Construction and Building Materials 136 (2017) 533–540

Contents lists available at ScienceDirect

Construction and Building Materials

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

Experimental investigation of Peruvian scallop used as fine aggregate in concrete

Christian Varhen *, Shirley Carrillo, Gaby Ruiz

University of Piura, Department of Civil Engineering, Av. Ramón Mugica 131, Urb. San Eduardo, Piura 353, Peru

HIGHLIGHTS

- Effect of using Peruvian scallop crushed seashell (CSS) in concretes were tested.
- Use of CSS as replacement of fine aggregates (FA) in concrete were discussed.
- Properties of fresh and hardened concrete with CSS as (FA) were evaluated.
- Replacement levels of FA by CSS depend on the w/c ratio used in concrete.
- Replacement levels of FA by CSS depend on given size of CSS particles.

ARTICLE INFO

Article history:
Received 12 August 2016
Received in revised form 18 December 2016
Accepted 21 January 2017

Keywords:
Seashell by-products
Seashell concrete
Fresh concrete
Compressive strength

ABSTRACT

To evaluate the impact of using Peruvian scallop crushed seashell (CSS) as fine aggregate a range of 0.75, 0.55, 0.45 and 0.41 w/c ratio concretes were tested. The hardened and fresh properties of concrete at 7, 28 and 90 day periods were investigated. The experimental results show that the effects of CSS replacement on concrete properties depend on the size particle distribution of the global aggregate after replacement, and that the angular shape of CSS particles can contribute to a better arrangement. The maximum level of CSS replacement is variable and limited to a maximum for a given size of CSS particles and a w/c ratio. A maximum of 40% replacement can be suggested in a range of 1.19–4.75 mm CSS particle size, but 5% can be considered optimal for all cases. It means that cleaned CSS can be used as fine aggregate replacement in conventional concretes.

1. Introduction

Oyster farming is an expanding economic activity worldwide [1]. In Peru, Peruvian scallop (Argopecten purpuratus) is one of the most important species to be cultivated [2], and it is now exported to China, the United Kingdom, Canada, Iceland, Australia and Chile [3]. In Sechura, Northern Peru, more than 80% of national production is managed, and up to 25,000 metric tons (MT) of empty hard seashell is discarded annually as waste in municipal landfills [4]. Considering that at least 70% of the mollusk extracted is valve residue, this activity generates thousands of tons of seashell by-products that are considered as waste [5,6]. These residues are accumulated in open-dump sites, where it becomes a source of environmental damage and pollution due to unpleasant odors, insects and fungi [7–14].

More effort is needed to find uses for this waste in such a way as to reduce environmental problems [1,8–15].

Using waste materials in civil engineering offers a low energy consumption alternative to recycling [14,16]. Unless the construction industry can resolve the ongoing environmental problems caused by its continuous exploration and depletion of natural resources, and the various toxic substances that are invariably emitted into the atmosphere during the manufacturing process of construction materials [16], industrial waste (inorganic) can be used as fine and coarse aggregates and help to reduce these impacts [17]. Recent experiences in Brazil have demonstrated that seashell residues washed, sun dried and crushed can be used in concrete pavement block production [14].

On the other hand, the cost of concrete is a concern that needs to be considered carefully. In places where natural aggregates are very difficult to obtain or environmental limitations increase their costs, the use of seashell wastes can be a considerable reduction in concrete costs. However, in places where natural aggregates are quite accessible, the use of these wastes in concrete is not cheaper

* Corresponding author.
E-mail address: christian.varhen@udep.pe (C. Varhen).

http://dx.doi.org/10.1016/j.conbuildmat.2017.01.067
0950-0618/

because the costs of cleaning and transporting seashell can be higher than natural aggregates [1], making the environmental consideration to reduce the pollution the only important concern. For example, in the coastal Bayelsa State, Nigeria, waste shells are used as replacement for granite, and as coarse and sand aggregate in mortar or light concrete as a traditional solution for the lack of aggregates [7].

Here, different seashell specie of mussels unlike other authors is used as sand replacement in three concrete mixtures with different w/c ratios. Four different levels of replacement (5%, 20%, 40%, and 60%) in a range of 4.75–1.19 mm of particle size of CSS are used. The workability, air content, unit weight, setting time, compressive strength and traction strength have been analyzed. The differences with other authors are highlighted and experimental results are presented.

1.1. Literature review

Some research has been undertaken on the use of waste seashell materials in civil engineering. Research using periwinkles, crushed scallops and crepidula shells as aggregate replacements in concrete have been carried out [8,10,11]. The general findings reveal that waste seashell does not affect the cement hydrate and only performs a role as filler in concrete matrix [11]. In addition, crushed seashells can be used as a fine aggregate replacement, whereas the coarse aggregate replacement seems to be less effective because the excessive flakiness of the particles. In both cases, angularity of the particles of shell requires more proportion of cement paste to make for effective bonding with aggregates [8,18]. This matter is the main concern that determines the maximum level of replacement of CSS in concrete to produce a concrete without reducing the workability nor compressive strength.

On the other hand, the salt content and chloride ion presence in seashells can be harmful to concrete and needs to be removed. Some soil and marine debris in the seashell waste should be properly washed before being used. In all cases, a process of washing with water and drying in a dryer at ±110 °C is used. Simplest process of cleaning needs more evaluation for reducing energy consumption.

Size of CSS particles used as sand replacement requires special consideration because flakiness of particles depends on thickness of mussels. The shells are essentially layered rock, whose thickness, strength and density differ from one species to another [19,20]. In crushing process, shells are separated in foliated layers and particles in high sizes can be some cubic, but when crushed in small, particles tend to be fine and thinner, as needles. Yoon et al. [12] found that even though chemical composition is similar for various oyster-shells, physical properties such as texture, porosity, specific surface and apparent density are different even in an oyster-shell.

Yang et al. [11] evaluated different percentages (5, 10, 15 and 20%) of dry crushed oyster shells as fine aggregate replacement in concrete production (less than 5 mm size). They found that the workability of the concrete measured as slump test, decreased when the substitution rate of oyster shell increased [11]. Similar results involving workability were found by other authors [8,9,11,17,21], even if it is used as concrete or mortar. In all cases, though, the angularity of seashell particles and changes in the finesse modulus (FM) of fine aggregate after substitution seem to be the main factors of influence. The causes of this behavior are not clear. Variation registered are not significant and are attributed by author to changes on FM or high absorption of oyster shell compared to natural aggregates, but detailed data about aggregates used in researches is not presented and cannot be verified.

On hardened concrete, results are also variable. Yang et al. [11] also found that the compressive strength of concrete at 28 days was not significantly reduced, or in some cases increased, by the oyster shell replacement; however, in the long term (until 365 days), compressive strength decreased significantly [10]. Safi et al. [17] found that compressive strength is slightly reduced at 28 days when it is used as fine aggregate in self-compacted mortars. Richardson et al. [8] found similar results, replacing both coarse and sand aggregate in conventional concrete. Kuo et al. [9] and Yang et al. [11] both found that a replacement of 5% makes a significant increase of compressive strength at 28 days and reduces as replacement is continuously increased.

The maximum replacement rate to limit the impact on workability or compressive strength of concrete is also variable, but it seems to be related to the particle size of the crushed shell. Some authors limit the replacement rate to 20% considering the salt content [11]. Richardson et al. [8] limits the replacement rate to 10% of both 20 mm and 4 mm sized particles considering compressive strength reduction, but 5% is not evaluated; Safi et al. [17] suggest 100% replacement of 5 mm size particles and Kuo et al. [9] limit the rate to 5% of 4.75 mm size particles considering the compressive strength reduction too. Wang et al. [13] suggest using 5–10% as sand replacement, but up to 40% still meets specifications for a normal concrete. Yoon et al. [12] suggest up to 40% of sand replacement in soil mortar based on compressive strength reduction, but 5% is not evaluated. It seems that the 5% of replacement, independent of the particle size, offers a good enough arrangement of particles that maintain a good workability and a better compressive strength of concrete, compared to original one. There are other properties to hardened concrete such as porosity, absorption, water permeability and resistance to chloride-ion penetration that seem to be related to the particle size of crushed seashell, hardness of the shell and other structural compositions of the valve [5,10,11,21].

Table 1 shows the properties of different seashell material when used as aggregate in the literature cited above. As can be seen, properties such as finesse modulus and particle porosity can change with crushing size, but specific gravity and absorption also changes from one species to another.

Yoon et al. [12] also demonstrated that specific gravity depends upon the degree of crushing. As the size decreases, the value of specific gravity approaches that of calcium carbonate, but it always remains lighter than sand. This variability on the properties can support the idea that different species of seashell will promote different behavior in the same concrete.

In previous research, workability reduces because they use a crushed seashell finest compared than natural sand and include particles less than 1 mm of size. If crushed seashell is coarser than natural sand used in control samples and small particles are retired, workability could improve. Cuadrado et al. [21] confirms this improvement because uses a CSS coarser than sand, but includes grains smaller than 1 mm and includes organic matter from the CSS. This organic matter has a significant effect on final properties of fresh and hardened concrete.

Additional, w/c ratio influences the effect of the CSS replacement. Yang et al. [11] uses a w/c ratio of 0.45 with no significant effects on the workability nor the compressive strength. Cuadrado et al. [21] uses a w/c ratio of 0.60 and found significant reduction on concrete properties. The content of aggregates in the mixture is low if w/c ratio is low too. In consequence, in concretes with low w/c ratio any change on aggregates configuration has less impact on the final properties than those with high w/c ratios.

In this research, crushed Peruvian scallop valve with a higher FM than natural sand without particles less than 1 mm of size is used as a fine aggregate replacement in conventional concretes from 21 to 32 MPa of compressive strength for structural applications, using the simplest cleaning and crushing process with minimal energy consumption. The three control concrete mixtures