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Research into Hybrid Construction Utilising FRP and Seawater Sea Sand Concrete

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Extended Abstract

Australia's population is projected to double within 50 years (ABS 2013). In Australia, about 80% of the population lives along the coast (E-Alert 2009). This will increase the huge demand for resources (e.g. fresh water) and infrastructure (e.g. bridges, highways, buildings, dams) especially along the coast. These are also among the major challenges worldwide because the global population is expected to increase from 6.9 billion in 2010 to 9.6 billion by 2050 (Kochhar 2014). The concrete industry uses about 2.5 billion tons of fresh water annually, for mixing, curing and cleaning (JCI 2014). By 2050, according to the United Nations, more than half of the world's population will be unable to get enough drinking water. The rapid pace of construction has caused large-scale sand-dredging and subsequent sand scarcity. Such over use and dredging can have devastating socio-environmental implications, such as depletion of fish stocks and erosion, landslides and flooding (The Economist 2014). The corrosion of steel reinforcement bars and external steel tubes is a challenge to the long-term performance of steel-concrete composite construction. The hybrid construction utilising seawater sea sand concrete (SWSSC) and fibre reinforced polymer (FRP) could be an attractive solution to address the above challenge (Teng et al. 2011, Teng 2014, Teng et al. 2016), which has attracted much research attention.

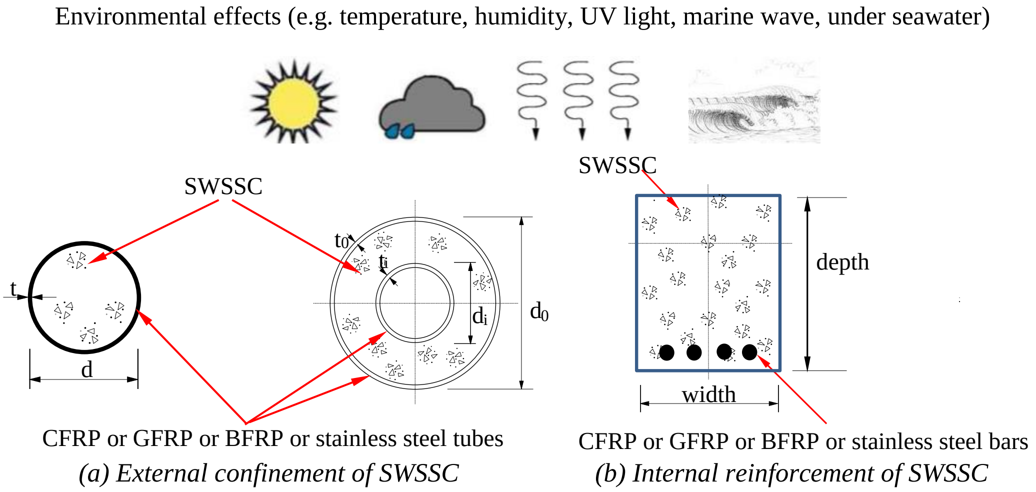


Figure 1. Schematic view of hybrid construction utilising SWSSC and FRP and/or stainless steel

Xiao et al. (2017) recently presented a critical review of existing studies on the effects of using sea sand and/or seawater as raw materials on the performance of concrete. An EU-US project titled SEACON (Bertola et al. 2016, Khatibmasjedi et al. 2016) was also introduced in Xiao et al. (2017), where GFRP reinforcement and SWSSC were used to construct a bridge deck. The research on SWSSC-FRP hybrid construction is still limited (e.g. Zha et al. 2010, Xu et al. 2015, Peng et al. 2014, Li et al. 2016a, 2016b, 2017, Dong et al. 2016, 2017, Wang et al. 2017a, 2017b). This paper gives a summary of current research at Monash University on hybrid construction using FRP and seawater sea sand concrete (SWSSC), as illustrated in Figure 1. This forms part of a research program sponsored by the Australian Research Council in collaboration with The Hong Kong Polytechnic University, Southeast University and Harbin Institute of Technology, China.

(1) Properties of SWSSC: Alkali activated slag concrete with seawater and sea sand was used in this research. Material properties measured include modulus of elasticity, compressive strength, bending strength at ambient temperature as well as elevated temperature. The main conclusions from Li et al. (2017) include:

(a) The mass loss is mainly contributed by the loss of free water, physical- and chemical-bonded water. The seawater and sea sand do not affect the mass loss behaviour obviously.

(b) The seawater, sea sand and coarse aggregate with larger size have a slightly (less than 10%) detrimental effect on residual strength. The samples become more deformable after heating and the residual Young's moduli drop more rapidly than residual strength when temperature is increased.

(c) The mechanical properties degradation of slag paste are mainly caused by cracks induced by temperature gradient and pore pressure and phase changes at high temperature, among which the cracks dominate the degradation. On the other hand, the main mechanism of the mechanical properties degradation of concrete, regardless using slag or cement, seawater or fresh water, river sand or sea sand, is the thermal expansion incompatibility between the contraction of paste matrix and expansion of aggregates. The influence of seawater and sea sand on the thermal properties is not obvious.

(2) Long-term behavior of fiber reinforced polymer (FRP): Filament-wound FRP tubes were adopted with three types of fibres (glass, carbon and basalt). Exposure temperatures include 25, 40, 60˚C with exposure time varies from 1 month to 12 months. Some preliminary results were reported in Guo et al. (2017) for CFRP tubes after pre-exposure to different solutions simulating seawater sea sand concrete and conventional concrete at 60 °C for 3 months. They are summarised here.

(a) Interface debonding and matrix degradation were found in each of the simulated concrete solutions. However, continuous cracks were found along fiber/matrix interface exclusively in the case of normal concrete solutions (i.e. SWSSNC, NC) that could provide easy paths for solution to penetrate.

(b) The highest weight gain (approx. 0.7%) was found in the case of normal concrete (NC) solution, followed by seawater sea sand normal concrete (SWSSNC), distilled water (DW), high performance concrete (HPC) and seawater sea sand high performance concrete (SWSSHPC) solutions. The observed lesser weight gain in SWSSC solutions (i.e. SWSSNC, SWSSHPC) than conventional concrete solutions (i.e. NC, HPC) can be attributed to osmotic effect.

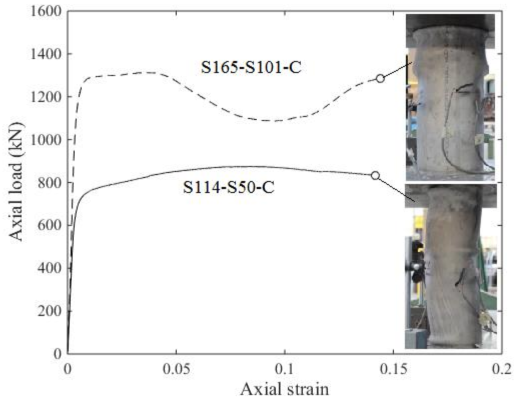
(3) SWSSC-filled FRP and stainless steel (SS) stub columns: Stub columns, including hollow sections and SWSSC fully filled tubes or double-skin tubes, were tested under axial compression. The effects of some key parameters (e.g., tube diameter-to-thickness ratio, cross-section types, outer tube types, and inner tube types) on the confinement effects were discussed. Some typical load versus axial strain curves are shown in Figure 2 for SWSSC-filled double skin tubes. The main conclusions from Li et al. (2016a, 2016b) can be summarised as:

(a) The strength and ductility of SWSSC-filled tubes are significantly enhanced in comparison with hollow section tubes and plain concrete.

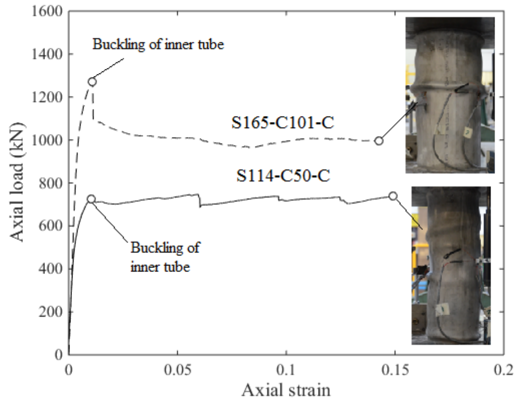
(b) The confinement effect provided by SS tubes is lower than that by BFRP/CFRP/GFRP tubes, but the confinement can be maintained for larger axial strain for SS tubes. The strength enhancement and ductility of SWSSC-filled CFRP tubes are higher than those of BFRP tubes mainly due to its higher hoop strength. The confinement provided by BFRP and GFRP tubes is quite similar.

(c) As the diameter-to-thickness ratio of tubes increases, the level of confinement reduces for all the four types of tubes (SS, GFRP, BFRP and CFRP). When compared with fully filled tubes, the confinement provided by the double skin tubes start to decrease at large deformation due to the buckling of inner FRP tubes. The influence of inner tube on confinement is not significant unless they are slender FRP tubes after an axial strain of 0.03.

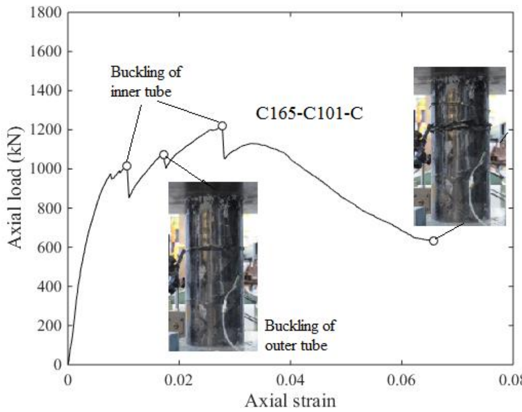
(d) Research is being conducted on the theoretical analysis of SWSSC-filled FRP tubes and the durability of SWSSC-filled FRP tubes.



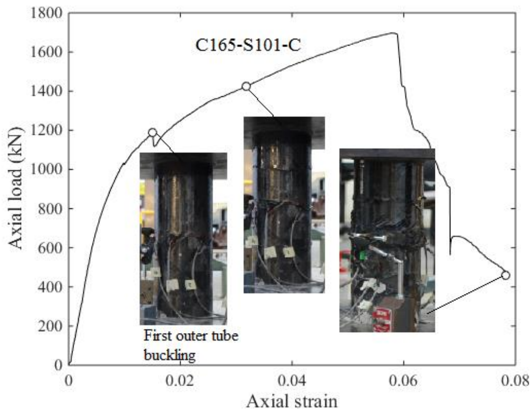
(a) Outer SS, inner SS



(b) Outer SS, inner CFRP



(c) Outer CFRP, inner CFRP



(d) Outer CFRP, inner SS

Figure 2. Axial load versus axial strain curves for SWSSC-filled double-skin tubes (Li et al. 2016a, 2016b)

(4) Durability of FRP bars in SWSSC environment: Accelerated corrosion tests were conducted on FRP bars using two types of SWSSC solutions at different pH and temperatures, and for different durations. The long-term behaviour of BFRP and GFRP bars under the service construction condition was predicted. The main conclusions from Wang et al. (2017a, 2017b) include:

(a) Nearly no change was found in Young's Modulus for GFRP and BFRP bars after exposure in SWSSC solutions.

(b) The degradations of GFRP and BFRP bars in SWSSC solution at high temperature both mainly include etching of fibre, hydrolysis of resin, and interface debonding.

(c) The water uptake and desorption results showed that the degradation of epoxy-based BFRP, GFRP and CFRP bars in SWSSC solutions is mainly from the hydrolysis of resin, which was also evidenced by the FTIR results.
(d) Arrhenius relationship theory was found to be conservative in predicting the long-term performance of BFRP and GFRP bars.
(e) A more accurate degradation model should be developed for FRP bars in SWSSC by considering the real temperature and humility ranges and pre-loading stress.

This paper gave a summary of current research at Monash University on hybrid construction using FRP and seawater sea sand concrete (SWSSC). It covered properties of SWSSC, long-term behavior of fiber reinforced polymer (FRP), SWSSC-filled FRP and stainless steel stub columns and durability of FRP bars in SWSSC environment.

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