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Characterization of ceramic waste aggregate concrete

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KEYWORDS

Aggregate;
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Abstract There is a growing interest in using waste materials such as ceramics as alternative aggregate materials for construction. While other ceramic product wastes such as sanitary wares and electrical insulators have been extensively investigated, not much findings are available on ceramic wall and floor tiles wastes. Thus, the current study focuses on the mechanical characterization of waste ceramic wall and floor tiles aggregate concrete. Ceramic wastes sourced from construction and demolition wastes were separated from other debris and crushed using a quarry metal hammer. Ceramic tiles were sieved into fine and coarse aggregates in line with standards. Other materials used were gravel, river sand, cement and potable water. Workability of the fresh concrete was checked through slump test, and concrete cubes of 150 mm dimensions and cylinders of 100 mm × 200 mm were cast in the laboratory. After 24 h of casting, the concrete samples were demolded and were cured by immersion in water tank at temperature of 22 °C. The compressive and split-tensile strengths of the hardened concrete samples were determined after curing them for 3, 7, 14 and 28 days. Results showed that both the compressive strength and split tensile strength increased appreciably with the curing age than the conventional concrete.

Introduction

Ceramic products are part of the essential construction materials used in most buildings. Some common manufactured ceramics include wall tiles, floor tiles, sanitary ware, household ceramics and technical ceramics. They are mostly produced using natural materials that contain high content of clay minerals. However, despite the ornamental benefits of ceramics, its wastes among others cause a lot of nuisance to the environment. As a general note, Omole and Isiorho [1] reported the

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devastating influence of solid wastes in the Nigerian community. Ceramic wastes are separated into two categories in accordance with the source of raw materials [2]. One category is formed through generated fired ceramic wastes by structural ceramic factories that use only red pastes for product (brick, blocks and roof tiles) manufacture. The second encompasses fired ceramic wastes which are produced in stoneware ceramic (wall, floor tiles and sanitary ware). Meanwhile during ceramic production, studies have shown that about 30% of the material goes to wastes [3,4], and currently they are not beneficially utilized. This attests to the need for exploring innovative ways of re-using ceramic wastes. Aggregates constitute about 70% of total constituents in concrete production. The cost is increasing as a result of high demand from rural and urban communities. Numerous researchers have identified ceramics as having the potential to replace natural aggregates [5,6]. Some investigations have suggested that ceramic wastes are good materials which could substitute conventional aggregates in concrete [7–9]. The influence of ceramic tiles wastes on the structural properties of concrete made using laterite was recently investigated [10]. It was reported that ceramic based laterized concrete performed considerably well when compared to the conventional concrete. Overall, ceramic waste utilization can solve problems of aggregate shortages in various construction sites. Moreover it can reduce environmental problems related to aggregate mining and waste disposal. However, most of the previous investigations were carried out using sanitary ware and electrical insulator ceramics, with not much information as regards the use of ceramic floor and wall tiles. Thus, there is a need to explore the usability of ceramic floor and wall tiles, because these ceramic products are produced at different temperatures which invariably determines their microstructures. Consequently, the current study explores the mechanical characterization of concrete made using ceramic floor and wall tiles wastes from construction and demolition sites as partial replacement of natural aggregates.

Materials and methods

Materials

The materials used in this study were ordinary Portland cement CEM I 42.5 grade, conforming to British Standards [11], granite of maximum particle size of 12.5 mm and granulometric modulus of 6.95, river sand of maximum particle size of 4 mm and granulometric modulus of 2.24, ceramic waste coarse aggregates of granulometric modulus of 6.88, ceramic fine aggregate of granulometric modulus of 2.20, and portable water. The water absorption percentages for ceramic and granite, which were obtained from an initial study [12], were 0.55% and 0.23% respectively. Ceramic waste aggregates (CWAs) used in this study (Fig. 1a) were mainly ceramic floor and wall tiles, obtained from construction and demolitions sites within Ota and Lagos, Nigeria. The ceramic waste pieces were crushed and sieved into required aggregate sizes (Fig. 1b), using a mechanical metal hammer and British Standard sieves respectively. As a result of the crushing process and the brittle nature of the CWA, they were angular in shape [13], and also the surface texture appeared rougher than that of sand and normal granite.

Concrete mix proportions

Nine concrete mixes were cast, comprising a control concrete mix (CC) and four recycled concrete mixes, each using ceramic fine aggregates (CFA) concrete: CFA-25, CFA-50, CFA-75 and CFA-100 for sand replacements and ceramic coarse aggregate (CCA) concrete; and CCA-25, CCA-50, CCA-75 and CCA-100 for gravel replacements. Thus, 25%, 50%, 75% and 100% by weight of natural sand and gravel were replaced by ceramic fine and coarse aggregates respectively. A constant water/cement (w/c) ratio of 0.6 by weight was adopted, and its selection complied with the provision of BS8110 [14] to ensure workability and durability of the concrete. Mixture proportion ratios by weight are summarized in Table 1. Concrete mix containing river sand was mixed in saturated surface-dry condition, while the ceramic waste aggregates were mixed in air-dry condition to control its low water absorption [15].

Methods

The ceramic tile wastes and natural aggregates were thoroughly cleansed to get rid of debris from the materials. A 1:2:4 concrete mix of cement, fine and coarse aggregates was adopted, and batching was conducted by weight. For all mixes, one hundred and eight (108) concrete cubes of 150 mm dimensions and cylindrical specimens of 100 mm diameter and 200 mm height were cast respectively. Thus, following the procedures of BS EN 12390-3:2003 [16] and BS EN 12390-6:2001 [17] for determining the compressive strength and split tensile

Fig. 1a Ceramic wall tiles wastes from a demolition site at Ota, Nigeria.

Fig. 1b Ceramic aggregates after crushing and grading.

Table 1 Mix proportions of concretes.

Mix	Cement (kg/m^3)	Fine Aggregates (kg/m^3)		Coarse Aggregates (kg/m^3)		w/c (%)
		River sand	CFA	Gravel	CCA	
CC	92	184	0	368	0	0.6
CFA-25	92	138	46	368	0	0.6
CFA-50	92	92	92	368	0	0.6
CFA-75	92	46	138	368	0	0.6
CFA-100	92	0	184	368	0	0.6
CCA-25	92	184	0	276	92	0.6
CCA-50	92	184	0	184	184	0.6
CCA-75	92	184	0	92	276	0.6
CCA-100	92	184	0	0	368	0.6

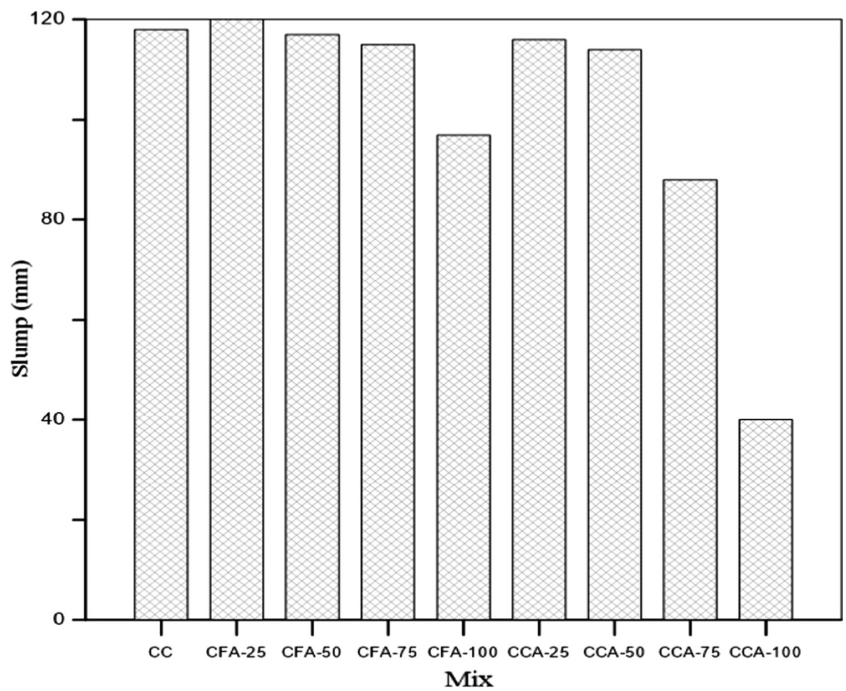

Fig. 2 Slump test results.

strength respectively, cubes and cylinders were tested in triplicates, after 3, 7, 14 and 28 days of curing.

Workability of each of the mixes was measured through slump test according to BS EN 12350-2 [18]. After fresh concrete was placed in molds, the exposed surface of the concrete samples were covered with a perforated waterproof sheet for 24 h, in order to ensure uniform saturation state in the concrete, and then they were demolded and cured in water at 20 ± 20C of room temperature until the test age. ELE compression machine of 2000 kN capacity was used for the strength determination and loading speed was maintained at 0.2 N/mm^2/s.

Results and discussions

Slump test

Slump test results of the fresh concrete mixes are presented in Fig. 2. The results indicate medium to high workability for mixes CC, CCA-25, CCA-50, CCA-75 CFA-25, CFA-50, CFA-75 and CFA-100, where their slump values ranged from 80 to 120 mm. According to BS8500 [19], samples within this slump range are in S2 and S3 categories, which are suitable for simple strip footings and cast in-situ hard-standing slabs or trench-filled foundations. However, workability of mix CCA-100 was low, with slump value of 40 mm. This low slump could be attributed to the glazy surface of the coarse ceramics, which did not bind well with other materials in the mix.

Compressive strength

Compressive strength of the hardened concrete was determined in alignment with the provision of BS EN 12390-3 [16]. Figs. 3 and 4 respectively show the compressive strength for CCA concrete and CFA as each varies with content (0%, 25%, 50%, 75% and 100%) for 3, 7, 14 and 28 days. As shown in Fig. 3, compressive strength increased with increasing CCA substitution. There was about 36.1% strength gain in concrete with 100% CCA when compared with the control mix at 28 days. At all testing ages, CCA mixes yielded higher strength

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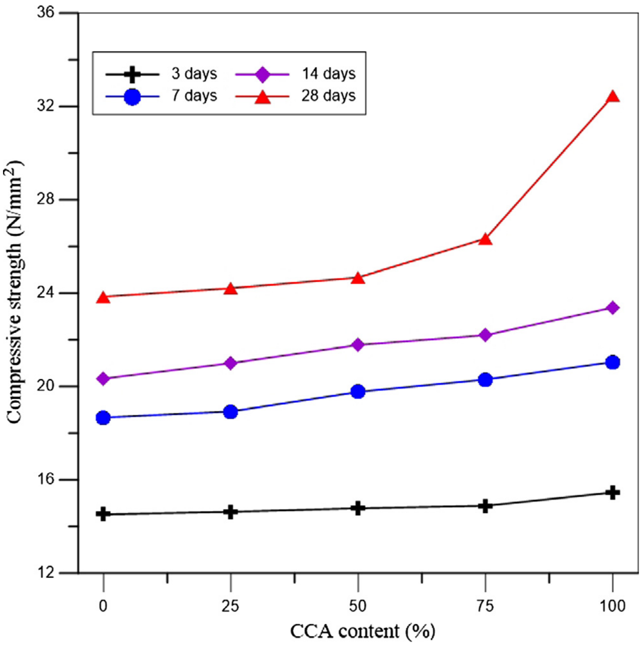

Fig. 3 Compressive Strength development for ceramic coarse aggregate (CCA) replacements.

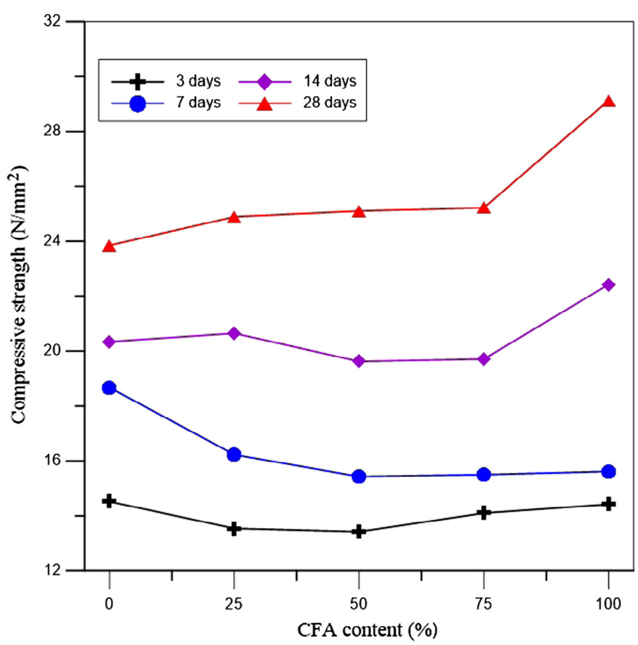

Fig. 4 Compressive Strength development for ceramic fine aggregate (CFA) replacements.

than the control concrete, a fact which could be traced to the irregular shape and rough surface of CCA, and this enhanced adequate bonding effect between aggregates and hardened cement paste [20,21].

Another author [22] corroborated that ceramic replacement of natural gravel increases compressive strength. On the other hand, for concrete with CFA substitution, the compressive strength result was not consistent. Control concrete developed early (3 and 7 days) strength than the CFA concretes, but as the curing age increased, the compressive strength of CFA concrete was higher than that of the control concrete.

The compressive strength of the CFA concretes increased as the percentage of substituted aggregate increased, by up to 22.1% with a substitution of 100%. The positive result could be due to influence of high water absorption of ceramics and moreover due to the pozzolanic activity of ceramic micro particle- when combined with cement compounds. Generally, the CCA graph shows the most substantive results: the compressive strength increased considerably with ceramic coarse aggregates over the control or normal concrete, the more the percentage of the gravel-size materials are replaced by the ceramics. Figs. 5 and 6 show the same graphs but with the size in the ordinate axis (compressive strength/compressive strength for normal concrete).

Split tensile strength

The split tensile strength is another method for determining performance of concrete under tensile stress and also gives its progressive cracking pattern [23]. The test was conducted in accordance with the provision of BS EN 12390-6 [17].

Similar to Figs. 3–6 on compressive strengths, Figs. 7–10 show parallel graphs for split tensile strengths. The graphs show similar patterns, only smaller in nature.

The split tensile strength results of concrete mixes with ceramic coarse aggregate substitution and ceramic fine aggregate substitution are shown in Figs. 7 and 8 respectively. For the CCA concrete, split tensile strength increased with increasing CCA. This result is synonymous with other findings. Medina et al. [8] obtained similar results with concretes made by replacing natural aggregates with ceramic sanitary ware aggregates. It can be seen that the control concrete developed early

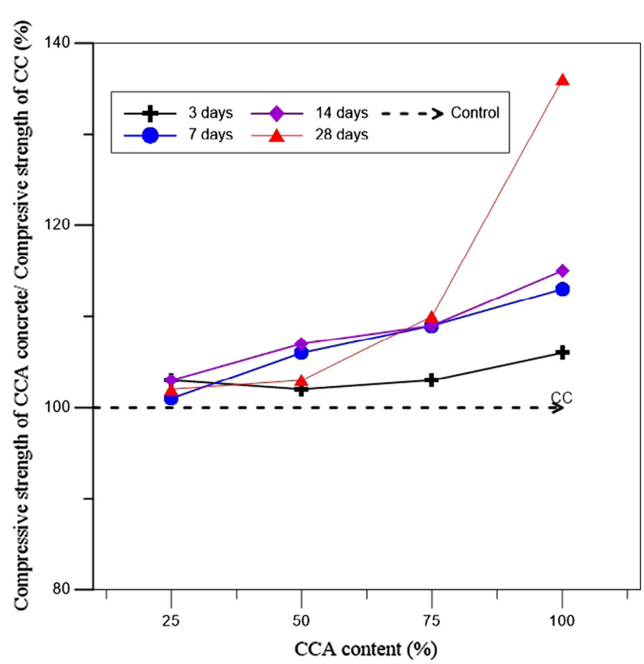

Fig. 5 Relative compressive strength for CCA concrete.

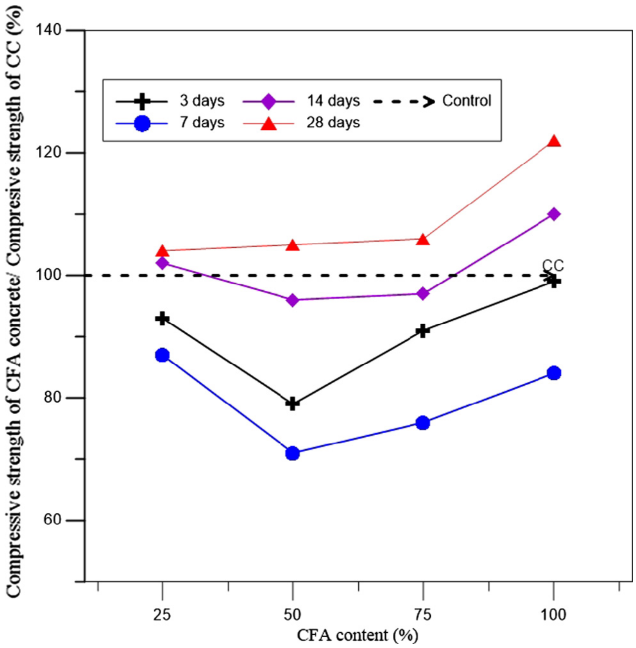

Fig. 6 Relative compressive strength for CFA concrete.

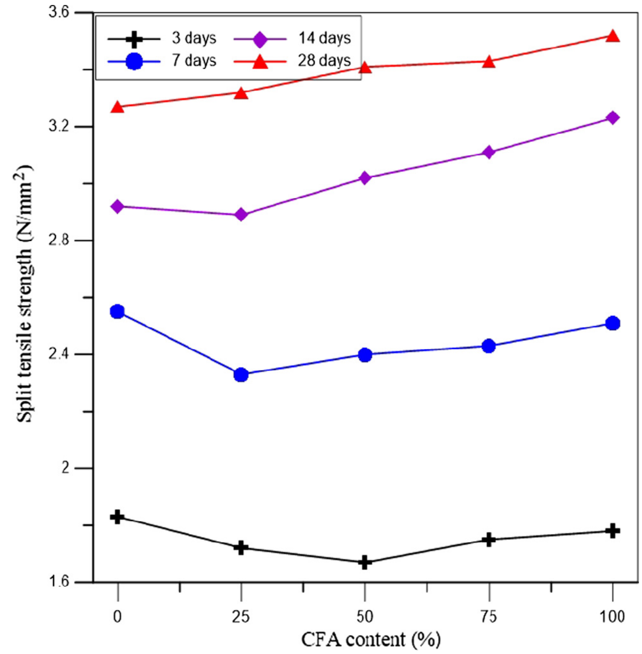

Fig. 8 Split tensile strength development for ceramic fine aggregate (CFA) replacements.

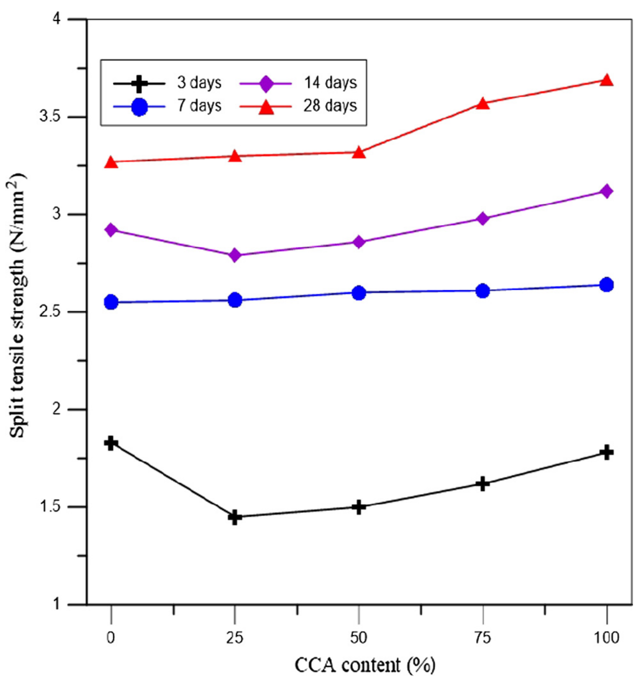

Fig. 7 Split tensile Strength development for ceramic coarse aggregate (CCA) replacements.

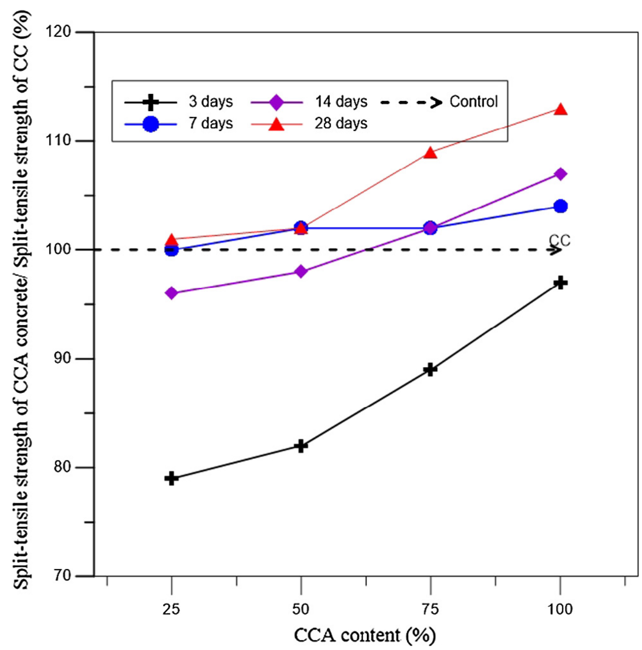

Fig. 9 Relative split tensile strength for CCA concrete.

(3 and 7 days) split tensile strength than the CCA concrete. On the other hand, for concrete with CFA, split tensile strength was adequately developed between 14 and 28 days of curing age, which yielded results between 2.8 N/mm^2 and 3.6 N/mm^2. Studies have indicated that inclusion of ceramic aggregates causes a refinement of the pore system, increasing the volume of capillary pores and decreasing the volume of macropores [3]. However, other investigations on the use of ceramic sanitary ware [5,24], contradict the results obtained regarding ceramic floor and wall tiles wastes, whereas, some other investigations [25,26] revealed that there is no difference between the strength properties of CWA concrete and the conventional concrete. This variation could be as a result of different conditions adopted during production of different ceramic products.

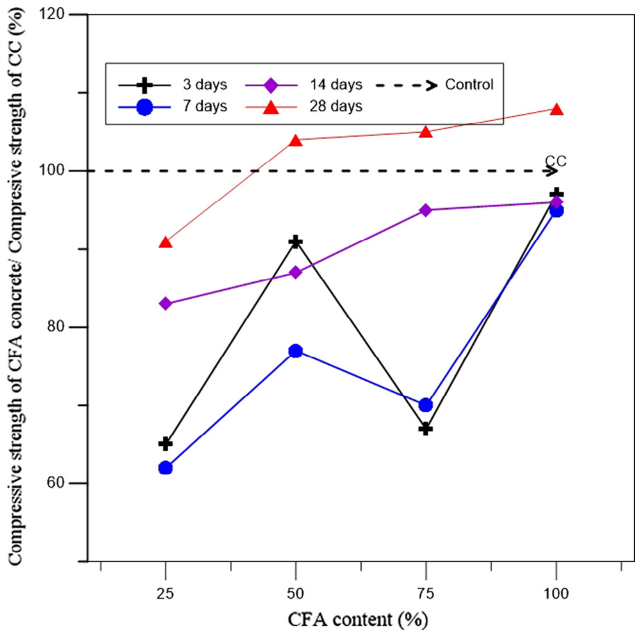

Fig. 10 Relative split tensile strength for CFA concrete.

Conclusion

This study evaluated the mechanical characterization of ceramic waste aggregate (CWA) concrete, in an attempt to ascertain its suitability construction. The workability of CWA concrete was comparable to the control concrete, which ranged between medium and high workability. That for CCA-100 mix (ceramic coarse aggregate with 100% ceramic coarse), was an exception. Overall, the mechanical performance of the CWA concretes was better than that of the control concrete. The highest compressive strength and split tensile strength were achieved by replacing 100% of the natural aggregate with CCA and ceramic fine aggregate (CFA) individually. The mechanical properties of CWA concretes improved as the replacement percentage of natural aggregates increased.

It can be concluded that, within the limited scope of the experiments carried out in this investigation, concrete made with CWA as a replacement for part of the natural aggregates can be considered a suitable alternative for normal concrete. In fact, where strength is concerned, it is even more suitable than conventional concrete.

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