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Study on Strength and Volume Stability of Coral Mortar

Qingzong Xue [a], Zhuqing Yu [a*], Xiaodong Shen [a, b]
a College of Materials Science and Engineering, Nanjing Tech University, 211816, Nanjing, P. R. China

b The synergetic innovation center for advanced materials, 211816, Nanjing, P. R. China

ABSTRACT

The continuous construction of islands and reefs requires a large amount of traditional building materials, such as cement, sand, and aggregate. Rational utilization of local coral reef sand is conducive to reduce the environmental loading, construction costs and project duration. A lot of research has been carried out about the use of coral aggregate in concrete, such as mixture design, mechanical properties and durability. As we known, the workability and volume stability are extremely important parameters to study the mechanical properties, even the durability of coral concrete. In this study, the flowability and length change of coral mortar are investigated firstly. Since coral sand has large porosity and high water absorption, the coral sand is used with the same volume of standard sand. Furthermore, 15% coral sand powder (CSP) and 15% limestone powder (LSP) is used to replace cement partially in order to reduce the use of cement, respectively. The study of length change of coral mortar includes the determination of wet expansion and drying shrinkage.

1. INTRODUCTION

With the development and utilization of marine resources, the construction of island projects is accelerating. Concrete has the advantages of low cost, good durability and convenient maintenance [1]. It is the most widely used building material in the process of island development and construction, such as pavement, building and port [2]. It is well known that the content of sand and gravel in concrete exceeds 70% by weight. That is time-consuming and resource-consuming to ship raw materials to island, since most islands are far away from the mainland. Therefore, it is of great significance for the development and construction of the island to find alternative aggregate.

In the tropical marine climate, coral reef sand resources are abundant [3]. The main composition of coral reef sand is calcium carbonate with more than 90%, therefore, it is a kind of calcareous sand. The mineral composition of coral reef sand includes aragonite, calcite (magnesium) and dolomite. Coral reef sand is formed by the bones of coral insects and other marine organisms after hundreds of years of accumulation and continuous scouring of seawater [4]. This leads to great differences in particle shape, size and strength of coral reef sand. Coral reef sand has rough surface, large porosity and small elastic modulus, resulting in high water absorption, low strength and easy to be broken [5-7]. Compared with common standard sand, coral reef sand crushed has higher edge angle and worse sphericity [8]. Due to the great difference between coral reef sand and standard sand, the preparation of concrete with coral sand as aggregate has attracted extensive attention of lots of scholars in island engineering construction.

In 1974, Howdyshell [9] pointed out in a report that it is feasible to prepare concrete with coral coarse aggregate, but the chloride concentration in coral aggregate should be controlled. Coral concrete has high early strength, even the 7 days-strength can reach 80% of 28 days-strength [10-12]. Coral sand owns ability of internal curing, which can also promote the hydration of interface transition zone [13]. The strength of coral concrete depends on the strength of aggregate, cement mortar and the interface between aggregate and mortar [14]. Meanwhile, cement paste and coral sand can form a close meshing structure [15]. Furthermore, coral sand can be ground into coral sand powder (CSP) and as mineral admixtures used in cement [16]. CSP can react with tricalcium aluminate and generate carboaluminate phases, which can affect the properties of cement-based materials.

At present, the demand for cement mortar is more extensive, such as revetment, retaining wall and grouting hole, etc. Therefore, the aim of this paper is to study the fluidity, mechanical properties and volume stability of cement mortar with coral sand as aggregate. Standard sand is used as reference. In addition, the effect of CSP is also taken into account and compared with limestone powder (LSP).

2. Experiments

2.1 Raw materials

The used cement is a kind of P I 42.5 cement with a specific surface area of 354 m^2/kg, produced by Fushun Cement Co., Ltd., China. Limestone powder

(LSP) was obtained from grinding limestone in a ball mill for 20 min. The used coral sand powder (CSP) was produced by milling waste coral sand for 5 min. The chemical compositions of cement, CSP and LSP are listed in Table 1. The particle size distributions of PC, CSP and LSP are shown in Figure 1, respectively. The median particle size (d_{50}) of PC, CSP and LSP are 14.49 μm, 22.17 μm and 14.84 μm, respectively. By using X-ray diffraction (XRD) analysis, the XRD patterns of CSP and LSP were presented in Figure 2. It is clear that the main minerals phase of CSP and LSP is aragonite and calcite, respectively. The used coral sand was made by crushing and screening the coral reef based on the particle distribution of ISO standard sand. The fineness modulus, bulk density and water absorption of coral sand and standard sand are listed in Table 2. Furthermore, from Figure 3. it can be seen that coral sand has some coarse porous and standard sand is with smooth surface.

Table 1. Chemical composition of PC, CSP and LSP, wt/%

Composition	Cement	Coral sand powder	Limestone powder
CaO	63.4	48.69	55.28
MgO	1.93	1.55	0.698
Al_2O_3	4.87	1.14	0.0568
SiO_2	21.04	3.78	0.146
Fe_2O_3	3.52	0.379	0.0792
SO_3	1.98	0.517	0.0263
K_2O+Na_2O	0.65	0.573	0.0099
TiO_2	0.33	0.0722	0.0066
Cl	--	0.0462	0.0167
LOI	1.5	42.49	43.63

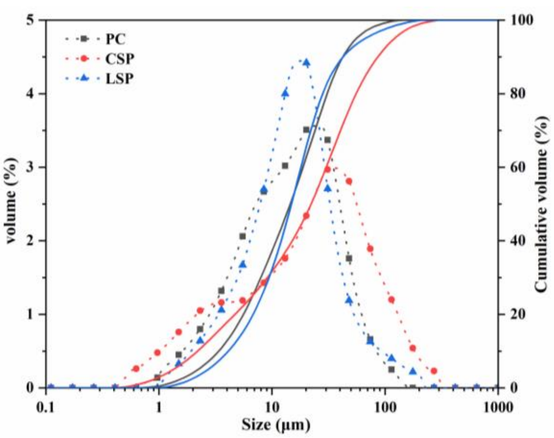

Figure 1. particle size distribution of PC, CSP and LSP

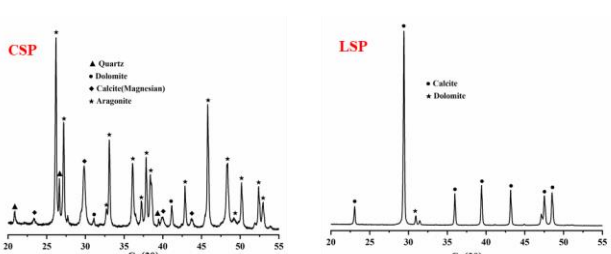

Figure 2. XRD pattern of CSP and LSP

Table 2. Physical properties of coral sand and standard sand

Aggregate type	Coral sand	Standard sand
Fineness modulus	2.69	2.32
Bulk density (kg/m^3)	1134.1	1568.4
Water absorption (%)	32.59	15.47

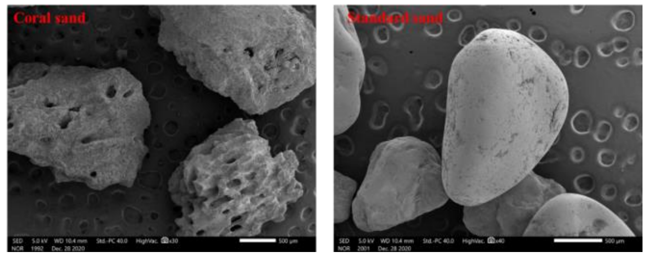

Figure 3. SEM figures of Coral sand and standard sand

2.2 Specimen preparation and test methods

Since coral sand is lighter than standard sand, in this study coral sand and standard sand were used with the equal volume. The mix proportion design is listed in Table 3. The used water to binder (w/b) ratio is 0.6 for all samples. All cement mortar samples were prepared according to GB/T 17671-1999.

2.2.1 Fluidity test

According to GB/T2419-2005, the fluidity of mortar was carried out for all samples.

2.2.2 Strength test

According to GB/T 17671--1999, the compressive strength and flexural strength of specimens were determined with an AEC-201-type automatic cement strength testing machine. The curing time is 3, 7, 28 and 90 d, respectively.

Table 3. The design of mix proportion

Sample Number	B-1	B-2	15CSP	15LSP
Sand type	Standard sand	Coral sand	Coral sand	Coral sand
Sand weight (g)	1350	1000	1000	1000
PC (%)	100	100	85	85
CSP (%)	0	0	15	0
LSP (%)	0	0	0	15

2.2.3 Wet expansion and dry shrinkage test

The preparation of wet expansion and dry shrinkage specimens is based on JGJ/T 70-2009. After curing for 24 h, the mortar samples for wet expansion test were demolded. The length of sample was determined as the initial length. Then, all samples were curd in 20±1℃ water for 1, 3, 7, 28, 56, 90, 120, 150 and 180 d, respectively. The dry shrinkage mortar specimens were cured with molds for 7 d. After demolding, all specimens were immediately put into the curing box at the temperature of 20±1℃ and relative humidity of 60±5%. After 4 h, the length of specimens was measured as the initial length. Then, the samples were put into the drying shrinkage box for 7, 14, 21, 28, 56 and 90 d respectively. The wet expansion and dry shrinkage of mortar are calculated as follows:

$$\varepsilon_t = \frac{L_0 - L_t}{L} \times 100\% \qquad (1)$$

Where, εt is the wet expansion rate and dry shrinkage rate of the sample at t time; L0 and Lt are the initial length of the sample and the length at t time, respectively; L is the length of the mortar sample minus the length of the nail head embedded in the mortar.

3. Results and discussion

3.1 Mortar fluidity

As shown in Figure 4, the fluidity of B-1 exceeds 300 mm and the fluidity of B-2 is around 150 mm. With the same w/b ratio of 0.6, the fluidity of coral mortar is much lower than standard sand mortar. One reason is that coral sand has sharp edges and corners, producing internal friction in the fresh mortar, and consequently resulting in the reduction of fluidity. Furthermore, coral sand is porous and rough. It requires more cement paste wrapping and it can absorb more water. In Figure 4, it can be seen that the addition of CSP and LSP in coral sand mortar can increases the fluidity of mortar since the effective water to cement ratio is increased.

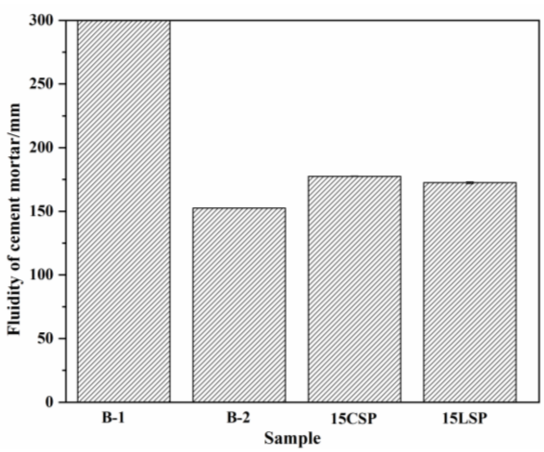

Figure 4. Fluidity of cement mortar

3.2 Mechanical properties of mortar

Figure 5 shows the flexural strength of mortar at different curing ages. As expected, the flexural strength of all samples increases rapidly from 3 to 28 d, and then flattens after 28 d. B-2 sample shows higher flexural strength than B-1 sample at each curing age. During mixing, cement paste can fill in the holes of coral sands. This can form a tight meshing structure in the interfacial transition zone and enhance the interfacial adhesion. In addition, coral sand owns water absorption and water return. At the initial stage of hydration, coral sand absorbs water decreasing the accumulation of water at the interface transition zone. The incorporation of 15% CSP and 15% LSP in the mortar decreases the flexural strength slightly.

The development of compressive strength of samples with curing time is shown in Figure 6. At the curing age of 3 and 7 d, the compressive strength of coral sand mortar is higher than that of standard sand mortar. After 7 d, the compressive strength of B-1 comes up with that of B-2. Although coral sand mortar shows appropriate fluidity and higher flexural strength at later ages, the low strength of coral sand lowers the compressive strength of coral and mortar. Since CSP and LSP mainly shows the dilution effect in the whole system, which results in the decrease of the compressive strength.

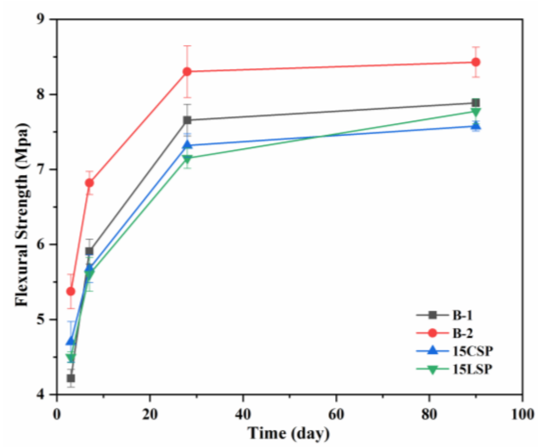

Figure 5. Flexural strength of cement mortar

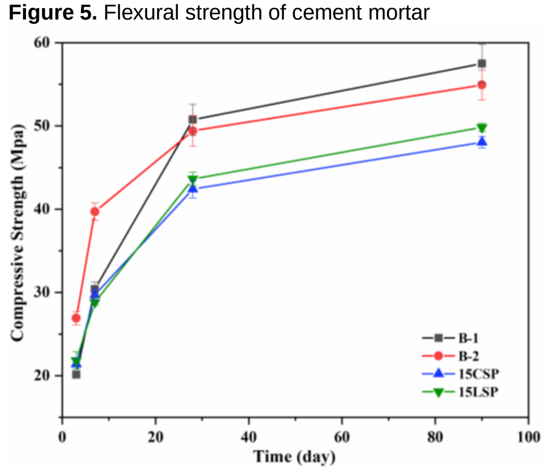

Figure 6. Compressive strength of cement mortar

3.3 Wet expansion of mortar

It is well known that cement-based material can expand in humid environment [17]. Under water curing condition, the volume change of mortar sample is determined and shown in Figure 7. From Figure 7, it can be seen that the wet expansion process can be divided into three stages. From 1 to 28 d, there is fluctuation in length change over time due to the continuous hydration of cement. But the expansion rate is little. From 28 to 60 d, the length change increases dramatically. The mortar absorbs water and expands [18], since in this period the hydration rate of cement tends to slow and the internal structure of mortar is basically stable. The expansion phenomenon of coral mortar is obvious than that of standard mortar. Coral sand has more porosity and smaller elastic modulus compared with standard sand. This can lead to easier water absorption and greater expansion of coral mortar. After 60 d, the length change of all mortar speicmens is basically stable. The sample of 15CSP and 15LSP has the similar development of length change, which is higher than other two samples. As mentioned above, the addition of CSP and LSP in cement can produce calcium carboaluminate. These reaction is a process of volume increase and volume expansion.

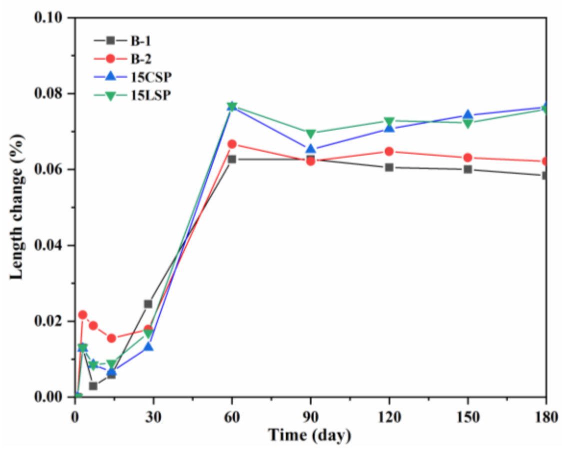

Figure 7. Wet expansion of cement mortar

3.4 Drying shrinkage of mortar

Drying shrinkage is caused by the decrease of water in the pores of hardened cement-based material. When the cement-based material is in a dry environment, the water in the pores forms a meniscus, then the particles are pulled closer to each other under the action of capillary force [19]. Drying shrinkage of all samples increases with the curing ages. That is due to the continuous water loss in the pores of samples. Figure 7 shows the change of drying shrinkage with time for two groups. From 1 to 28 d, the water loss rate is faster and the drying shrinkage rate is large, since all specimens contain a lot of free water and the internal humidity is high. It's worth noting that the drying shrinkage rate and value of B-1 are lower than coral sand mortar. One side, the poor fluidity of fresh coral mortar leads to low compactness and high porosity of coral mortar. Moreover, Coral sand has a lower elastic modulus than standard sand. From 28 to 90 d, the mortar drying shrinkage rate decreases due to the decrease of free water content and internal humidity. During this period, the water return of coral sand enables the coral mortar to maintain high humidity for a long time. Therefore, the drying shrinkage of coral mortar can be maintained at a high shrinkage rate. The addition of CSP and LSP can improve the particle gradation, which reduces the porosity, improving the coral sand mortar drying shrinkage.

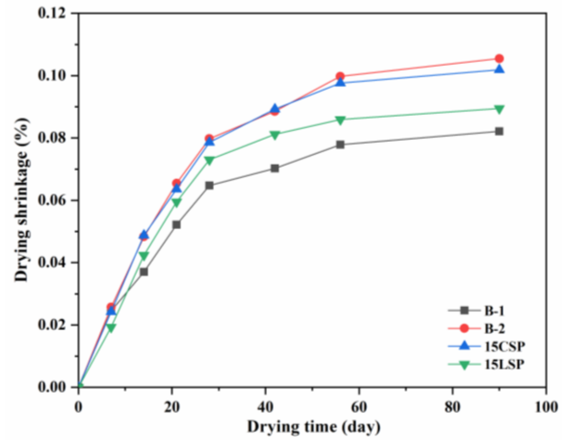

Figure 8. Drying shrinkage of cement mortar

4. Conclusions

This paper investigated the fluidity, mechanical properties and volume stability of coral mortar. Furthermore, the effect of CSP on these properties of coral mortar was also studied compared with LSP, The following conclusions can be drawn:

1)The rough and porous structure of coral sand makes the fluidity of coral mortar very poor. The addition of CSP and LSP improves the fluidity of mortar.

2)The compressive strength of coral mortar develops rapidly from 3 to 7d, and the 7d strength reaches 80.34% of the 28d strength. After 7 days, the compressive strength of B-2 is lower than that of B-1. In addition, the flexural strength of coral mortar is always higher than that of standard sand mortar.

3)The volume stability of coral mortar is poor. Compared with standard sand, the coral sand mortar is large wet expansion and dry shrinkage. The return water effect of coral sand can prolong drying shrinkage time of coral mortar. CSP and LSP have the same effect, reducing drying shrinkage and increasing wet expansion.

Acknowledgments

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