© Universiti Tun Hussein Onn Malaysia Publisher's Office

**IJIE**

http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

# Preliminary Experimental Work on Concrete-Fly Ash Compressive Strength Blended with Seawater as Mixing Water

**Firdaus Zulkifli[1], Nurazuwa Md Noor[1*]**

[1]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2023.15.06.013
Received 16 July 2023; Accepted 30 September 2023; Available online 21 December 2023

**Abstract:** Fly ash is widely used in the construction sector, but application with seawater has not fully utilised. Seawater is used in construction to minimise the scarcity of drinking water. The concrete was strengthened by the application of fly ash. Seawater replacing 100% tapwater as mixing water. Meanwhile, fly ash was substituted with ordinary Portland cement at 10%, 20%, 30%, and 40%. To achive the objective, the 100 mm x 100 mm x 100 mm cube size with 0.33 water-cementitious ratio were prepared. All series of mixture were casted and cured in water for 7 and 28 days. The fly ash blended with seawater in concrete were investigate through its compressive strength. In addition, scanning electron miscroscope were carried out to capture surface image of the specimen. The experimental work result shows, with the existence of fly ash in concrete mixture, it decreases workability, density and compressive strength. Though the decreasing pattern was seen in every series, the structural strength was still deemed adequate.

**Keywords:** Seawater, fly ash, sustainability, compressive strength

## 1. Introduction

Concrete is increasingly utilised due to the expanding population and demand for construction in urban and rural locations. Nonetheless, there would ultimately be a knock-on effect from the growing demand for concrete on environmental issues such as environmental contamination. A significant contributor to carbon dioxide ($CO_2$) emissions is the manufacture of cement, an essential component of concrete. $CO_2$ is a by-product of the clinker formation process in cement kilns. Creating more environmentally friendly cement formulations is one of the initiatives aimed at lowering these emissions. Meanwhile, water is required for concrete mixing and curing. Excessive water consumption in concrete manufacturing can burden local water resources, especially in locations where water shortage is an issue. By incorporating sustainable resources into concrete elements, research in concrete has discovered alternative ways of reducing the use of concrete material. In the long run, this system will enable society to advance in the building and construction sectors while maintaining sustainability [1].

The most efficient way to produce concrete sustainably is to utilise waste and by-product materials rather than natural resources [2]. A fine, powdery material known as fly ash is produced when pulverised coal is burned in power plants. Along with boiler slag, bottom ash, and components used in flue gas desulfurisation (FGD), it is one of the by-products of coal combustion. Fly ash is commonly categorised into two primary categories according to its characteristics and origins. Fly ash classified as Class F can react with lime to generate cementitious compounds due to its pozzolanic qualities and Class C possesses pozzolanic and self-cementing capabilities. Using fly ash in concrete is considered a sustainable practise since it decreases the demand for conventional cement, lessening concrete's carbon footprint. The utilisation of fly ash in the concrete mixture was proven to improve the properties of concrete and be

*Corresponding author: nurazuwa@uthm.edu.my

environmentally friendly. Based on past studies, the use of fly ash in concrete increases the concrete's compressive strength at 28 days and 120 days of curing due to the continuity activity of pozzolanic activity in fly ash with time [3]. Fly ash can occasionally cause an early-age compressive strength decrease, usually between 7 and 28 days [4]. This occurrence is referred to as the "pozzolanic effect delay". After hydration, fly ash and calcium hydroxide undergo a slower pozzolanic reaction than Portland cement. As a result, the concrete may show reduced strength values in the short term (see Fig. 1). But at the later age, the strength is increasing. As a pozzolanic substance, fly ash creates more cementitious compounds when it combines with calcium hydroxide during hydration. This process enhances the cohesiveness of the concrete mixture, making it more workable [5]. The use of fly ash in the construction industry has also been commercialised in Malaysia and practically used in conventional concrete design. In Malaysia, the use of fly ash in concrete is usually controlled by local rules and regulations. These restrictions may stipulate the types of fly ash that can be used, the replacement ratios that can be utilised, and quality control procedures [6].

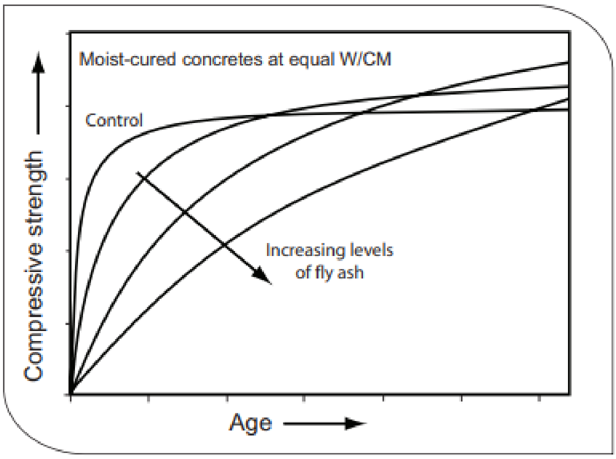



**Fig. 1 - Fly ash's effect on the development of concrete's compressive strength** [7]

Another essential material in concrete is the tap water used as mixing water. As part of concrete production, tap water is also widely consumed by flora and fauna, the agriculture industry and humankind. Malaysia is facing several issues with water supply, distribution, and management, including water shortage, a significant problem. In Malaysia, several factors lead to water shortage: uneven distribution, climate change, increasing demand, deforestation, pollution, inefficient water management, dams and reservoirs and transboundary issues [8]. Climate change, including fluctuations in rainfall and temperature, can impact water availability. Malaysia has seen erratic rainfall patterns, resulting in droughts in certain areas and affecting water availability. Much research, including fundamental and applied has been performed on seawater-mixed concrete. There is worldwide interest in using seawater-mixed concrete to reduce concrete tap water consumption [8]. Seawater is abundant and can be a suitable water supply for concrete mixing in coastal building projects. Seawater can be a sustainable choice in coastal places where there are few tap water supplies. This reduces the need for tap water for building activities. In some circumstances, using seawater in concrete can be explored; nevertheless, it will need to be carefully studied along with any potential drawbacks and the necessary steps to mitigate them. Seawater usage could be more appropriate for non-structural applications and non-reinforced concrete, such as concrete blocks, when used in conjunction with proper mix design, material selection, and quality control procedures. Using seawater can sometimes lead to improved early strength development. Specific ions in seawater, such as sulphate and magnesium, may accelerate the hydration process, causing an early strength boost and a more rapid setting. However, seawater can cause a decrease in the compressive strength of concrete, especially over time. Several elements, including the concrete mix design, exposure circumstances, and seawater quality, determine the influence on strength. For non-reinforced concrete, replacing tap water in the concrete mixture with seawater can benefit and maintain the concrete production's sustainability [9]. Several variables influence concrete strength, including the quality of the concrete compaction, humidity, water-cement ratio, raw materials, and concrete curing. A study by Hairan et al. [10] shows that the compressive strength of seawater-concrete result is comparable to the control mixture of conventional concrete.

Adding fly ash as a replacement cementitious ingredient and utilising seawater as the mixing water component is known as "blending" seawater with fly ash in concrete. Seawater can present some challenges when used in concrete, but when combined with fly ash, additional consideration is introduced. Combining seawater and fly ash is a viable solution, particularly in coastal areas with limited tap water supplies. This method decreases the need for tap water in concrete mixing. Continuous research and development in Malaysia's building sector may lead to breakthroughs in using these alternative and sustainable resources in concrete. Researchers and industry experts may investigate optimised mix designs and building practices to maximise the benefits of blending fly ash and seawater in concrete. To account for the combination of fly ash and seawater, the concrete mix design should be carefully optimised. This can involve adjusting the water-cement ratio, using chemical admixtures, and taking into account other additional materials.

## 2. Materials and Experimental Procedures

The experimental work starts with collecting seawater and fly ash from the resources area. Seawater (SW) was collected from Pantai Sungai Lurus, Batu Pahat Johor during high tide and at locations 5 to 10 meters from the seashore. It was used directly as mixing water without any treatment. Fly ash (FA) was taken from Tanjung Bin Power Plant located in Pontian, Johor and classified as Class F fly ash. FA was sieved passing 75 µm and replaced ordinary Portland cement (OPC) at 10% to 40% by weight. Other concrete materials were river sand passing 5 mm and crushed aggregate passing 20 mm sieve as prescribed in BS 12620:2002+A1:2008 [11] and BS EN 933-2-2020 [12]. Table 1 presents the concrete material's properties, including water absorption for the aggregates. The density for seawater, gravel, and kerosene was determined following BS EN 1097-3:1998 [13], while the binder's specific gravity was determined using ASTM D854-10 [14]. The density of fly ash was measured at 2.05 g/cm$^3$, which is lower than the OPC, meaning that a given volume of fly ash will weigh less than the same volume of OPC. From the literature review, the density of fly ash is usually between 1.9 and 2.4 g/cm$^{3,}$ and it can influence the hardened density of concrete at 28 days [15]. As for seawater, it gets denser when its temperature drops and its salinity rises. Under typical conditions, seawater has a density of around 1.025 g/cm$^3$, and in this experimental work, 1.03 g/cm$^3$ seawater density was recorded, aligning with other findings [16]- [18].

The water absorption for fine and coarse aggregate was 2.59% and 1.13%, respectively. Highly absorbent particles often absorb a significant portion of the mixing water, which modifies the concrete mix's total water-to-cement ratio. This may lead to decreased workability and difficulty in attaining uniformity and placement ease. Thus, aggregate water absorption properties must be considered while designing concrete mixes. To obtain the intended performance, adjusting the mix proportions, including the quantity of free-water used and the usage of chemical admixtures, could be essential. This experimental work divided mix design into two main groups: tap water and seawater. Six mixture series were developed to achieve the research objective, as tabulated in Table 2. Water-to-cementitious was fixed at 0.33, and seawater was used 100% in replacing tap water. The control mixture (TW-0FA) was designed using the British Design of Experiment Method (DOE) with a target strength of 60 MPa at 28 days of water curing. Other series were designed according to each material density, as presented in Table 1.

**Table 1 - Materials physical properties**

| Material | Density (g/cm$^3$) | Water absorption (%) |
|---|---|---|
| Tapwater | 1.00 | - |
| Seawater | 1.03 | - |
| Ordinary Portland cement | 2.96 | - |
| Fly ash | 2.05 | - |
| Fine aggregate | 2.42 | 2.59 |
| Coarse aggregate | 2.65 | 1.13 |
| Kerosene | 0.79 | - |

**Table 2 - Series of the mix design**

| Mixing water | Designation | Description | w/c | TW | SW | OPC | FA | S | CA |
|---|---|---|---|---|---|---|---|---|---|
| | | | | (kg/m$^3$) | | | | | |
| Tapwater (TW) | TW-0FA | TW + 100OPC | 0.33 | 199 | 0 | 601 | 0 | 581 | 949 |
| Seawater (SW) | SW-0FA | SW + 100OPC | | 0 | 205 | 620 | 0 | 581 | 949 |
| | SW-10FA | SW + 10% FA + 90% OPC | | 0 | 205 | 558 | 62 | 581 | 949 |
| | SW-20FA | SW + 20% FA + 80% OPC | | 0 | 205 | 496 | 124 | 581 | 949 |
| | SW-30FA | SW + 30% FA + 70% OPC | | 0 | 205 | 434 | 186 | 581 | 949 |
| | SW-40FA | SW + 40% FA + 60% OPC | | 0 | 205 | 372 | 248 | 581 | 949 |

TW= Tap water; SW= seawater; OPC=ordinary Portland cement; FA= fly ash; S=sand; CA= coarse aggregate.

## 3. Results and Discussion

### 3.1 Hardened Density and Workability of Concrete

Table 3 shows the result of concrete slump, hardened density and strength development at 7 and 28 days. It was observed that there were no significant changes in slump value when seawater replaced tap water in SW-0FA series. However, when fly ash was added, a reduction pattern can be seen with the increase of fly ash (10% to 40%) in the mix design. Compared to a similar amount of Portland cement, a larger volume (weight) of fly ash is required to achieve a specific mass because it is less dense, which might increase water demand [19]. A similar decrease trend was seen in 28 days of hardened density, except for the combination in which 10% of fly ash was blended with seawater (SW-10FA). Hardened density for this series was 2.4%, slightly higher than the control series (TW-0FA). This may be caused by a lower density of fly ash than ordinary Portland cement [20]. When the amount of fly ash was increased in the series mixture, the total weight of fly ash also increased. This contributes to the concrete hardened density reduction.

### 3.2 Concrete Compressive Strength and Pore Volume

Compressive strength for 7 and 28 days is presented in Table 3. A systematic strength reduction can be seen in all mixture series. At 28 days, strength for the seawater series without fly ash (SW-0FA) decreased by 4% in comparison with the control series. The same reduction percentage was seen in SW-10FA. This loss increased with the increment of fly ash in the mixture series, with a 24% drop in strength recorded at 40% fly ash-seawater substitution, as illustrated in Fig. 2. The mechanism of strength reduction is shown in Fig. 1. When compared to 100% ordinary Portland cement concrete, the pozzolanic reaction of FA is slower, produces fewer hydration products, and has a larger porosity in its early stages [21]. In the seawater group, the highest strength was seen in 10% fly ash replacement. Even though the strength was reduced when fly ash was utilised up to 40%, compressive strength showed a positive result where 52.6 MPa was still under the accepted structural strength level. According to Cho et al. [22], replacing 50% of Portland cement (PC) mass with supplementary cement materials reduces $CO_2$ emissions by 1 billion tons annually.

**Table 3 - Slump, density and concrete compressive strength**

| Series | Slump (mm) | Hardened density (kg/m$^3$) | Compressive strength (N/mm$^2$) | |
|---|---|---|---|---|
| | | 28 days | 7 days | 28 days |
| TW-0FA | 230 | 2430 | 64.1 | 69.5 |
| SW-0FA | 230 | 2419 ⇩ | 61.8 | 66.8 |
| SW-10FA | 180 ⇩ | 2491 ⇧ | 57.4 | 66.7 |
| SW-20FA | 170 ⇩ | 2410 ⇩ | 48.7 | 62.2 |
| SW-30FA | 170 ⇩ | 2397 ⇩ | 46.0 | 57.0 |
| SW-40FA | 172 ⇩ | 2374 ⇩ | 40.8 | 52.6 |

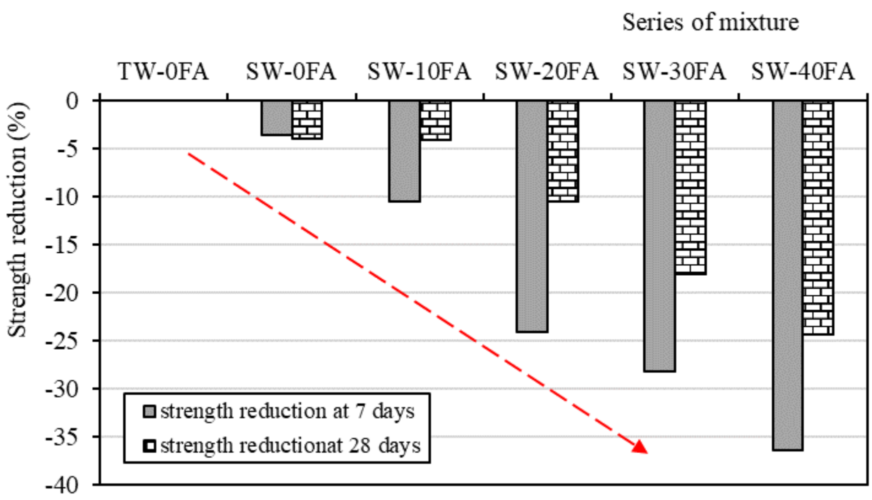



**Fig. 2 - Concrete strength reduction at 7 and 28 days**

The relation between compressive strength ($y$) and total pore volume ($x$) is evaluated using data obtained by Rita [23] as illustrated in Fig. 3. The relationship is given in Eq. (1). The volume of voids or pores inside the concrete material is referred to as the total pore volume of concrete. Total pore volume of control sample (TW-0FA) is calculated as 11.5 percent with compressive strength of 69.5 MPa. When fly ash was blended with seawater (SW-10FA), total pore volume slightly increased to 11.94 percent. At 40 percent fly ash replacement, total pore volume rose marginally to 14.2 percent. Fly ash is a pozzolanic substance that contributes to a refined pore structure and thereby reduces the overall pore volume in the concrete. However, increment in fly ash content may lead to an increase in total pore volume in some situations. Several factors which can influence the relationship between fly ash content and total pore volume are particle size distribution, water demand and workability, cement replacement ratio, curing condition, mix design and composition and specific characteristics of fly ash.

$$y = -79.79 \ln(x) + 264.26 \quad (1)$$

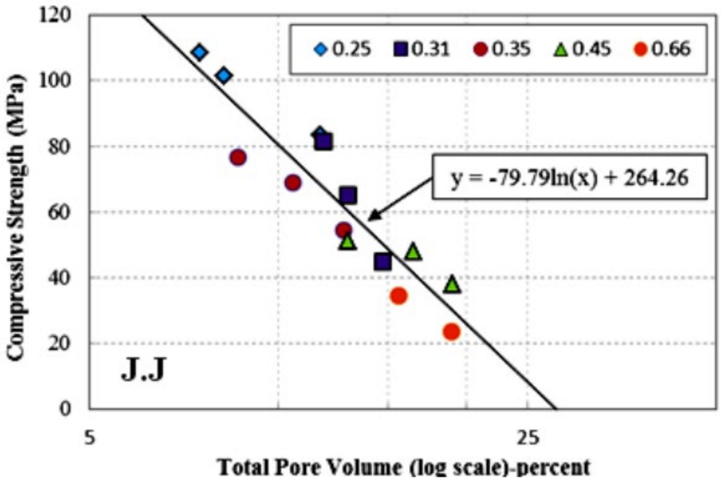
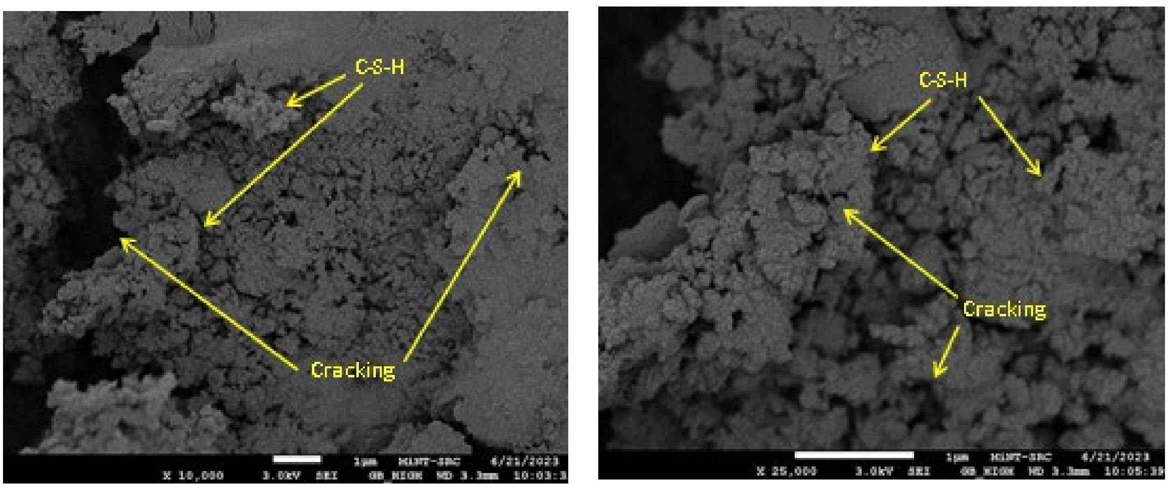



**Fig. 3 - Relationship between compressive strength and total pore volume [23]**

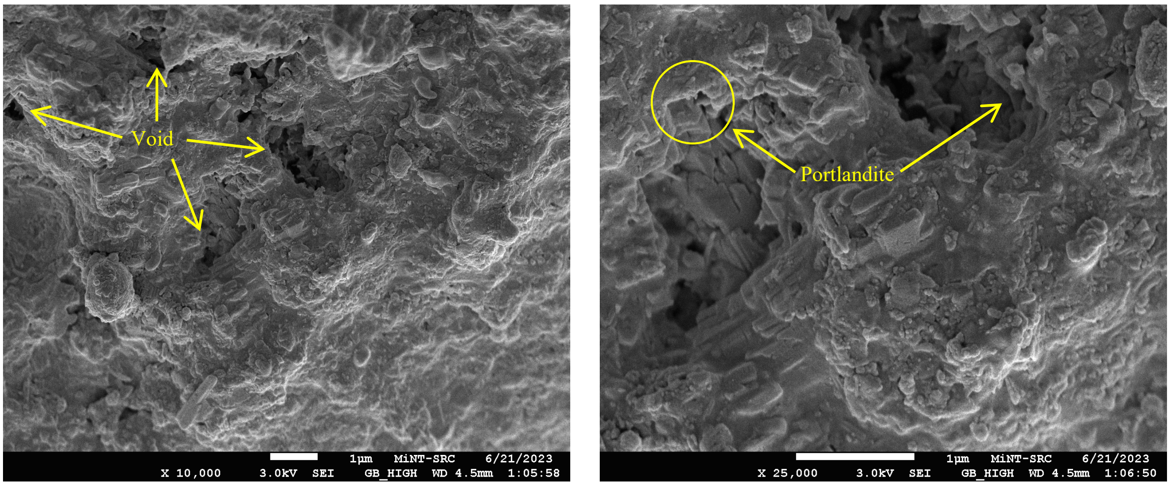
## 3.3 Scanning Electron Microscope (SEM)

The presence of C-S-H in most cement-based materials becomes the main factor of its strength and durability [24]. Fig. 4 shows an image of TW-0FA sample in the magnitude of 10,000 and 25,000 using a scanning electron microscope (SEM). The observation of TW-0FA micro-structure resulted in many C-S-H being produced from the reaction of $C_3S$ and $H_2O$ from ordinary Portland cement and water. There were cracking, which may lead to a reduction in the strength of the concrete. [25]. However, the compressive strength result was 69.5 MPa, exceeding the targeted strength and considered a good result. Fig. 5 shows the image of SW-10FA concrete surface. Based on Fig. 5(a), voids were detected. The presence of voids in the concrete mixture led to the decrement of compressive strength. There were slight differences in the compressive strength of SW-10FA concrete compared to the control mixture.




(a) (b)

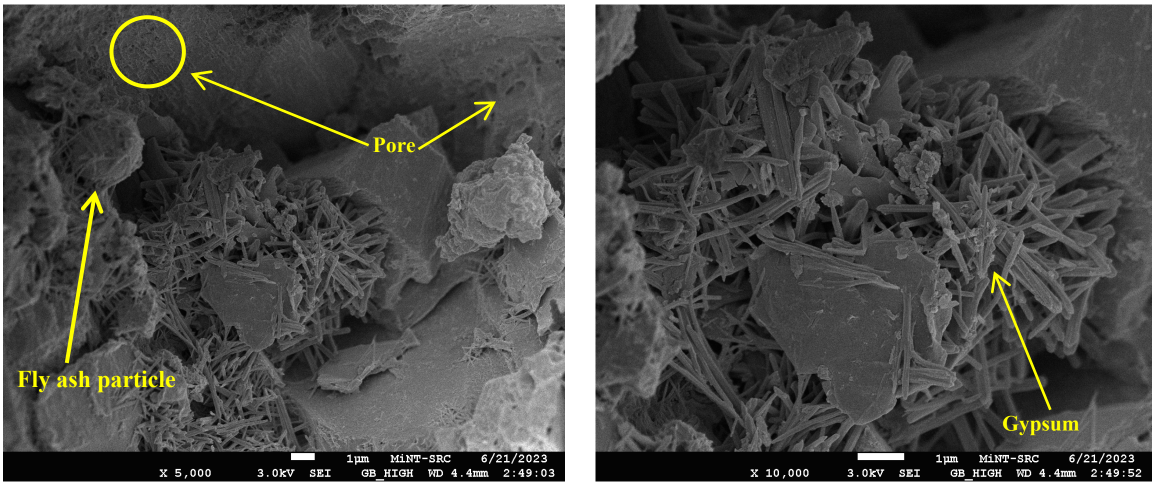
**Fig. 4 - SEM image for TW-0FA in (a) 10,000 magnitude, and; (b) 25,000 magnitude**




(a) (b)

**Fig. 5 - SEM image for SW-10FA in (a) 10,000 magnitude, and; (b) 25,000 magnitude**

However, the pozzolan material such as fly ash required more time to enhance their strength due to the pozzolanic effect delay. Another substance has been found in the concrete mixture shown in Fig. 5(b) which is portlandite ($Ca(OH)_2$). The main effect of the cement on the pozzolanic reaction is the provision of the $Ca(OH)_2$ that reacts with the glassy silica to form the calcium silicate hydrate (C-S-H) [26]. The production of C-S-H will improve the later age of concrete strength while filling the void in the concrete. Fig. 6 is the image for the series with 40 percent fly ash replacement and a smaller result of compressive strength. Fig. 6(a) shows there was an unreacted fly ash particle ($SiO_2$) in the concrete specimen that can reduce the concrete strength. Other factors contributing to the low strength of SW-40FA concrete are pores, gypsum and cracking. Study from Li et al. [27] mentioned that the pore structure of concrete affected concrete where there was deterioration in durability and strength of concrete. Fig. 6(b) shows a large quantity of developing gypsum and a lot of voids and microcracks on this concrete mixture. Excessive gypsum can reduce the concrete's compressive strength [28].




(a) (b)

**Fig. 6 - SEM image for SW- 40FA in (a) 5,000 magnitude, and; (b) 10,000 magnitude**

## 4. Conclusion

Fly ash's low density resulted in a 24% drop in compressive strength when it was used up to 40% of the total binder. The existence of gypsum affects this result. A decrease in slump, density, and compressive strength was observed in concrete with increasing fly ash dose. Even though all results show a reduction in all testing, the fresh mixture was still workable and density in the range of 2370 $kg/m^3$ to 2400 $kg/m^3$. Furthermore, the strength remains within the range of acceptable structural strength values. However, there was no significant result on the role of seawater in the study due to the study's limitations. In future studies, research can be conducted on the specimen pH, salinity, chloride content, mixture setting time and long-term compressive strength. The observation of the SEM picture also supported the result of SW-10FA as an optimum replacement where the presence of portlandite in the concrete mixture is expected to improve the concrete's later strength. This research may include using non-reinforced concrete, such as concrete blocks. Seawater can be used in concrete, but it requires careful consideration and appropriate measures to mitigate the potential adverse effects. Advantagely, using seawater and fly ash in concrete is a sustainable approach and cost-saving.

## Acknowledgement

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through Tier 1 (Vot. Q341). Authors appreciation also goes to The Department of Environment, Putrajaya and Tanjung Bin Power Plant Station, Johor in providing fly ash.

## References

[1] Meena C. S., Kumar A., Jain S., Rehman A. U., Mishra S., Sharma N. K., Bajaj M., Shafiq M. & Eldin E. T. (2022). Innovation in green building sector for sustainable future. Energies, 15(18), 6631.
[2] Prakash R., Thenmozhi R. & Raman S. N. (2019). Mechanical characterisation and flexural performance of eco-friendly concrete produced with fly ash as cement replacement and coconut shell coarse aggregate. International Journal of Environment and Sustainable Development,18(2), 131-148.
[3] Mustapha F. A., Sulaiman A., Mohamed R. N. & Umara S. A. (2019). The effect of fly ash and silica fume on self-compacting high-performance concrete. Materials Today: Proceedings, 39, 965-969.
[4] Li Y., Wu B. & Wang R. (2022). Critical review and gap analysis on the use of high-volume fly ash as a substitute constituent in concrete. Construction and Building Materials, 341, 127889.
[5] Gao Y., Jing H., Fu G., Zhao Z. & Shi X. (2021). Studies on combined effects of graphene oxide-fly ash hybrid on the workability, mechanical performance and pore structures of cementitious grouting under high W/C ratio. Construction and Building Materials, 281, 122578.
[6] Darmansyah D., You S. J. & Wang Y. F. (2023). Advancements of coal fly ash and its prospective implications for sustainable materials in Southeast Asian countries: A review. Renewable and Sustainable Energy Reviews, 188, 113895.
[7] Thomas M. D. A. (2007). Optimising The Use of Fly Ash in Concrete. Portland Cement Association.
[8] Rathnarajan S. & Sikora P. (2023). Seawater-mixed concretes containing natural and sea sand aggregates - A review. Results in Engineering, https://doi.org/10.1016/j.rineng.2023.101457.
[9] Sikora P., Afsar L., Rathnarajan S., Nikravan M., Chung S. Y., Stephan D. & Abd Elrahman M. (2023). Seawater-mixed lightweight aggregate concretes with dune sand, waste glass and nanosilica: Experimental and life cycle analysis. International Journal of Concrete Structures and Materials, 17(1), 47.
[10] Hairan M. H., Jamil N. R., Looi L. J. & Azmai M. N. A. (2021). The assessment of environmental flow status in Southeast Asian Rivers: A review. Journal of Cleaner Production, 295, 126411.
[11] BS 12620:2002+A1 (2008). Aggregates for concrete. British Standards Institute.
[12] BS EN 1097-3:1998 (2008). Tests for mechanical and physical properties of aggregates. Determination of loose bulk density and voids. British Standards Institute.
[13] ASTM D854-10 (2010). Standard test methods for specific gravity of soil solids by water pycnometer. ASTM American Society for Testing and Materials.
[14] BS EN 933-2-2020 (2008). Tests for geometrical properties of aggregates. Determination of particle size distribution. test sieves, nominal size of apertures. British Standards Institute.
[15] Roviello G., Ricciotti L., Molino A. J., Menna C., Ferone C., Asprone D., Cioffi R., Ferrandiz-Mas V., Russo P. & Tarallo O. (2020). Hybrid fly ash-based geopolymeric foams: Microstructural, thermal and mechanical properties. Materials, 13(13), 2919.
[16] Hamada H., Otsuki N. & Nishida T. (2021). Seawater in concrete mix. CRC Press.
[17] Hussain Z., Noor N. M. & Caronge M. A. (2019). Workability and compressive strength of seawater-mixed concrete containing rice husk ash as supplementary cementitious material. International Journal of Integrated Engineering, 11(9), 192-200.
[18] Waliyo R. A. & Noor N. M. (2022). Investigation on material physical properties for application in seawater-RHA concrete added with coal bottom ash. IOP Conference Series: Earth and Environmental Science, 1022, 012051.
[19] Lam N. T. (2020). Assessment of the compressive strength and strength activity index of cement incorporating fly ash. In IOP Conference Series: Materials Science and Engineering, 869, 32052.
[20] Nanda B. & Rout S. (2021). Properties of concrete containing fly ash and bottom ash mixture as fine aggregate. International Journal of Sustainable Engineering, 14(4), 809-819.
[21] Jiang P., Jiang L., Zha J., Song Z. (2017). Influence of temperature history on chloride diffusion in high volume fly ash concrete. Construction and Building Materials, 144, 677-685.
[22] Cho Y. K., Jung S. H. & Choi Y. C. (2019). Effects of chemical composition of fly ash on compressive strength of fly ash cement mortar. Construction and Building Materials, 204, 255-264.
[23] Irmawaty R. (2013). A study on long-term performance of concrete over 50MPa in compressive strength. Doctoral Dissertation, Kyushu University.

[24] Madadi A. & Wei J. (2022). Characterisation of calcium silicate hydrate gels with different calcium to silica ratios and polymer modifications. Gels, 8(2), 75.
[25] Thiedeitz M., Schmidt W., Härder M. & Kränkel T. (2020). Performance of rice husk ash as supplementary cementitious material after production in the field and in the lab. Materials, 13(19), 1-17.
[26] Singh N. B. (2021). Fly ash in the construction industry. Handbook of Fly Ash, Elsevier, 565-610.
[27] Li Y., Ma H., Wen L., Yuan J., Zhang Y., Li Y., Zhou H. & Chen J. (2022). Influence of pore size distribution on concrete cracking with different AEA content and curing age using acoustic emission and low-field NMR. Journal of Building Engineering, 58, 105059.
[28] Taveriyanto A., Andiyarto H. T. C., Saefullah M. V. & Haliza M. P. (2022). The utilisation of gypsum board and fly ash waste on brick in terms of compressive strength to reduce environmental pollution. IOP Conference Series: Earth and Environmental Science, 969 (1), 012012.