EFFECTS OF SEAWATER AND SEA-SAND ON THE BEHAVIOUR OF FRP-CONFINED CONCRETE

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Abstract
This paper presents the results of a series of compression tests on FRP-confined concrete that was cast with seawater or sea-sand or both. A total of 48 standard concrete cylinders were tested in four series: reference normal concrete, sea-sand concrete, seawater concrete and seawater/sea-sand concrete. The concrete cylinders were either unconfined or confined with a 1-ply or 2-ply CFRP jacket. The unconfined specimens were tested at ages of 7 and 28 days and the confined specimens were tested at the age of 28 days. The test results show that concrete made with seawater and/or sea-sand developed a higher strength than normal concrete at the ages of 7 and 28 days. The test results also show that the four types of concrete have similar stress-strain behavior when confined with FRP; the use of seawater and sea-sand does not appear to have a significant effect on the effectiveness of FRP confinement.

1. Introduction
Depletion of natural resources is a problem caused by many industries across the world. In the concrete industry, billions of tons of freshwater and river sand are consumed every year, making them increasingly scarce in many parts of the world. To address this challenge, some island and coastal countries, such as Japan, have been investigating and practicing the use of seawater and sea-sand as substitutes for freshwater and river sand for concrete production. Such concrete features a number of distinct properties in comparison with normal concrete due mainly to the high content of chloride and sulfate ions in seawater and sea-sand. The chloride ions accelerate the hydration of concrete, which leads to a shortened setting time and an expedited strength gain at early ages [1]. However, the concrete may experience a reduction in strength growth with time at later stages and the long-term strength may be similar or slightly higher than that of normal concrete with a similar mix proportion [2]. The sulfate ions are involved in a number of chemical reactions in the hydration process that result in expansive products which may lead to cracking and spalling of concrete [3]. In addition to the above effects on concrete, the chloride ions greatly accelerate the corrosion process of steel reinforcement in concrete. It has been shown that the corrosion resistance of steel reinforcement due to chloride attacks may be improved by adding mineral products such as blast furnace slag and coating steel bars with a corrosion inhibitor [4]. However, the former only retards the corrosion of steel reinforcement temporarily while the latter is very costly and may result in the formation of secondary hazardous substances [5, 6]. To overcome these shortcomings, fiber reinforced polymer (FRP) composites has been proposed by Teng et al. [7] as an ideal material for use with concrete containing seawater and/or sea-sand to form steel-free structures (e.g., as internal FRP reinforcing bars and FRP
tubes) because FRP composites have excellent corrosion resistance [7]. Among the many possible use of FRP in concrete structures, FRP confining tubes for compressive members is particularly attractive as it not only protects the concrete from the aggressive marine environment (e.g. chloride attacks and frequent wet-dry cycles) [8] but also provides confinement to the concrete, leading to much enhanced strength and ductility of concrete [9].

2. Experimental Program

2.1. Test Specimens

A total of 48 standard concrete cylinder specimens (Φ150 mm×300 mm) were tested in four series: 1) reference normal concrete (NC) series in which the specimens were made with freshwater and river sand; 2) sea-sand concrete (SC) series made with freshwater and sea-sand; 3) seawater concrete (SwC) series made with seawater and river sand; and 4) seawater/sea-sand concrete (SSC) series made with seawater and sea-sand. The mix proportions of the four series were the same, except for the different types of water and sand. Each series consisted of 12 specimens, including six unconfined and six confined specimens. Of the six confined specimens, three were wrapped with a 1-ply CFRP jacket and the other three wrapped with a 2-ply CFRP jacket. The specimens were designated with the abbreviation of the series, followed by the letter “C”, and then a numeral denoting the number of CFRP plies of the jacket. The tests were conducted on concrete confined by a wet-layup FRP jacket instead of concrete-filled filament-wound FRP tubes, which typically have a significant axial stiffness, to focus our attention on the effect of FRP confinement on concrete.

The seawater and sea-sand used in the tests were sourced from Dameisha seashore in Shenzhen. The CFRP jacket was formed using the wet lay-up procedure with a uni-directional carbon fiber sheet (Toray UT 70-30) which had a nominal thickness of 0.167 mm per ply and an elastic modulus of 242 GPa. The specimens were demolded one day after casting and were immediately sandwiched between a top and a bottom plastic sheet in the laboratory. The top plastic sheet was removed twice a day for spraying the specimens with water. The NC and SC specimens were sprayed with freshwater while the SwC and SSC specimens were sprayed with seawater. The unconfined specimens were tested at the ages of 7 and 28 days respectively and the confined specimens were all tested at the age of 28 days. All specimens were capped with gypsum to ensure a smooth and level loading surface one day before testing.

2.2. Instrumentation and Test Set-up

For each unconfined specimen, two 80mm foil strain gauges centered at the mid-height were installed to measure the hoop strains and two 100mm gauges were employed to measure the axial strains. For FRP-confined specimens, 20 mm foil gauges were used, with each specimen having six hoop gauges and two axial gauges installed at the mid-height. Among the six hoop gauges, five were equally spaced at 45 degrees outside the overlapping zone (Fig. 1). All specimens were also equipped with a pair of linear variable displacement transducers (LVDT) covering the 120 mm mid-height region to measure the axial strains. All compression tests were conducted using a 5000 kN MATEST testing machine under displacement control. The average reading of the two LVDTs divided by their gauge length (120 mm) was treated as the axial strain.

3. Test Results and Discussion

3.1. Unconfined Specimens

For specimens cast using and cured with seawater, salt deposits were observed on their surfaces at the end of curing. Their surfaces were also darker than those of the normal concrete specimens. The
unconfined specimens were tested at the ages of 7 and 28 days to determine their compressive strength and modulus of elasticity. Fig. 2 shows that the compressive strength of the concrete made with seawater, and seawater/sea-sand is higher than, but the strength of sea-sand concrete is similar to that of the normal concrete at 7 days. This trend still stands at 28 days and the strength of sea-sand concrete is now also higher than that of the normal concrete. The same relationship applies for the modulus of elasticity at 28 days, but is invalid at 7 days (Fig. 3). Among the four series, the SwC specimens had the highest compressive strength and modulus of elasticity.

Figure 1. Layout of strain gauges and LVDTs

Figure 2. Compressive strength of unconfined specimens

Figure 3. Elastic modulus of unconfined specimens

Figure 4. Stress-strain curves of confined specimens
3.2. Confined Specimens

Of the 24 confined specimens, all failed by the sudden rupture of the CFRP jacket, with at least 10 specimens at the ends of the FRP overlapping zone. The stress-strain curves of the confined specimens are shown in Fig. 4. For clarity, in each group of three nominally identical specimens, only the one with the intermediate compressive strength is shown. It can be seen that all the stress-strain curves feature a bi-linear shape terminating at a significantly enhanced ultimate condition (compressive strength and ultimate axial strain). The four types of specimens exhibited similar stress-strain behavior in general with the slopes of the linear second branch being very close to each other, indicating a similar effectiveness of FRP confinement for the four types of concrete. A small difference is that the stress-strain curve of the SwC specimen bends over at a slightly higher level of axial stress which is attributed to the relatively higher compressive strength of the unconfined SwC specimens (Fig. 2).

4. Conclusions

The strength and behavior of four types of concrete, namely, normal concrete, sea-sand concrete, seawater concrete, and seawater/sea-sand concrete, with or without FRP confinement, have been studied and compared in this paper. From the results and discussions presented above, the following conclusions may be drawn:

- Concrete made with seawater and/or sea-sand developed a higher strength than normal concrete at the ages of 7 and 28 days. Among the four types of concrete, the seawater concrete had the highest 7-day and 28-day compressive strengths, which were 13.1% and 9.0% higher than those of the normal concrete, respectively.
- FRP confinement is effective for concrete made with seawater and/or sea-sand. Such concrete also features the well-known bi-linear stress-strain curve with its compressive strength and ductility both significantly enhanced when confined with a sufficient amount of FRP.
- The four types of concrete are similar in their stress-strain behavior when confined with FRP. The use of seawater and sea-sand does not appear to have any noticeable effect on the effectiveness of FRP confinement.

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References


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