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A Systematic Literature Review on the Effect of Seawater as A Promising Material on the Physical and Mechanical Performance of Concrete

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Abstract: Concrete is made from freshwater, cement, and aggregate and the only material shared with mankind, flora, and fauna is freshwater. One of the most concerning problems the world has been facing over the last few decades is the rising demand for freshwater due to the increasing global population and depleting source of freshwater by 2050. In Malaysia, the population is expected to rise from 32 million people in 2020 to 40.50 million people in 2050, which would correspondingly increase the demand for domestic houses, industrial areas, and other building construction as well as increase the overall usage of freshwater. The utilisation of seawater has been applied in constructing buildings and infrastructures since the time of the Roman Empire and the structures still survive for more than 2000 years against chemical attacks and underwater wave force. Given that seawater is considered an alternative mixing agent in concrete production, research on seawater-based concrete has continued to gain interest from the scientific community and undergone swift development. Therefore, the aim of this study was to present a systematic literature review on the recent development of concrete with seawater as the mixing agent and its effect on the physical and mechanical performance of the concrete. A four-stage investigation criterion was conducted for the data collection from the Scopus database, which includes the search parameter, identification, screening, and writing. The screening of the literature retrieved 53 articles, which were then classified based on the physical and mechanical properties of the concrete. Based on the review, the use of seawater as a single mixing agent reduced the physical and mechanical performance of the concrete. However, the incorporation of seawater with special chemical admixture, mineral admixture, and reinforcement with certain treatment resulted in a higher performance of the concrete. Finally, the review highlighted the various potential studies that can be performed to investigate the utilisation of seawater in the construction industry while achieving a sustainable solution to preserve the environment.

Keywords: Seawater, concrete, freshwater, construction, sustainable, fibre

1. Introduction

According to United Nations World Water Development Report 2019, in the event of an inevitable global freshwater shortage, over 685 million people would have restricted access to freshwater by 2050 as the human population in cities and urbanisation continues to skyrocket (UNESCO, 2019). In order to avoid such a crisis, a new

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approach is urgently required to solve this problem. The idea of using seawater instead of freshwater in concrete mixtures has emerged as part of a solution to conserve freshwater given that the surface of the earth is 75% covered with water, which consists of approximately 97.6% seawater and 2.4% freshwater (Oki et al., 2009).

The construction industry consumes a significant quantity of freshwater in the production of concrete. Seawater appears to be a viable possible alternative as freshwater replacement for mixing concrete to save freshwater supplies (Younis et al., 2018). The use of seawater in the production of concrete could also preserve and assist the development of environmental restoration and reduce the environmental effect of concrete, especially in coastal areas where potable water is a scarce resource (Redaelli et al., 2018). From a sustainable standpoint, using seawater for concrete mixture is favourable but the high chloride levels in seawater would cause the steel reinforcement to corrode. This problem can be solved by replacing steel reinforcement with Fibre Reinforced Polymer (FRP) bars as non-corrosive reinforcement (Younis et al., 2018) to maintain the durability of the concrete structures and infrastructures (Redaelli et al., 2018). The use of concrete reinforced with non-corrosive reinforcement or unreinforced concrete provides greater strength to the mixture with seawater (Montanari et al., 2019). Thus, the evolution use of seawater as a substitute for freshwater is a feasible approach nowadays.

The development of seawater-based concrete construction had started from the very beginning with the construction of Caesarea in Palestine. Large quantities of seawater were used in concrete production by Roman architects more than 2000 years ago, which can still be found in 11 harbours along the Mediterranean coast (Elsen et al., 2013). From 1920 onwards, the exploration of the effect of seawater on concrete led to the development of seawater concrete that benefits the development of maritime structure, especially during the height of World War 2 (Sharp et al., 1996). The combination of seawater with other materials in concrete has also been proven over the previous decades. For instance, the combination of seawater with pozzolanic materials, such as fly ash, showed an enhanced concrete performance and reduced calcium hydroxide ($Ca(OH)_2$) content, which was opposite to normal concrete where the $Ca(OH)_2$ content increased over time (Montanari et al., 2019). Thus, the reduction of $Ca(OH)_2$ and water absorption resulted in an improved strength development of seawater-fly ash concrete.

The major purpose of this study was to review the recent development of the potential utilisation of seawater and other usable material in concrete applications. This focus stems from the rising understanding of the environmental impact of the construction industry. The principal research question that has been developed to fulfil the main question is: What is the role of seawater in concrete application and how do academics approach the subject? Based on the main research question, several specific research questions were outlined:

- How did seawater studies for concrete application develop over time?
- How is seawater employed in the concrete?
- How does seawater affect the physical performance of concrete?
- How does seawater affect the mechanical performance of concrete?

The specific objectives of this paper were:

- To assess how interest in this topic has changed over time and how it is distributed geographically.
- To provide an updated overview of the incorporation of seawater with/without recycled materials in concrete construction.
- To explore the effects of seawater on the physical performance of concrete and its recent development.
- To evaluate the effects of seawater on the mechanical performance of concrete and its recent development.

Following the introduction, the research methodology applied in this study was described in Section 2. In Section 3, the material collection process was highlighted, while Section 4 focused on the evaluation of the findings of this study. Hence, through this review, a collective understanding was suggested based on the analysis of various articles that studied the utilisation of seawater in concrete mixing and the evolution of seawater studies in the construction industry with the aim of providing an alternative material in the field of engineering and a mitigating solution towards sustainable and environmental issues (Merli et al., 2020).

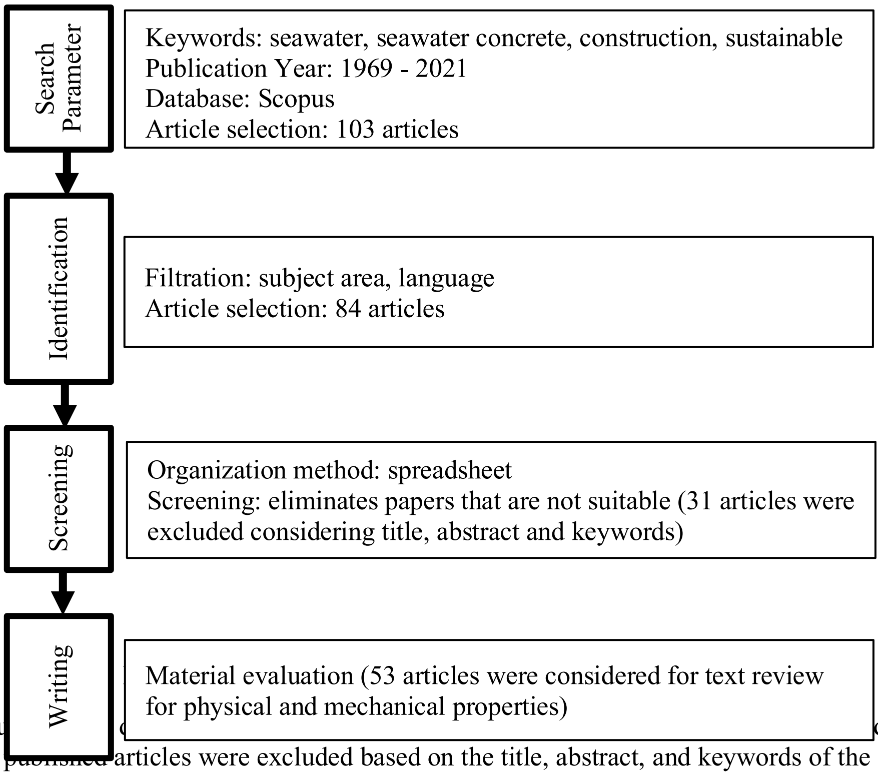
2. Research Methodology

In this study, the research methodology was developed based on a systematic literature review of seawater in concrete using Scopus as the source of the database. Figure 1 shows the four stages to carry out the data collection from the database. Following the guidelines in previous studies (Ismail et al., 2021; Merli et al., 2020; Silvestro et al., 2020), the four stages include the search parameter, identification, screening, and writing. The search parameter involved the use of Scopus as the selected database to obtain the related published papers. The terms 'seawater' and 'concrete' were used as the main keyword, while 'construction' and 'sustainable' were applied as the secondary keywords. Additional parameters were applied to search the related topics in this study, which was summed up as the outcome below:

TITLE-ABS-KEY ((("seawater concrete" OR "sea-con" OR "sea concrete" OR "roman seawater concrete") AND ("seawater" OR "concrete" OR "mixing seawater" OR " seawater mixing") OR ("sustainable" OR "recycle"))).

The range of the publication year was set from 1969 to 2021 (since the study was conducted in June 2021) in which a total of 103 published articles were retrieved. It was important to note that the main keyword used was seawater concrete as a single term so that specific and accurate data on seawater concrete was obtained and avoided the inclusion of studies on the exploration of seawater usage in other sectors.

Next, 84 articles were selected from the identification stage that involved the filtering process of the 103 articles based on the subject area and language of the article. Articles in English were chosen exclusively since English is the



most common langu … de. Following the screening stage, 31 published articles were excluded based on the title, abstract, and keywords of the articles that were not compatible with the scope of the study. Therefore, a total of 53 published papers were selected as the source of articles for the text review in the final writing stage of this study. The data was divided into several categories, such as publication year and subject area of seawater studies. Another category was formed to focus on the influence (either in positive or negative results) of the physical and mechanical properties of concrete using seawater.

3. Synthesis of Results

Based on the data collection method in Figure 1, the identification stage categorised the collected literature studies into two main aspects: the evolution of seawater studies by years and the subject area of the seawater studies, as presented in Figures 2 and 3, respectively. Figure 2 shows that the highest number of papers related to the evolution of seawater studies was 20 papers in 2020, followed by 19 papers in 2019. Interestingly, there were only seven papers in 2017 and 2018 on the same topic, indicating a surge of interest in seawater studies beginning in 2019. The average number of published papers on seawater studies from 1969 to 2018 was 2.125 (two papers per year within 49 years of research). The sudden increase in interest in this topic, which was reflected by the 10% rise in published papers in 2019 and 2020 compared to the previous years, was suggested to be related to the increasing awareness on the potential application of seawater as a valuable material in the construction industry. Hence, various studies were carried out to explore the possibility of seawater as an alternative component in concrete production to reduce the usage of freshwater and provide a sustainable supply of eco-friendly material.

Given that the data collection was performed in June 2021, it was likely that the number of papers related to seawater studies would increase by the end of the year. In addition, the global Coronavirus Disease 2019 (COVID-19) pandemic could have contributed to the increasing number of published papers on seawater studies across 12 different fields. Besides the fact that seawater is non-potable, the usage of seawater could be exploited in other applications. As shown in Figure 3, the engineering sector emerged as the top subject area with 82 published papers, followed by materials science with 53 published papers. Despite the difference in the total number of published papers between the two subject areas, which was approximately 30 papers published in Scopus within 52 years, studies on seawater concrete were published the most in the field of materials science. Moreover, the huge gap between materials science and the energy field with eight papers demonstrated the active research and development of seawater concrete.

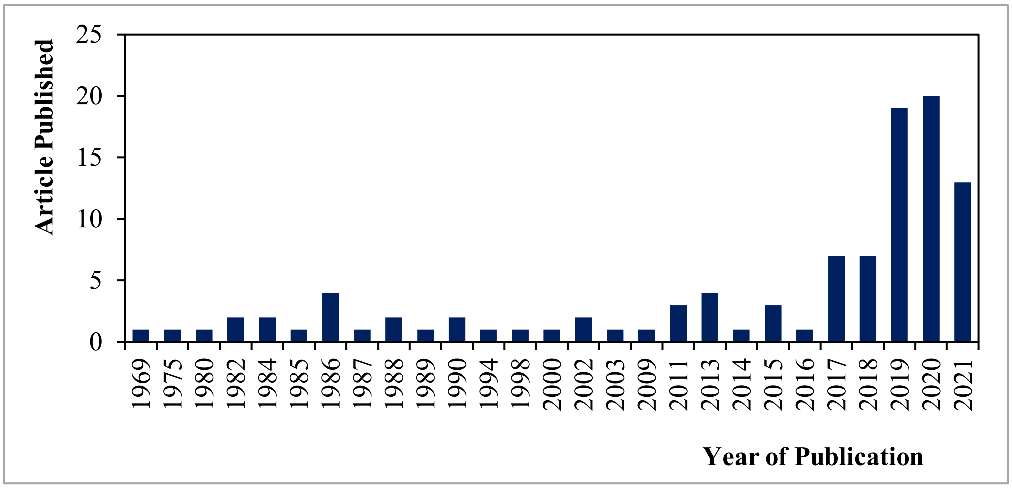


Fig. 2 - Evolution of published studies on seawater studies

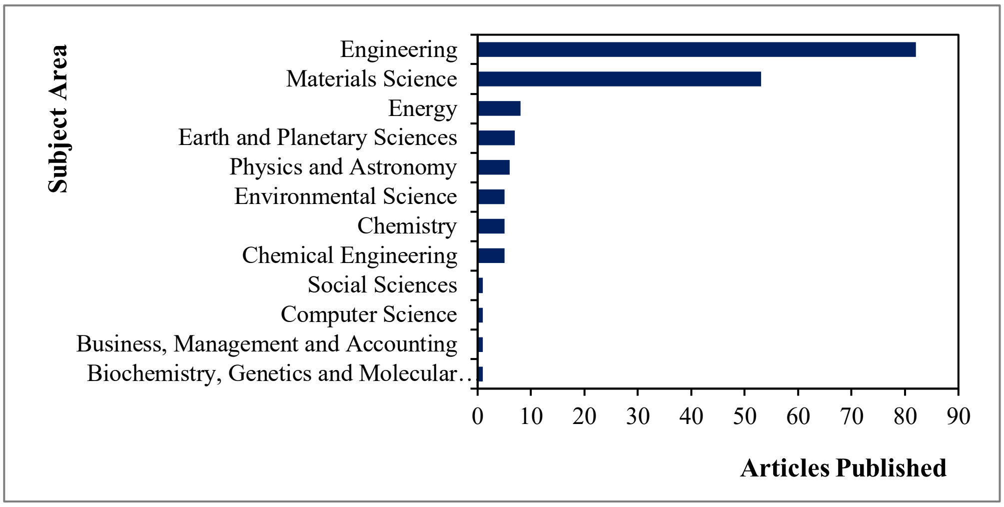


Fig. 3 - Distribution among subject areas about seawater studies

Realising the huge consumption of freshwater in the construction industry, ranging from material preparation in factories, such as mixing and curing of concrete, to the construction of buildings and infrastructures (Rahman & Rahman, 2019), the utilisation of seawater in the engineering field would reduce the use of freshwater while maintaining or improving the concrete performance. According to the origin of the articles, the vast majority of the 53 papers were originated from China (23), followed by unknown/not stated (11), United States (3), and other countries, as shown in Figure 4. Meanwhile, Figure 5 depicts the most frequently used keyword families that were used by each paper with the highest keyword were 'seawater' (28) and 'reinforced concrete' (21). Generally, many keyword families were related to the physical and mechanical properties of seawater concrete.

In the final writing stage of this study, the 53 articles were divided into two categories comprising articles that were reviewed based on the physical properties of concrete and articles that were reviewed based on the mechanical properties of concrete, as presented in Table 1 and Table 2. According to the data distribution of the reviewed articles on the physical properties of the concrete in Table 1, the selected categories were density (20 citations), workability (13 citations), and air content (six citations). The most important physical properties of concrete that should be determined were the density and workability. Usually, the preparation of concrete production begins with the evaluation of the specific gravity to identify the density of the concrete. Based on the density result, the workability was measured using the slump test, which is a critical parameter to develop concrete with a new formulation, such as seawater concrete.

Besides that, Table 2 shows the most essential analysis usually performed in seawater concrete studies. The compressive strength is the most crucial and frequent analysis applied among the 53 articles with 29 citations. The second-highest analysis was the flexural strength, followed by splitting tensile strength analysis with five and four citations, respectively.

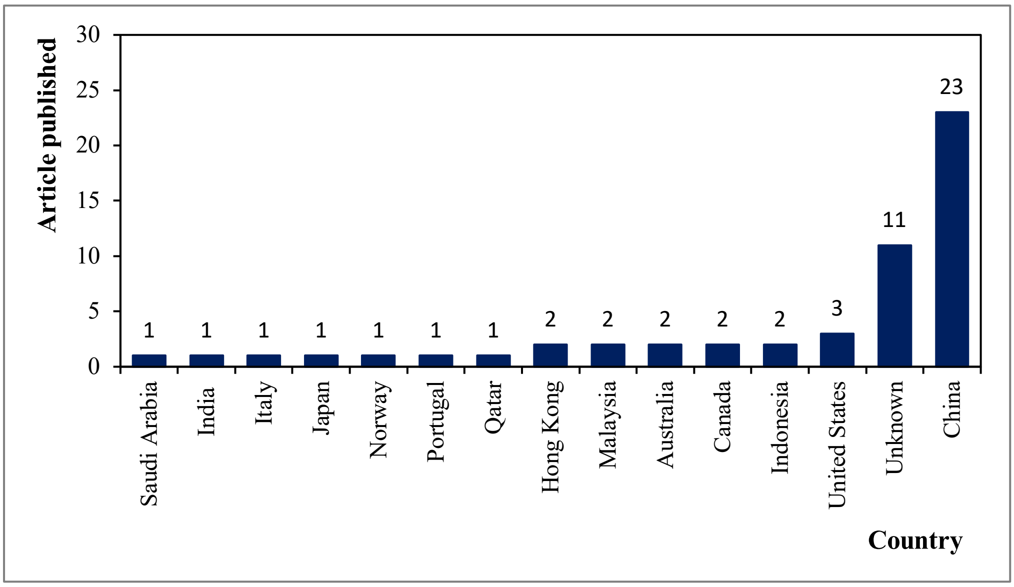


Fig. 4 - Distribution among countries related to 53 seawater-concrete studies under engineering subject area

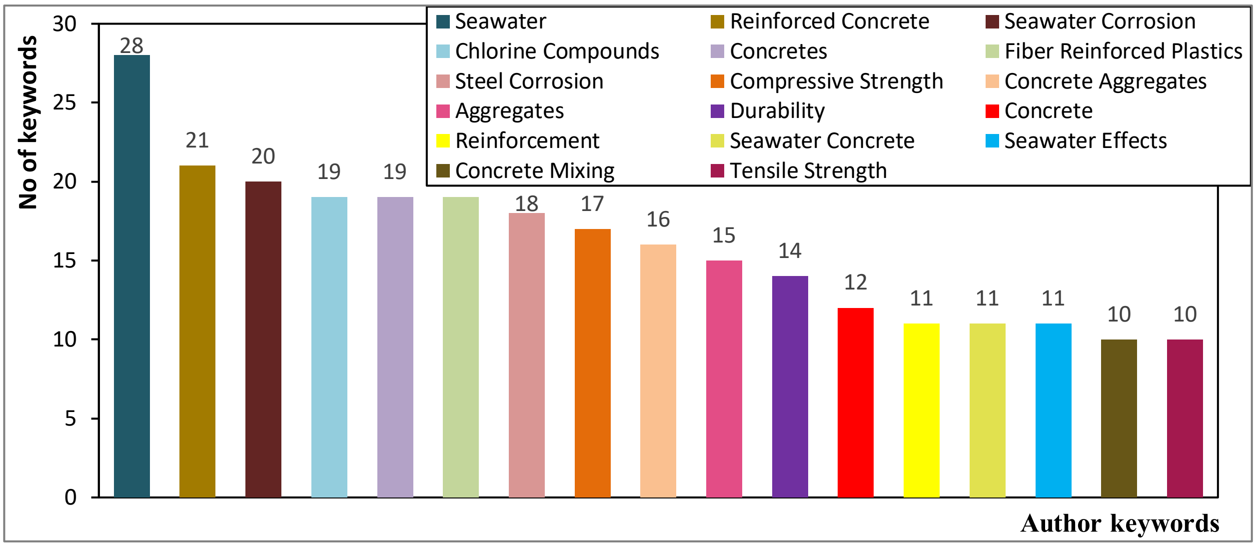


Fig. 5 - Keywords families

Table 1 - Articles reviewed for physical properties

Physical Properties	Articles	References
Workability	13	(Ting M. Z.Y. et al., 2021; Dhondy et al., 2021; Sun et al., 2021; Gao et al., 2020; Li et al., 2021; Parvizi et al., 2020; Ting M. Z. Y et al., 2020; Chen G et al., 2020; Soares et al., 2020; Li, L. G., et al, 2019; Younis et al., 2018; Xiao et al., 2017; Duan et al., 2015)

Density	20	(Ting M. Z.Y et al., 2021; Morales C.R et al., 2021; Dhondy et al., 2021; Sun et al., 2021; Li et al., 2021; He. Z. et al, 2020; Gao et al., 2020; Yin S et al., 2020; Wu. Z et al., 2020; Wang. N. et al., 2020; Ting M Z.Y. et al., 2020; Chen G et al., 2020; Montanari L. et al, 2019; Li, L. G., et al, 2019; Jiang J. et al., 2019; Younis et al., 2018; Mao Y. Z et al., 2018; Shang. B et al., 2018; Xiao et al., 2017; Duan et al., 2015)
Air content	6	(Li et al, 2021; Sun et al, 2021; Ting M. Z. Y. et al., 2020; Montanari et al., 2019; Younis et al., 2018; Duan et al., 2015)

Table 2 - Articles reviewed for mechanical properties

Mechanical Properties	Articles	References
Compressive strength	29	(Ting M.Z.Y. et al., 2021; Sun et al., 2021; Wang et al., 2021; Morales et al., 2021; Dhondy et al., 2021; Zhou J et al., 2021; Da B et al, 2021; Li et al., 2021; Yue C et al., 2021; Dhondy et al., 2020; He X et al.,2020; Yin et al., 2020; Parvizi et al., 2020; Chen G et al., 2020; Mansyur & Permana, 2020; Ma H et al., 2020; Gao et al., 2020; Soares et al., 2020; Adnan et al., 2020; Li, L. G., et al, 2019; ; Montanari L. et al, 2019; Yu H et al., 2019; Gong W et al., 2019; Madona & Sivakumar, 2019; Jiang et al., 2019; Younis et al., 2019; Tan Y et al., 2018; Younis et al., 2018; Duan et al., 2015)
Flexural strength	5	(Li. et al., 2021; Gao et al., 2020; Parvizi et al., 2020; Jiang et al., 2019; Duan et al., 2015)
Splitting tensile strength	4	(Ting M.Z.Y. et al., 2020; Parvizi et al., 2020; Yin et al., 2020; Younis et al., 2018)

4.0 Analysis and Discussions

The water-cement ratio highly influences the workability of the concrete mixture due to the amount of water content. Generally, the water-cement ratio for conventional concrete is 0.5. A low water-cement ratio mixture contains more cement content, which increases the concrete strength but reduced the workability. Hence, a chemical admixture should be added to enhance the workability. In contrast, a low water-cement ratio in seawater concrete mixture exhibits a higher strength but at the cost of reduced workability. Moreover, the presence of chloride in seawater slightly affects the workability compared to normal concrete. The workability can be improved by adding a superplasticiser (chemical admixture) into the concrete mixture. The following section describes the effects of seawater on the physical and mechanical performance of concrete based on the reviewed articles in this study.

4.1 Effect of Seawater On Concrete Workability and Density

The workability effect refers to the compactness of the binder in the concrete mixture to avoid segregation. Previously, the use of seawater as the ‘glue’ in the concrete mixture was able to decrease the initial and final setting duration at 25% and 22%, respectively (Ghorab et al., 1990). However, certain construction-related issues may be greatly solved if the concrete flow could be enhanced without segregation while simultaneously enhances the consistency and workability of the concrete (Grove et al., 2010).

The workability of concrete can be affected by both sea sand and seawater, but the effect is mild and depends on the amount of seashells in the sea sand. Furthermore, seawater concrete exhibits a faster start and ultimate setting time than regular concrete. Nonetheless, the chloride content in seawater would affect the performance of the concrete over time and lead to a decrease in workability, durability, long-term strength, and the worst situation is the collapse of the structural element (Xiao et al., 2017). A lower water-cement ratio was also used in seawater concrete because the salinity of the seawater was found to affect the overall performance of the concrete (Dhondy et al., 2021). In addition, the use of seawater would slightly reduce the slump and spread of cement paste generated in the concrete mixture compared to that of freshwater (Younis et al., 2018).

The incorporation of a superplasticiser in the concrete mixture would improve the performance of seawater concrete. Previously, the use of 0.40 water-cement ratio mixed with 20% fly ash as the superplasticiser showed an increased hydration kinetic process that led to higher heat release of up to 10% compared to normal cement paste concrete (Montanari et al., 2019). Using the same water-cement ratio and the quantity of superplasticiser, the effect of the workability on the slump and spread of the seawater concrete paste was slightly lower than freshwater concrete paste (Li et al., 2019). Moreover, concrete mixed with seawater requires an additional 15% superplasticiser to attain similar workability to the control concrete, while the salt content in seawater decreased over the period it takes for the concrete to cure, resulting in a faster loss of workability (Younis et al., 2018). The volume of water-cement ratio can influence the workability performance either in negative or positive ways.

In terms of the fresh and hardened properties of seawater concrete paste, the water-cement ratio has a positive effect on the workability. A positive effect on adhesiveness was recorded when the water-cement ratio is lower than the optimum range of normal water-cement ratio for maximum adhesiveness, while a negative effect on adhesiveness was recorded when the water-cement ratio is higher than the optimum for maximum adhesiveness. In addition, a positive effect on the cube strength was observed when the water-cement ratio is lower than the optimum for maximum adhesiveness, while a negative effect on the cube strength was observed when the water-cement ratio is higher than the optimum for maximum adhesiveness. The effects of the water-cement ratio on the fresh and hardened properties of seawater paste were the same as the freshwater paste (Li et al., 2019).

Furthermore, the seawater concrete with Glass Fibre Reinforcement Polymer (GFRP) showed similar behaviour for each batch of specimen in terms of the workability of the fresh concrete. There was an insignificant decrease in the consolidation or workability of the seawater mixtures compared to the control batch of specimens. Moreover, the seawater-GFRP concrete was also easily workable into the cube-sized blocks (Parvizi et al., 2020). In another study, the workability of seawater concrete was reduced to 62 mm when seawater was applied to the concrete mixture. The findings could be associated with the lower water-cement ratio, which was the best condition for the seawater concrete rather than control concrete because the seawater concrete consisted of 6.1% ions and demonstrated that the water was not bounded to the ions (Chen, 2020). The chloride content in seawater also affected the acceleration of the cement hydration performance of seawater concrete, which reduced the setting time in the concrete mixture. Other combinations of materials in seawater concrete, such as silicomanganese (SiMn) slag as coarse aggregate and marine sand, reduced the water absorption of the concrete (Ting et al., 2020). The presence of friedel salt reduced the porosity of the concrete as the pores were filled up, resulting in higher concrete strength. Although the workability was relatively low, it was still within an acceptable range.

4.2 Effect of Seawater on Compressive Strength and Hydration of Seawater Concrete

The compressive strength is a key factor in producing an effective alternative concrete product that can be commercialised and used as a convenient material in the construction industry. The compressive strength should be evaluated within 7 to 28 days of the curing process to achieve an optimum strength that can last throughout the service life of the concrete. The initial strength of seawater concrete varies according to the water-cement ratio used in the mixture.

The initial compressive strength of the seawater concrete was higher at 22.5 MPa compared to freshwater concrete at 17.2 MPa in three days (Duan et al., 2015). Other studies found that several initial strengths of seawater concrete increased but eventually weakened. The different exposure of seawater either in control condition or exposed to seawater showed a similar percentage increase compared to the 28-day laboratory control test, demonstrating that the substitution of seawater from freshwater did not affect the compressive capabilities of the concrete (Khatib et al., 2016). In addition, the compressive strength of seawater concrete after 28 days was 7-10% lower than the control sample (Guo et al., 2018). In comparison to concrete with distilled water as the mixing agent, the compressive strength of the cement mortar with seawater at a water-cement ratio of 0.4 rose by 15% and 5% after seven and 14 days, respectively. However, at 28 days, the compressive strength of seawater concrete was almost similar to the concrete with distilled water (Li et al., 2020).

Meanwhile, seawater concrete exhibited a greater compressive strength than conventional concrete with approximately 30% and 16% at seven and 28 days, respectively, in both atmospheric conditions and curing under natural marine conditions (Dhondy et al., 2020). In addition, seawater Sea Sand Concrete (SSC) demonstrated an average strength of 50.90 MPa compared to conventional concrete with an average strength of 49.34 MPa. The strength of SSC was 3.25% higher than the conventional concrete due to the fact that seawater and sea sand do not affect the strength of the concrete. Thus, SSC would be a suitable material to build marine concrete buildings (Gao et al., 2020). However, when the seawater concrete with sea sand was mixed with Basalt Fibre Reinforcement Polymer (BFRP) as the three-dimensional (3D) printing concrete, the reduction percentage of compressive strength increase from 23.5% to 41.8% at 28 days. On the contrary, the compressive strength increased to 120.31 MPa in the absence of the fibres in the seawater-coral sand concrete (CSC)mixture at 28 days (Li et al., 2021). Thus, the results showed the potential application of seawater and coral sand for the production of regular concrete with greater strength.

Moreover, the long-aged development of seawater concrete showed that the compressive strength of self-compacting with seawater using a water-cement ratio of 0.35 increased between 50 MPa and 60 MPa from 60 days to 90 days compared to freshwater concrete (Erniati et al., 2015). The strength of freshwater concrete samples followed by curing with seawater decreased approximately 7%, while the strength of seawater concrete samples followed by curing with seawater decreased approximately 15% in 90 days compared to the control concrete (Guo et al., 2018). After 60 days, the compressive strength decreased to between 60 MPa and 70 MPa at a water-cement ratio of 0.34 (Younis et al., 2018). In contrast, as the water-cement ratio increased from 0.35 to 0.52, the effect of compressive strength of seawater-sea sand concrete dropped from 34.71% to 10.16%. Hence, the high volume of water-cement ratio resulted in the decrease in the compressive strength of the seawater concrete in 90 days due to the reduced density of the concrete and the increase in water absorption (He et al., 2020).

The compressive strength of seawater concrete was also influenced by the chemical content of hydration products, such as chlorine (Cl_2). In one thermodynamic study, in order to optimise the microstructure performance and enhance the compressive strength of the concrete, the pozzolanic reaction between the hydration of cement ($Ca(OH)_2$) and mineral admixture formed a stable hydration product, which consisted of ettringite and siliceous hydrogarnet in the paste (Duan et al., 2015). The hydration process kinetics was considerably improved through the combination of seawater and nano-silica as well as an improved pozzolanic reaction of the paste that produced greater hydration rates. Thus, more C-S-H gel was generated using seawater due to an increased amount of $Ca(OH)_2$ that was accessible for the pozzolanic reaction with nano-silica (Sikora et al., 2020). Using seawater, the reaction rate of the accelerated hydration started between 2 and 48 hours, which resulted in a positive effect. Hence, seawater concrete was able to speed up the hydration of pozzolanic reaction in cement due to the presence of chloride that expedites the precipitation of calcium, ferrite, and aluminate (Li et al., 2020).

Furthermore, the fine porous structure of concrete also affects the compressive strength of seawater concrete. Recently, the pore structure and compressive strength were shown to have a strong connection. Concrete with a higher porosity ratio exhibits a more uniform pore size distribution, better microhardness, and a narrower Interfacial Transition Zone (ITZ) width that provides a higher compressive strength (Duan et al., 2015). In the early stage of seawater concrete development, the compressive strength was higher than that of freshwater concrete because of the increasing limited width of ITZ thickness and the microhardness. However, after 28 days, the lower volume of fine porous structure led to a significant decrease in compressive strength of the seawater concrete at which the strength of freshwater concrete was higher than the strength of seawater concrete by 180 days (Duan et al., 2015). Although cement paste with and without saltwater have equal total porosity, cement paste with seawater exhibited a slightly finer pore structure than paste with deionised water (Montanari et al., 2019). Seawater concrete has a specific influence on the overall porosity reduction and pore structure refinement in the cement paste. Thus, the addition of nano-silica in the cement paste improved the pore structure and reduced the overall porosity (Sikora et al., 2020).

4.3 Effect of Seawater on Flexural Strength and Splitting Tensile Strength

The flexural strength of seawater as part of the concrete material resulted in the flexural crack when 3.0 kN was applied to the beam. In contrast, when the load was increased from 4.8 kN to 9.0 kN, seawater-sea sand concrete mixed with ultra-high ductile cementitious composite created two flexural cracks at the pure bending moment zone (Jiang et al., 2019). The equivalent static load technique and the critical load capacity are used to predict the critical blast loading of seawater-sea sand concrete slab using the quasi-static flexural test (Gao et al., 2020). However, the reduction percentage of flexural strength of seawater-sea sand concrete with Basalt fibre reinforcement (BFR) increase from 1.1% to 14.7% in 28 days but the flexural strength of seawater-sea sand concrete without reinforced fibre was 9.46 MPa (Li et al., 2021). Thus, seawater-sea sand concrete with fibre was able to maintain good flexural strength in concrete as long as the fibre ratio was less than 0.01.

Moreover, the splitting tensile strength of seawater concrete with BFRP bars showed that the strain under tensile testing was 50.79%, which was only 1.28% compared to the average strain rupture (Jiang et al., 2019). The ratio of the actual maximum tensile stress of the BFRP bars to their ultimate tensile strength was an essential element for the determination of the blast resistance of the concrete slabs. Engineers may use the technique to construct seawater-sea sand concrete as the slabs protection since it can accurately anticipate the amount of critical blast loading the slab can withstand (Gao et al., 2020). However, the use of a large amount of fibre needs to be avoided during the mortar making so that the binder is able to mix without difficulty, which would otherwise cause the fibre to tangle and promote air void entrapment, consequently lowering the tensile strength of the mortar. The crack-bridging action of the fibre was reported to improve the tensile strength of the mortar although the amount of fibre added was minimal (Li et al., 2021).

5.0 Conclusion

Based on the four-stage literature review analysis, the number of published articles related to seawater studies has rapidly increased since 2019 due to the increasing awareness of the potential application of seawater as a valuable material in the construction industry. Geographically, the majority of the studies on seawater concrete were from China, United States, and other countries. Most of the studies were related to the evaluation of the physical and mechanical properties of seawater concrete, as indicated by the frequency of the keyword families applied in those studies. Within a span of 49 years, various combinations of materials with seawater have been studied to improve the performance of seawater as an alternative mixing agent in concrete production as well as reducing the negative effect in the concrete. A greater emphasis was given to the development of the physical and mechanical properties of seawater concrete. The use of different water-cement ratios highly affects the physical properties of seawater concrete, particularly the compressive strength. In turn, the compressive strength of seawater concrete can be modified in the early age of the concrete development through the hydration performance in the concrete when the cementitious material reacts with the seawater. It can be concluded that the compressive strength of seawater concrete exhibited the highest strength at an early age compared to the normal concrete. Hence, in the long-aged development, the compressive strength drops along with the increasing porosity and the corrosion in the seawater concrete. However, the strength is still within the acceptable range of above 30 MPa.

The best material to be incorporated in seawater concrete is non-corrosion material, such as polymers, which would avoid the problem of corrosion as experienced with metals in concrete mixtures. The mixing of high silicate content material with seawater concrete forms a considerably robust combination and effective performance in terms of the compressive strength due to the strong C-S-H chain. However, the flexural strength of the seawater concrete was reduced, which led to the cracking of the concrete structure. Thus, the minimal use of fibre in seawater concrete was shown to prevent crack and enhanced the tensile performance.

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