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# THE IMPACT OF USING SEAWATER AND SEA SAND FOR THE PRODUCTION OF CONCRETE

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## ABSTRACT

With the dramatic increase in the construction of infrastructures worldwide, raw materials such as river sand and fresh water for concrete production could face enormous shortages, especially in marine regions. Researchers are investigating the compatibility of consuming seawater and sea sand for concrete production to alleviate the issue. In this report, three types of concrete were analyzed: seawater and sea sand concrete (SSC), sea sand concrete (SC), and ordinary concrete (OC), which were prepared with two water/binder ratios of 0.38 and 0.28. The concrete samples were tested for compressive strength, flexural strength, and microstructural analysis using SEM to probe the internal changes. It was observed that using seawater and sea sand has increased the early age compressive strength but slightly decreased the 28 days strength. The flexural strength of seawater and sea sand concrete, and sea sand concrete has been enhanced at 28 days when compared to ordinary concrete; scanning electron microscopy (SEM) analyses further confirm the notable influence of sea sand and seawater on the surface morphology and a significant difference from ordinary concrete due to the dominance of ettringite phase with long crystals that have a fibrous shape, that can improve the mechanical performance of concrete attributed to the compacted and less porous structure of the made concrete.

**KEYWORDS:** seawater; sea sand; compressive strength; flexural strength; SEM

## INTRODUCTION

Over the last few decades, concrete has been substantially exploited worldwide (Monteiro et al. 2017; Shaikh 2016). The development of infrastructures and constructions has significantly increased the demand for raw materials like fresh water and river sand (Colangelo et al., 2018; Engelsen et al. 2017; Wijayasundara et al. 2018). Recent research has shown that continuous manipulation of natural resources can raise severe environmental issues (Priyadharshini et al. 2018). Efforts have been made to amend the scarcity of natural fine aggregates by exploring unusual, new, and recycled waste materials.

Fine aggregates alternatives such as copper slag for high-performance concrete (HPC) (Al-Jabri et al. 2009), and bottom ash (Rafieizonooz et al. 2016) to study the change in the workability and compressive strength of concrete made with the replacement rates (20%, 50%, 75%, and 100%) of river sand. Used-foundry sand (UFS) was also used to investigate the mechanical properties of concrete, which proved to be effective in increasing the compressive strength along with the percentage of USF (Siddique et al. 2016). Granite powder waste (Vijayalakshmi et al. 2013) was used as a substitute for river sand. It can replace natural river sand up to 15% without causing undesirable consequences on concrete's durability and mechanical properties.

It’s well known that seawater and sea sand are inexhaustible natural resources; seawater alone has 96.5% of the total water on earth (Elimelech and Phillip 2011). Several concerns have been realized from utilizing seawater and/or sea sand for concrete production due to the high salinity, which might cause some issues in the internal structure of concrete, which might lead to the inevitable corrosion of steel bars reinforcement (Yan et al. 2016; Gonzalez et al. 1998).

One method to alleviate the salinity problem is rinsing sea sand with fresh water to reduce the amount of salt (Liu et al. 2016; Thunga and Venkat 2020). However, these methods come with additional costs and waste of natural resources such as freshwater, which is already scarce inshore regions. Several approaches have been utilized to introduce sea sand to concrete production; one is substituting part of river sand with sea sand to control the amount of salt to follow the standard requirements. Partial replacement of river sand with different types and proportions of sea sand between 5%, 10%, 20%, 40%, 60%, 80%, and 100%). The replacement has proved effective and didn't impact the mechanical properties of concrete. Still, the optimum replacement was up to 40% when the compressive strength was increased by 13.4% compared to ordinary concrete. (Sidhardhan et al. 2017; Ting et al. 2020; Huang et al. 2018)

This research investigation studies seawater and sea sand used for concrete production compared to ordinary concrete prepared with fresh water and river sand. Seawater and sea sand concrete (SSC), sea sand concrete (SC), and ordinary concrete (OC) samples were prepared and subjected to the same conditions, the samples' mechanical properties were tested by compressive strength and flexural strength, and the internal microstructure was evaluated by scanning electron microscopy (SEM)

## MATERIALS & METHODS

Materials: Portland cement type 52.5N (Japan), Fly ash class F (Hong Kong), Condensed silica fume, CSF (CAN/CSA A23.5-M86) (Norway). The fine aggregates and coarse aggregates conformed with BS EN 122620 [19] [34]( BS EN 122620:2013). Sea sand and river sand are mined from Guangdong, China. Two superplasticizers were used to enhance the workability: Rheomca 1002 and Glenium SP8S, BASF Limited, Hong Kong. Artificial seawater was used in this study, and it was prepared following the standard preparation method ASTM D1141-98 [18] [35] (ASTMD1141-98 2013).

**Table 1 Chemical compositions of cement, fly ash, and silica fume**

| Component | Cement (%) | Fly ash (%) | Silica fume (%) |
|---|---|---|---|
| **CaO** | 67.16 | 22.11 | 0 |
| **$SiO_2$** | 18.93 | 35.73 | 94.93 |
| **$Al_2O_3$** | 3.84 | 15.29 | 0 |
| **$SO_3$** | 3.48 | 2.96 | 0 |
| **$Fe_2O_3$** | 2.86 | 13.85 | 3.47 |
| **CdO** | 1.32 | 0 | 0 |
| **MgO** | 1.18 | 7.37 | 0.72 |
| **$K_2O$** | 0.77 | 1.36 | 0.73 |
| **$TiO_2$** | 0.36 | 1.02 | 0 |
| **MnO** | 0.1 | 0.31 | 0.15 |

**Table 2 Chemical compositions of Artificial seawater**

| Compound | NaCl | $MgCl_2$ | $Na_2SO_4$ | $CaCl_2$ | KCl | $NaHCO_3$ | KBr | $H_3BO_3$ | $SrCl_2$ | NaF |
|---|---|---|---|---|---|---|---|---|---|---|
| Concentration /g/L | 24.53 | 5.2 | 4.09 | 1.16 | 0.695 | 0.201 | 0.101 | 0.027 | 0.025 | 0.003 |

In this study, two groups (A&B) of concrete with six mixes were prepared following two water/binder ratios 0.38 for group A and 0.28 for group B. The mixes include ordinary concrete (A0&B0) has fresh water and river sand that represents reference concrete; Sea sand concrete SC (A1&B1) has fresh water and sea sand; Seawater

Sea sand concrete SSC (A2&B2) has seawater and sea sand. Table 3. Mix proportions (in kg/m$^3$). The concrete mixing order is per ASTM C192/C192M-19 (ASTM C192 / C192M – 19 2020). After adding the raw materials to the mixer, concrete was mixed for 5 minutes, then transferred into the designated molds for casting, followed by demolding after 24hrs at an ambient temperature. The samples were cured in a humidity chamber at 23℃ and 95% humidity until specific hydration age was reached.

**Table 3 Mix proportions (in kg/m**

| Group | Mix-A0 | Mix-A1 | Mix-A2 | Mix-B0 | Mix-B1 | Mix-B2 |
|---|---|---|---|---|---|---|
| **W/B** | **0.38** | | | **0.28** | | |
| **Cement** | 330 | 330 | 330 | 400 | 400 | 400 |
| **Freshwater** | 165 | 165 | 0 | 150 | 150 | 0 |
| **Seawater** | 0 | 0 | 165 | 0 | 0 | 150 |
| **River Sand** | 730 | 0 | 0 | 740 | 0 | 0 |
| **Sea Sand** | 0 | 730 | 730 | 0 | 740 | 740 |
| **Fly Ash** | 110 | 110 | 110 | 110 | 110 | 110 |
| **Silica Fume** | 0 | 0 | 0 | 30 | 30 | 30 |
| **Coarse Aggregate (20mm)** | 565 | 565 | 565 | 530 | 530 | 530 |
| **Coarse Aggregate (10mm)** | 465 | 465 | 465 | 430 | 430 | 430 |
| **Admixture** | 2.65 | 2.65 | 2.65 | 5.25 | 5.25 | 5.25 |

Compressive strength was conducted on cubes samples sized (100 mm x 100 mm x100mm), three cubes were tested for each mix design, and then the average value was measured. The loading rate was 2.5 kN/s at three different ages, 3, 7, and 28 days as per ASTM C109/C109M-13 (ASTM C109/C109M-13 2015)

Flexural strength of the concrete beams (100 mm × 100 mm × 500 mm) with a loading rate of 0.2 kN/s was conducted to assess the resistance to deformation capacity at 28 days following BS EN 12390-5 (BS EN 12390-5 2019). Three beams were prepared in each mix, and the mean value of flexural strength was calculated.

## RESULTS AND DISCUSSIONS

### 1. Compressive strength

The compressive strength of groups A & B at 3, 7, and 28 days are shown in Figure 1&2. It was observed that the early age compressive strength at 3 days while using sea sand (A1) and sea sand /seawater (A2) had increased significantly compared with ordinary concrete (A0) strength. The higher compressive strength values imply that using seawater and sea sand for concrete production can improve the internal structure of concrete to withstand higher loads. Previous investigations have reached similar conclusions on concrete prepared with seawater (Wegian 2010; Younis et al. 2018). The compressive strength value at 7 days for sea sand concrete was the highest in group A, followed by ordinary concrete and seawater/sea sand concrete.

As for group B, the compressive strength values developed similarly to group A at an early age (3 days). However, at 7 days, seawater/sea sand concrete (B2) has higher compressive strength than ordinary concrete (B0), which indicates that at a lower water-to-binder ratio, seawater/sea sand concrete has better mechanical properties. At 28 days, the values changed to be the highest for sea sand concrete (A1)> ordinary concrete (A0)> seawater/sea sand concrete (A2), and parallel development was observed for group B samples. The results revealed that when the water-to-binder ratio at 0.38, sea sand concrete and ordinary concrete have comparable values. Whereas at a water-to-binder ratio of 0.28, sea sand concrete exhibited higher values than seawater/sea sand concrete and ordinary concrete.

Despite the difference in the compressive strength values among the three types of concrete at an early age. The strength values appear to be comparable with increasing the aging time. The enhanced compressive strength of the concrete prepared with sea sand or with seawater/sea sand could be attributed to several factors, such as the lower permeability of concrete due to the high content of soluble salts, like sodium sulfates, calcium chloride, magnesium chloride, and sodium chloride, etc that can accelerate the hydration process of $C_3S/C_2S$ significantly and releasing a vital amount of $Ca^{2+}$ ions to form major hydrates (as CH and CSH), which participate in the chemical reaction to produce a certain amount of gypsum crystals when compared to ordinary concrete (OC) (Bonen 1992; Yaseen et al. 2020). Additionally, the high concentration of chloride and sulfate ions in seawater or sea sand is believed to interact with Portland cement phases and hydration phases to form new phases such as Friedel's salt and Kuzel's salt (Bonen 1992; Li et al. 2018). The accelerated hydration process in SC and SSC may affect the early-age compressive strength in two different ways. Lower water/binder ratio mixes have higher Portland cement content and less water available for hydration which may result in a longer accelerated hydration process at 3 day age and a comparable hydration rate to OC at 7 day age. Higher water/binder ratio mixes contain more water, which means that a higher percentage of salts is available to react faster with Portland cement phases and hydration products. The use of seawater and/or sea sand as alternatives for concrete production could be employed in a wide range of infrastructures reinforced with fiber-reinforced polymer (FRP) composites; when using seawater and/or sea sand with conventional concrete, corrosion of the reinforcing bar can lead to the fast deterioration of structures.

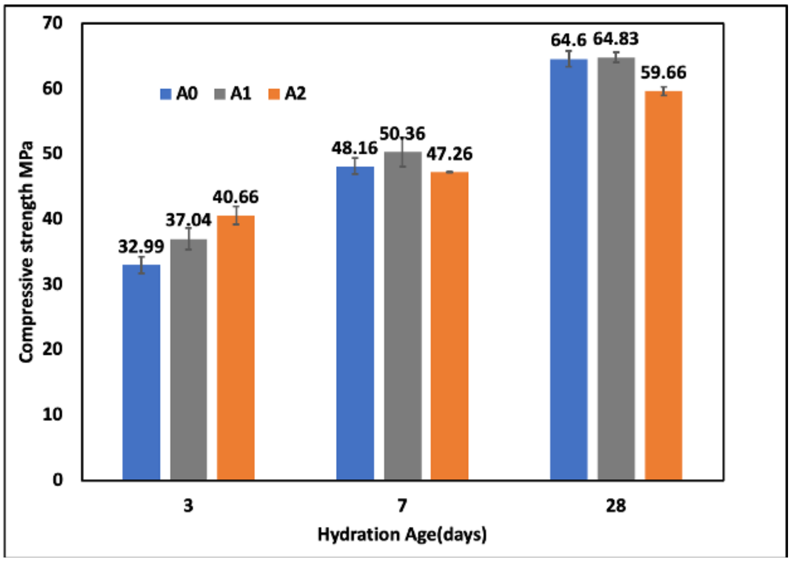


**Figure 1 compressive strength of group A at 3, 7 &28 days.**

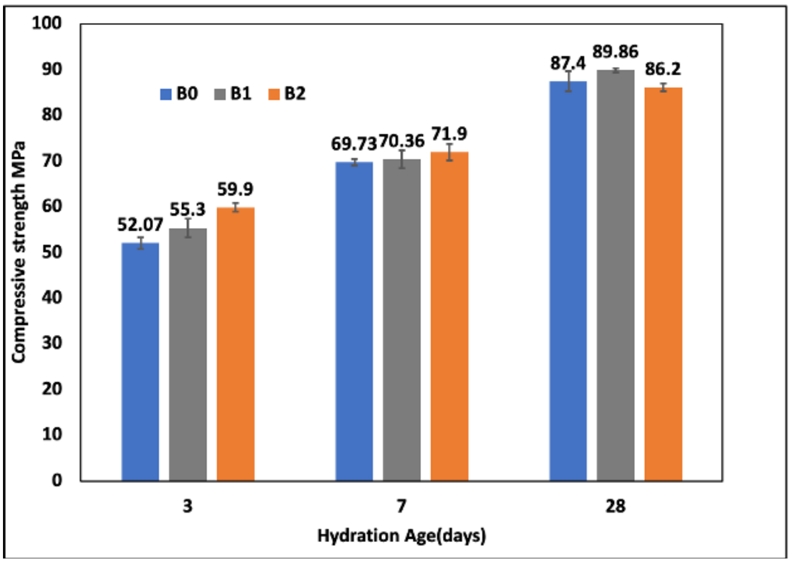


**Figure 2 compressive strength of group B at 3, 7 &28 days.**

## 2. Flexural strength

The flexural test was conducted using a four-point setup, with three beams for each combination in group A&B. The flexural strength results are shown in Figure 3. Flexural strength results of group A are in a descendant order, where seawater/sea sand concrete (A2) has the highest value, followed by sea sand concrete (A1) and then ordinary concrete (A0). A similar phenomenon was observed in group B samples; the results indicate that using seawater/sea sand or sea sand to replace fresh water and river sand can positively impact the flexural strength of the casted concrete. Furthermore, adding to the offsetting of the external load compensation and the self-equilibrium stress caused by shrinkage, all these factors can improve the bending strength of sea sand concrete and seawater/sea sand concrete compared with ordinary concrete (Tang et al. 2015). The flexural strength results in this study are in agreement with previous reports on concrete prepared with seawater or sea sand (Limeira et al. 2012; Weerdt et al. 2014; Mesbah et al. 2011)

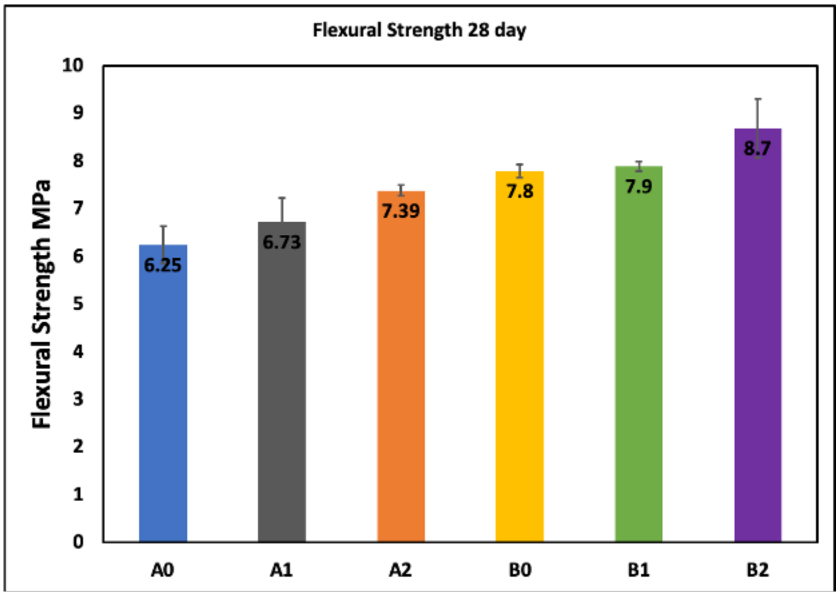


**Figure 3 Flexural strength of groups A&B at 28 days.**

## 3. SEM analysis

SEM was employed to reveal the influence of using sea sand or seawater/sea sand on the surface morphology of the produced concrete. Figure 4&5 presents the morphology of ordinary concrete (A0, B0), sea sand concrete (A1, B1), and seawater/sea sand concrete (A2, B2). The SEM images compare the microstructural development among all the casted samples. At 3 days of age, group A with no added silica fume showed that the presence of major hydrates ettringite, portlandite, and calcium silicate hydrate (C-S-H) is evident in the SEM imaging. Sea sand concrete (A1), seawater/sea sand concrete, exhibited significant development and a noteworthy difference from ordinary concrete (A0). It could be seen as a dense structure with fewer cracks and more C-S-H. Additionally, the increased formation of ettringite crystals that have the shape of fibers and Friedel's salt as a new crystal phase. The higher formation of these crystals in the case of sea sand concrete and seawater/sea sand concrete could lead to a compacted and less porous structure (Guo et al. 2019).

Whereas for group B, similar interpretations would be predicted for the hydration products of sea sand concrete (B1) and seawater/sea sand concrete (B2). The morphology in group B appears to be more densified with C-S-H, which is attributed to the (5%) of the added silica fume. Group B's surface morphology, in comparison with group A, showed different features, such as a more refined surface and observed less Portlandite crystals, the structure for group B appeared with a compacted and less porous structure like group A. The results agree with previous reports (Gleize et al. 2003). In the SEM images, some unreacted fly ash and silica could be visible in both groups' A&B samples. At 28 days, the morphology of sea sand concrete and seawater/sea sand concrete showed the consistent formation of C-S-H with a denser structure and lesser unreacted cement phases than ordinary concrete (Wang et al. 2018; Shi et al. 2019).

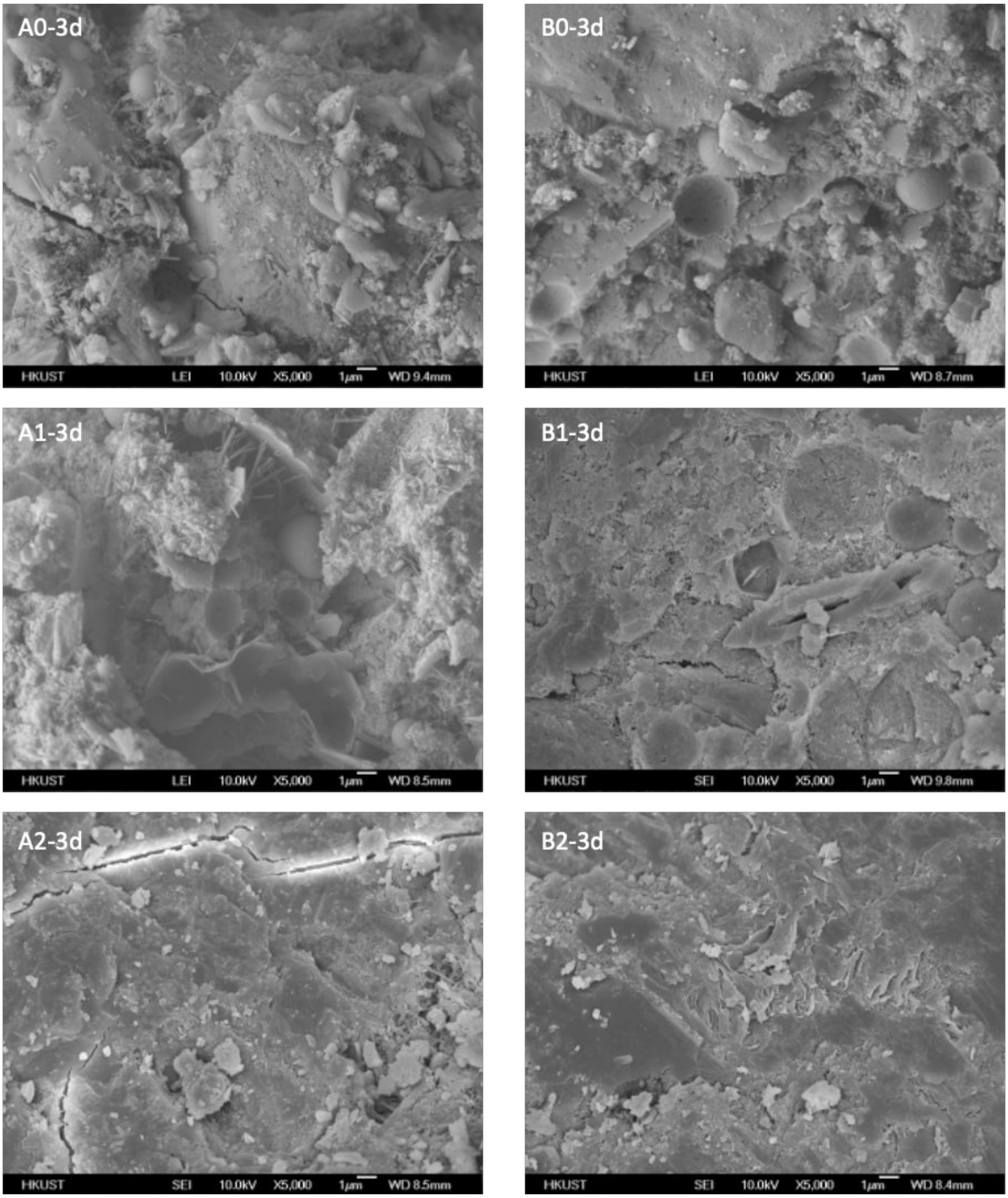


**Figure 4 SEM images of groups A&B at 28 days.**

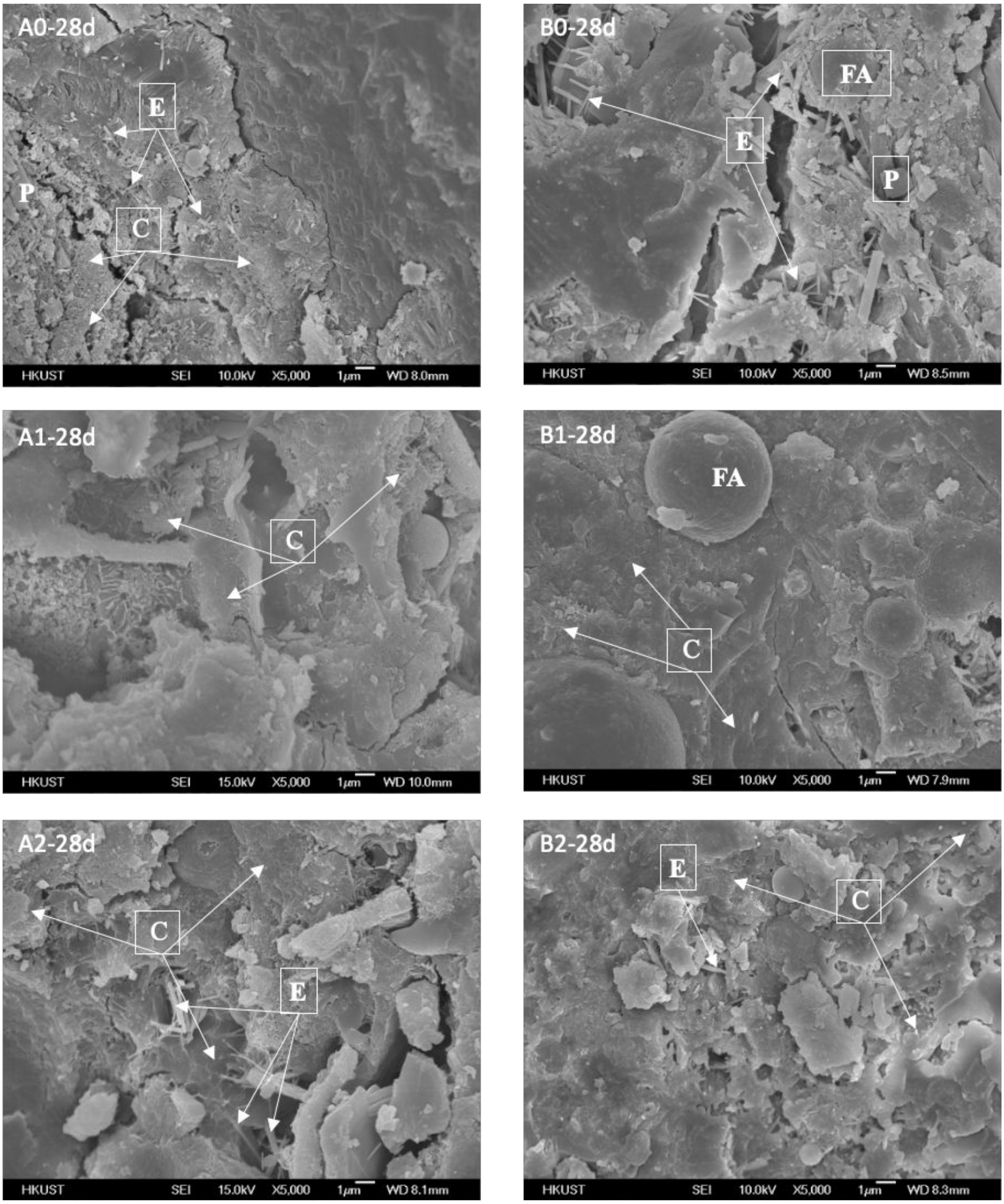


**Figure 5 SEM images of groups A&B at 28 days.**

## CONCLUSION

This research study investigates the feasibility of using seawater and sea sand as alternatives for fresh water and river sand for concrete production to address the challenges facing the construction industry's raw materials (fresh water and river sand), especially in the coastal regions. Seawater and sea sand can significantly and positively affect concrete's microstructural and mechanical properties.

1. Seawater and sea sand have the aptitude to increase the compressive strength of concrete at an early age, despite the marginal decrease in the compressive strength at 28 days. The flexural strength showed a similar tendency as well.

2. SEM analyses reflected the substantial influence of seawater and sea sand on the morphology of the made concrete. SEM analyses showed a massive difference among the samples of both groups A&B when using seawater and/or sea sand compared to ordinary concrete. Seawater and /or sea sand concrete has a compacted, more dense structure with the domination of ettringite crystals that can improve the mechanical performance of concrete.

## ACKNOWLEDGMENTS

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