction factor of 0.9 or higher for the fresh concrete mixes.

2.2. Mix proportioning

The concrete mix proportions followed in the study are presented in Table 2. The mix proportioning of the concrete was done as per the guidelines of BIS 10,262 [20]. A total of 18 mixes were prepared with three different water-to-binder (w/b) ratios (0.35, 0.45 and 0.55). Natural fine aggregate was replaced by fine bone china aggregate in proportions of 0%, 20%, 40%, 60%, 80% and 100%. To maintain a constant water-to-binder ratio, supplementary water was added during the mixing process to compensate for the water absorption of the aggregates. The nomenclature of the mixes followed was: series A for 0.35 w/b, series B for 0.45 w/b and series C for 0.55 w/b.

The ingredients of the concrete mix were dry-mixed in a mixer for a duration of 2–3 min. After thorough dry mixing, the total mixing water was introduced into the mixer and superplasticizer was used to facilitate the desired workability and uniformity in the mix. Superplasticizer was added as a percentage by weight of the cement content in the mix. The mixes were poured into moulds after they showed proper workability and uniform distribution of constituent materials.

2.3. Testing regime

2.3.1. Compressive and flexural strength

The compressive strength and flexural strength tests were conducted on 100 mm cubic specimens and 100 mm × 100 mm × 500 mm prisms respectively. An average of 3 specimens was reported as per the guidelines of BIS 516 [21].

A scanning electron microscope (Nova Nano FESEM 450) was utilised to obtain the microscopic images of the concrete specimens. 28 days cured concrete specimens were cut into 10 mm × 10 mm × 10 mm sample sizes. The samples were then grinded to obtain a smooth surface for proper microscopic investigations.

2.3.2. Split tensile strength

The split tensile strength on 150 mm cubic specimens was examined following the guidelines of BIS 5816 [22].

2.3.3. Modulus of elasticity

The modulus of elasticity was calculated on cylindrical specimens of 150 mm diameter and 300 mm height, following the guidelines of ASTM C469 [23].