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# Evaluating feasibility of using sea water curing for green artificial reef concrete

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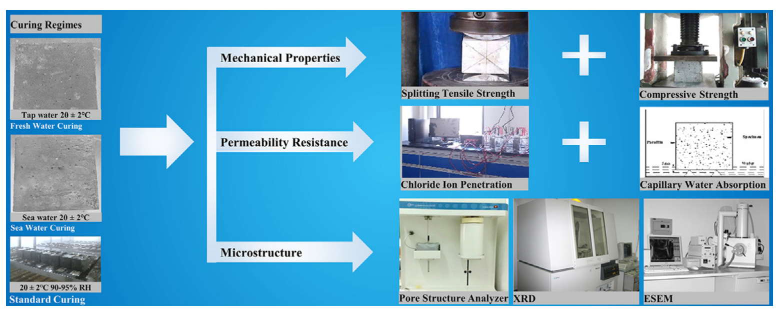
## HIGHLIGHTS

- The feasibility of sea water curing is evaluated for green artificial reef concrete.
- The studied curing regimes have few effects on mechanical properties.
- Sea water curing slightly reduces permeability persistence of concretes.
- The microstructure is discerned with ESEM, XRD, and pore structure analyzer.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Sea water curing (SWC, 20 ± 2 °C) has been proposed to obtain economic benefits for green artificial reef concrete (GARC) in coastal areas. This study evaluated the feasibility of SWC based on the mechanical properties and permeability resistance of GARC. Three curing regimes were used: SWC (20 ± 2 °C), standard curing (SC, 90–95% relative humidity at 20 ± 2 °C), and fresh water curing (FWC, 20 ± 2 °C). The results showed that there were little effects on compressive strength and splitting tensile strength of GARC under the three curing regimes. In addition, SWC slightly increased the permeability of GARC. SWC appeared to be an effective technique to cure GARC in marine environments, which was further confirmed by evaluating the microstructure using environmental scanning electron microscope, X-ray diffractometer, and pore structure analyzer.



## 1. Introduction

Artificial reefs (AR) are man-made benthic structures intended to provide habitats for marine organism [1]. The benefits of AR include economic, environmental, and social dimensions, from improving fishing production, restoring marine ecological conditions, and developing tourism and recreational activities [1–3]. Therefore, the AR technology is applied widely and considered as a sustainable solution in marine ecosystems.

The materials for AR differ in steel vessels and barges, natural rocks, industrial wastes, and concrete blocks [4,5]. Among these, artificial reef concrete (ARC) is acknowledged to be the most widely used material due to its flexible shape, high strength, and convenient construction and transportation process [4,5]. However, the limited constructed materials in coastal areas, such as fresh water and river sand, improve the economic cost of ARC. In addition, the high surface pH value of ARC, which is commonly constructed by Portland cement, hinders the habitats of the marine organism at the early 6-month age [4,6]. To achieve economic

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benefits and decrease the surface pH value of ARC, a green artificial reef concrete (GARC) was proposed in our previous work, which was made with sulphoaluminate cement (SAC), marine sand, sea water, and admixtures [4]. In particular, the environmental benefits of the proposed GARC were achieved by the application of SAC with low emission of $CO_2$, and locally available marine sand and sea water.

Curing is essential to improving water holding capacity of concrete and ensuring sufficient moisture for cement hydration [7–15]. A properly cured concrete has better surface hardness and durability, lower permeability, and smaller plastic shrinkage [7,8]. For the different components of concrete, the curing regimes have different influence on the mechanical properties and microstructure. Sajedi and Razak [7] studied the effect of curing regimes and cement fineness on compressive strength of ordinary Portland cement (OPC) mortars. The results showed that the specimen (grounded OPC for 6 h) under water curing achieved the highest compressive strength, while the lowest compressive strength was achieved by the specimen under air curing at room temperature after heating (60 °C) for a 20-h duration (WH/ac).

Sajedi et al. [8,9] investigated the influence of curing regimes and duration on compressive strength of OPC-slag mortars. The results concluded that the compressive strength of all mortars was affected significantly by curing regimes and their durations. With a duration of 3–7 d, the optimum curing regime was WH/ac for all mortars, but for a long-term duration (28–90 d), the optimum curing regimes of all mortars were different. Researchers studied the influence of curing regimes on the performance of concretes incorporating silica fume (SF) and fly ash (FA) [10–13]. The results showed that water curing contributed the highest compressive strength of concrete, and air curing reduced the compressive strength. With the increasing dosage of FA, the concrete showed more sensitive to poor curing than the standard moist-curing [10]. In addition, liquid paraffin wax curing was effective on flexural strength of all mortars with SF and FA [13].

Hiremath and Yaragal [14] reviewed the compressive strength of reactive powder concrete (RPC) under various curing regimes, including autoclave, thermal, and normal curing conditions. The results showed that autoclave curing contributed the highest compressive strength of RPC, which differed in applying pre-setting pressures and temperatures. The disadvantages of autoclave curing were noted, such as reduced bond strength (up to 50%) between concrete and reinforcement compared to normal curing, porous and weak microstructure of concrete. In addition, thermal curing had strong influence on strength growth for RPC, and normal curing showed slow strength development and hardening process of RPC.

Sea water curing (SWC) was explored to promote the use of sea water in coastal areas and to reduce the cost of GARC in our previous work [4,16]. However, the performance of GARC under different curing regimes was not conducted, and there is a need to evaluate the feasibility of using SWC. In addition, based on the preceding review, previous studies focused only on the effect of curing regimes on the properties of Portland cement-based concrete, and limited work was conducted on the evaluation of SAC-based concrete under various curing regimes.

The purpose of this study is to investigate the effect of various curing regimes on the mechanical properties, permeability resistance, and microstructure of SAC-based GARC. Three curing regimes were used in this study, including SWC, fresh water curing (FWC), and standard curing (SC). Among these, SC is considered the most effective curing technique for ordinary concrete since the exposed surface is continuously sprayed with water to keep the proper humidity, which is the ideal condition for cement hydration and strength development [7]. For this reason, SC was considered as the control curing in this study, and the comparison of the mechanical properties and permeability resistance of GARC under various curing regimes were conducted. In addition, the microstructure of GARC under various curing regimes was discerned with environmental scanning electron microscope (ESEM), X-ray diffractometer (XRD), and pore structure analyzer.

## 2. Materials and experiment design

The GARC was prepared with C30 mix proportions using six types of materials: SAC, crushed stone, marine sand, sea water, superplasticizer, and retarder. After that, the prepared samples were cured by SC, FWC, and SWC, respectively. To investigate the effect of curing regimes on the mechanical properties, permeability resistance, and microstructure of GARC, the experimental design of this study is shown in Fig. 1.

### 2.1. Raw materials and mix proportion

#### 2.1.1. Raw materials

Grade 42.5R fast-hardening SAC was the main component of GARC, which was a commercial product developed in China. The compositions and properties of SAC are shown in Tables 1 and 2, respectively. The properties and gradation of coarse aggregate used in GARC are presented in Tables 3 and 4, respectively. Marine sand was acted as fine aggregate from Lianjiang, Fujian Province, China, of which the properties and gradation are presented in Table 5 and 6, respectively. The artificial sea water used in GARC was made by simulating the composition of sea water, and the chemical components are shown in Table 7. Superplasticizer (SP) was used to obtain 25% water-reducing ratio in this study. The commercial retarder was a chemical additive developed in China.

#### 2.1.2. Mix proportion

Mix proportion of GARC with C30 was prepared in accordance with the design specification [17] as shown in Table 8. The water-cement ratio was 0.5, and the amount of retarder and SP were 0.3% and 1.0% (by the weight of cement), respectively.

### 2.2. Preparation of specimens and curing regimes

Based on the designed method of mix proportion [17], a solution was formed by SP, retarder, and sea water, and then SAC, marine sand, and coarse aggregate were stirred in a container for 1 min. After that, the solution was mixed into the container and stirred for 2 min. Subsequently, the mixture was poured into the moulds with the inner surfaces oiled ($100 \times 100 \times 100$ mm, $100 \times 100 \times 400$ mm), and then compacted and covered with plastic film for a 24-h duration. Finally, the GARC specimens were demoulded, and then cured under SC, FWC, and SWC for 3, 7, and 28 d, respectively. For FWC and SWC, the specimens were cured in tap water and artificial sea water with the temperature of $20 \pm 2$ °C, respectively. The specimens under SC were cured in a moist chamber with the relative humidity (RH) of 90–95% at $20 \pm 2$ °C.

### 2.3. Test methods

#### 2.3.1. Mechanical properties tests

To investigate the mechanical properties of GARC under various curing regimes, the compressive strength at 3, 7, and 28 d, and splitting tensile strength at 28 d were conducted, according to GB/T50081-2002 [18].