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R.A. RAZAK[1,2*], K. YEN NG[2], M.M. AL BAKRI ABDULLAH[1,3], Z. YAHYA[1,2], R. MOHAMED[1], K. MUTHUSAMY[4], W.A.W. JUSOH[5], M. NABIAŁEK[6], B. JEŻ[7]

INFLUENCE OF SALINITY OF MIXING WATER TOWARDS PHYSICAL AND MECHANICAL PROPERTIES OF HIGH STRENGTH CONCRETE

Dramatic population and economic growth result in increasing demand for concrete infrastructure, which leads to an increment of freshwater demand and a reduction of freshwater resources. However, freshwater is a finite resource, which means that freshwater will be used up someday in the future when freshwater demand keeps increasing while freshwater resources are limited. Therefore, replacing freshwater with seawater in concrete blending seems potentially beneficial for maintaining the freshwater resources as well as advantageous alternatives to the construction work near the sea. There have been few experimental research on the effect of blending water salt content on the mechanical and physical characteristics of concrete, particularly high-strength concrete. Therefore, a research study on the influence of salt concentration of blending water on the physical and mechanical properties of high-strength concrete is necessary. This study covered the blending water salinity, which varied from 17.5 g/L to 52.5 g/L and was determined on the physical and mechanical properties, including workability, density, compressive strength, and flexural strength. The test results indicate that the use of sea salt in blending water had a slight negative influence on both the workability and the density of high strength concrete. It also indicates that the use of sea salt in blending water had a positive influence on both the compressive strength and the flexural strength of high-strength concrete in an earlystage.

Keywords: seawater; salinity; blending water; high strength concrete; compressive strength

1. Introduction

In recent years, the application of seawater to replace freshwater in concrete blending has raised research attention to address the shortage of freshwater due to dramatic population and economic growth [1-2]. Great efforts were made to substitute blending water for freshwater in concrete mixing with seawater in order to reduce redundant resource waste alongside promoting sustainable development in the construction industry [3-5]. The application of seawater in concrete mixing could be promoted by understanding and discovering the key factors that influence the difference in concrete properties between freshwater blended concrete and seawater blended concrete [6].

Dhondy et al. [1] performed a slump test in accordance with ASTM C143 to determine the influence of blending water with different salt concentrations on the workability of normal strength concrete. They discovered that the artificial seawater blended concrete provided a higher slump value compared to freshwater blended concrete. Besides that, Teng et al. [7] performed a free mini-slump spread test in accordance with ASTM C1856 to determine the influence of blending water with different salt concentrations on the workability of ultra-high strength concrete. They observed that the artificial seawater blended concrete had a lower slump spread compared to the freshwater blended concrete. Both of the observations can be explained by the influence of chloride ions on hydration where the chloride ions chemically bound with the AFm (aluminate-ferrite-mono) phase to form a stable phase which is named as Friedel's salt: $3CaO \cdot Al_2O_3 \cdot CaCl_2 \cdot 10H_2O$, thus enhancing the hydration process [3].

Teng et al. [8] performed a density test in accordance with ASTM C642-13 to determine the influence of different salt con-

1 UNIVERSITI MALAYSIA PERLIS, GEOPOLYMER AND GREEN TECHNOLOGY, CENTER OF EXCELLENCE (CEGEOGTECH), KANGAR, MALAYSIA
2 UNIVERSITI MALAYSIA PERLIS (UNIMAP), FACULTY OF CIVIL ENGINEERING TECHNOLOGY, PERLIS, MALAYSIA
3 UNIVERSITI MALAYSIA PERLIS (UNIMAP), FACULTY OF CHEMICAL ENGINEERING TECHNOLOGY PERLIS, MALAYSIA
4 MALAYSIA PAHANG, FACULTY OF CIVIL ENGINEERING TECHNOLOGY, UNIVERSITI PAHANG MALAYSIA
5 UNIVERSITI TUN HUSSEIN ONN, FACULTY OF ENGINEERING TECHNOLOGY, PAGOH, JOHOR, MALAYSIA
6 CZĘSTOCHOWA UNIVERSITY OF TECHNOLOGY, FACULTY OF PRODUCTION ENGINEERING AND MATERIALS TECHNOLOGY, DEPARTMENT OF PHYSICS, 19 ARMII KRAJOWEJ AV., 42-200 CZĘSTOCHOWA, POLAND
7 CZESTOCHOWA UNIVERSITY OF TECHNOLOGY, FACULTY OF MECHANICAL ENGINEERING AND COMPUTER SCIENCE, DEPARTMENT OF TECHNOLOGY AND AUTOMATION, L9C ARMII KRAJOWEJ AV., 42-200 CZESTOCHOWA, POLAND

* Corresponding author: rafizarazak@unimap.edu.my

centrations on the density of ultra-high strength concrete. They found out that the artificial seawater blended concrete had lower density compared to the freshwater blended concrete at curing periods of 1-day, 28-day and 90-day. Furthermore, the density of the artificial seawater mixed concrete generally decreased as the salt concentration of the blending water increased from 18 g/L to 72 g/L.

Dhondy et al. [1] performed a compressive strength test in accordance with ASTM C469 by using the M500-50 computer controlled universal materials testing machine to determine the influence of blending water with different salt concentrations on the compressive strength of normal strength concrete at curing periods of 1 day, 7 days, 14 days, 28 days, 60 days, and 90 days. They determined that adding artificial saltwater to concrete boosted its early strength, and the suggested optimal salt content of blending water for standard strength concrete was 33 g/L. Furthermore, Teng et al. [6]conducted an ASTM C109 cube compressive strength test to examine the effect of mixing water with varied salt concentrations on the compressive strength of ultra-high strength concrete during curing times of 1 day, 7 days, 14 days, 28 days, and 90 days. They found out that the application of artificial seawater also increased the early strength of concrete and the recommended optimum salt concentration of blending water for ultra-high strength concrete was 18 g/L. The higher compressive strength in both of the previous studies could be explained by the chloride ion effect in artificial seawater. The chloride ions promoted the formation of Friedel's salt during the hydration process and led to the densification of the concrete microstructure [1].Thus, the complete variation of blending water at different salt concentrations is crucial to be explored since it greatly affects the strength of concrete. Therefore, the purpose of this research is to investigate the effect of blending water salinity on the physical and mechanical properties of high-strength concrete.

2. Methodology

2.1. Materials

Type I ordinary Portland cement (OPC) with a 52.5 grade conforming to EN 197-1 CEM I 52.5N was used in this study. Meanwhile, for aggregates, sand passing through a 5 mm sieve was used as the fine aggregates, whereas gravel passing through a 20 mm sieve and predominantly retained on a 10 mm sieve was used as the coarse aggregates. Superplasticizer (MasterGlenium SKY 8333) was also utilized to improve the slump retention and workability of concrete for both freshwater blended concrete and artificial seawater blended concrete. The dosage of MasterGlenium SKY 8333 was 1.5% of the weight of cement..

Tap water was used as blending water for Mix 1 and as curing water for all mixes. Besides that, artificial seawater was used as blending water for Mixes 2 to 4. The artificial seawater was a combination of tap water and dissolved sea salt with three different doses, which ranged from 17.5 g/L to 52.5 g/L with a gap of 17.5 g/L to simulate 50% to 150% of the average salt concentration of the world ocean.

2.2. Sample Preparation

Four mixes of samples were prepared as indicated in TABLE 1. Mix 1 was blended with tap water which acted as the control group. Mixes 2 to 4 were blended with three different salt concentrations of artificial seawater which ranged from 17.5 g/L to 52.5 g/L with a gap of 17.5 g/L.

TABLE 1

Mix proportions of freshwater blended concrete and artificial seawater blended concrete

Concrete Mix	OPC (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water (kg/m^3)	SP (kg/m^3)	Salt dose (g/L)
Mix 1	487	495	1211	180	7.31	0.0
Mix 2	487	495	1211	180	7.31	17.5
Mix 3	487	495	1211	180	7.31	35.0
Mix 4	487	495	1211	180	7.31	52.5

Note: OPC: Ordinary Portland Cement; SP: Superplasticizer.

Firstly, the ordinary Portland cement, fine aggregates, and coarse aggregates were mixed evenly for 6 minutes. Next, superplasticizer and 60% of water were poured in and continued the mixing process for 3 minutes. Finally, the remaining water was added in and continued mixing for 5 minutes until an acceptable level of fluidity in the concrete was reached.

The freshly blended concrete was cast into 100 mm × 100 mm × 100 mm of cube moulds and 500 mm × 100 mm × 100 mm of rectangular prism moulds. The fresh concrete was poured into the moulds in three equal layers, and each layer was stroked 35 times by a tamping rod. The specimens were demoulded after 24 hours and cured in a curing chamber which was maintained with a humidity of 50% and temperature of 23 ± 2°C.

For physical properties tests of concrete, 36 cube specimens were cured in freshwater for curing periods of 1-day, 7-day and 28-day for dry density test. For mechanical properties tests of concrete, 36 cube specimens were cured in freshwater for curing periods of 1-day, 7-day and 28-day for compressive strength test of concrete cubes and 36 rectangular prism specimens were cured in freshwater for curing periods of 1 day, 7-day and 28-day for flexural strength test. Hence, there were a total of 72 cube specimens and 36 rectangular prism specimens prepared in this study.

2.3. Testing

BS EN 12350-5 (2009) [8] flow table test was performed to assess the workability of new concrete by measuring the spread of concrete on a jolted flat plate.The mould was placed in the centre of the flow table and filled by using the scoop with concrete in two equal levels. Each layer was levelled by softly tamping ten times with the tamping rod. The mould was elevated vertically by the handles. The flow table was raised until it reached the higher stop and allowed to fall to the lower stop for a total of 15 drops. The maximum size of the concrete spread in two directions, d1 and d2, parallel to the table borders, was measured and recorded.

To estimate the density of hardened concrete in a saturated state, a dry density test was performed in accordance with BS 1881-114 (1983) [9]. The specimen was completely submerged in water. The specimen was taken from the curing chamber and weighed after 1-day, 7-day, and 28-day curing periods. The saturated density of the specimen was calculated by dividing the mass of the saturated specimen in air in kilogrammes by the volume of the specimen determined by its dimensions in cubic metres.

To evaluate the compressive strength of concrete cubes, a compressive strength test was performed in line with BS 1881-116 (1983) [10]. The cube specimen was removed from the curing chamber and placed in the concrete compression machine after 7-day, 14-day, and 28-day curing periods. The load was applied and constantly raised at a nominal rate of 10 mm/min until no further load could be maintained. The greatest load that could be applied to the specimen was recorded.

To assess the flexural strength of hardened concrete, a flexural strength test was performed in line with BS 1881-118 (1983) [11]. The rectangular prism specimen was removed from the curing chamber after 1-day, 7-day, and 28-day curing periods and accurately centred in the universal testing machine, with the longitudinal axis of the specimen at right angles to the rollers. The load was applied and constantly raised at a nominal rate of 10 mm/min until no further load could be maintained. The greatest load that could be applied to the specimen was recorded.

3. Result and Discussions

3.1. Workability

The workability with different salinity of blending water can be presented as in Fig. 1. According to Fig. 1, the workability decreased gradually when the salinity of blending water increased from 0.0 g/L to 52.5 g/L with a gap of 17.5 g/L. These observations can be explained by the effect of chloride ions in salt water. During the hydration process, the calcium, aluminate, and ferrite ions were consumed to create Friedel's salt, thus increasing the hydration kinetics and speeding the hydration rate of C3S, C3A, and C4AF[2] [12]. Moreover, artificial seawater blended concrete with a salinity of 17.5 g/L had the highest workability among the artificial seawater blended concretes, and thus 17.5 g/L was recommended as the optimum salinity of blending water for the workability of concrete.

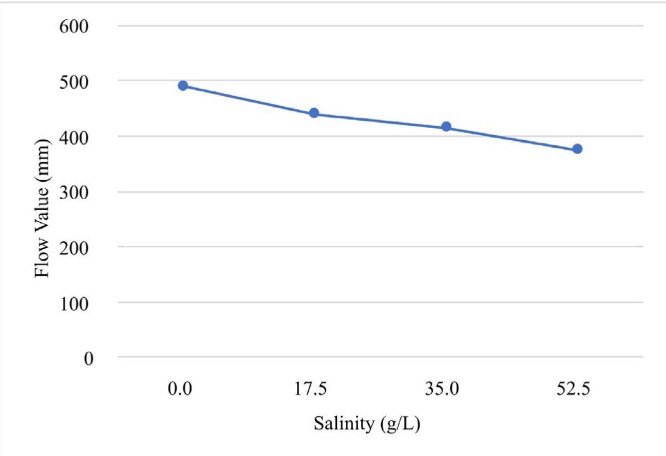

Fig. 1. Relationship between flow value and salinity of blending water

3.2. Density

Fig. 2 shows the density development of concrete with different salinity applied. As shown in Fig. 2, the density of all the concretes increased with age due to the constant water absorption process of concretes during tap water curing. Besides that, the density generally decreased when the salinity of the blending water increased from 0.0 g/L to 52.5 g/L with a gap of 17.5 g/L. Moreover, the artificial seawater blended concrete with a salinity of 17.5 g/L had the highest density among the artificial seawater blended concretes at curing periods of 1-day, 7-days and 28-days. However, other salinities also showed comparable density with the Mix 2 with salinity of 17.5 g/L.

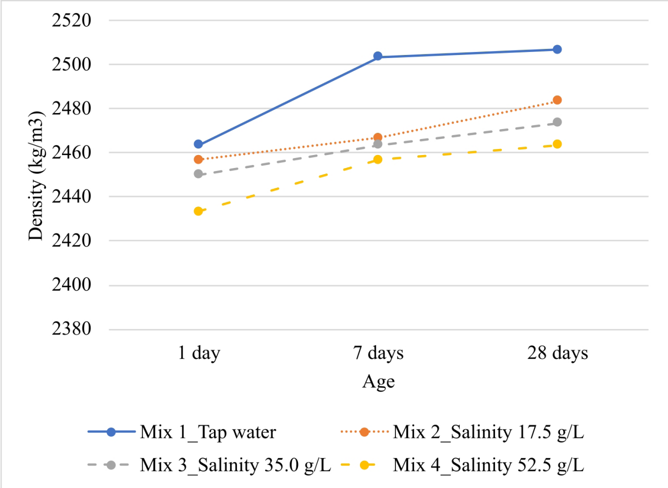

Fig. 2. Density development of concrete

3.3. Compressive strength

Fig. 3 indicates the compressive strength development of concrete. According to Fig. 3, the compressive strength of all the concretes increased with age and the maximum strength of 86 MPa was observed at 28 days for 17.5 g/L and 35.0 g/L samples, which can be explained due to the constant water absorption process of concretes during tap water curing . Besides that, at curing periods of 1-day and 28-day, the artificial seawater blended concrete had higher compressive strength compared to the freshwater blended concrete. This observation can be explained by the effect of chloride ions in salt water. The chloride ions promoted the formation of Friedel's salt during the hydration process and led to the densification of concrete microstructure [1,13]. In addition, the formation of calcium chloride ($CaCl_2$) when the salt or sodium chloride (NaCl) in mixing water reacted with calcium hydroxide ($Ca(OH)_2$) in the concrete mixtures was believed to accelerate the hydration process and increase the heat released [1,3]. In other words, the accelerated hydration process caused the concrete to be hardened faster and thus resulted in a reduction in concrete workability, which was proved by the reduction of flow value found in this study [14].

Moreover, at curing periods of 1-day, 7-day and 28-day, the compressive strength of concrete increased when the salinity of blending water increased from 0 g/L to 17.5 g/L. However, the compressive strength of concrete started to decrease when the salinity of blending water kept increasing from 17.5 g/L to 52.5 g/L with a gap of 17.5 g/L, but still comparable with the control sample of Mix 1. Since the artificial seawater blended concrete with a salinity of blending water of 35.0 g/L has almost similar compressive strength to the artificial seawater blended concrete with a salinity of blending water of 17.5 g/L, 35.0 g/L was recommended as the optimum salinity of blending water for compressive strength of concrete.

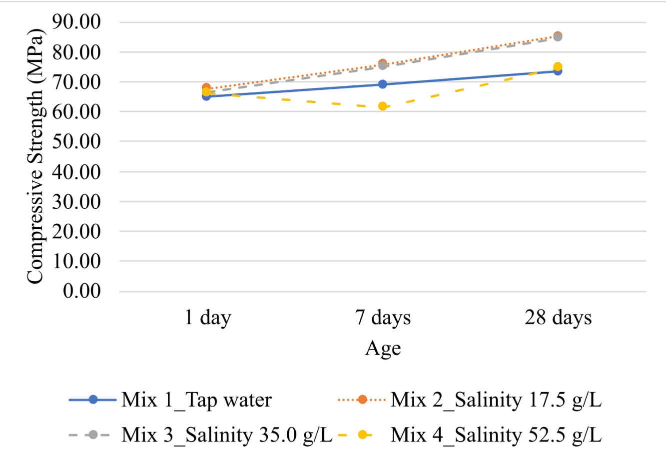

Fig. 3. Compressive strength development of concrete

3.4. Flexural strength

Fig. 4 shows the results of the flexural strength development of concrete. As depicted in Fig. 4, the flexural strength of all the concretes increased with age. These observations can be explained by the constant water absorption process of concrete during tap water curing. Besides that, at curing periods of 1-day and 28-day, the artificial seawater blended concrete with blending water salinity of 17.5 g/L and 35.0 g/L had higher flexural strength compared to the freshwater blended concrete. This observation can be explained by the effect of chloride ions in salt water. The densification of the concrete microstructure was led by the creation of Friedel's salt during the hydration process, which was promoted by the chloride ions [1,15]. Moreover, at curing periods of 1-day, 7-day, and 28-day, the flexural strength of concrete increased when the salinity of blending water increased from 0 g/L to 35.0 g/L. However, the flexural strength of concrete started to decrease when the salinity of blending water kept increasing from 35.0 g/L to 52.5 g/L, which tallied with the finding of compressive strength. Therefore, 35.0 g/L was recommended as the optimum salinity of blending water for the flexural strength of concrete. This result of flexural strength also contradicts with the study carried out by Bhargav et al. [16] which stated that the concrete mixed and cured with seawater had slightly lower flexural strength compared to the concrete mixed and cured with freshwater. This study proves the better increment of flexural strength of concrete with blending water at a salinity of 35.0 g/L compared to freshwater only.

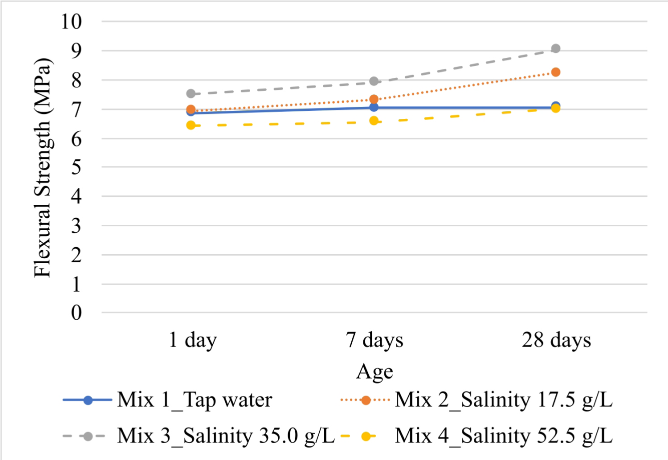

Fig. 4. Flexural strength development of concrete

4. Conclusions

In conclusion, the utilization of sea salt in blending water had a slight negative influence on both the workability and the density of high strength concrete. Besides that, 17.5 g/L was the optimum blending water salinity for both the workability and the density of high strength concrete. However, the 35.0 g/L sample did not differ significantly from the 17.5 g/L result in both workability and density tests. Therefore, 17.5 g/L to 35.0 g/L can be concluded as the optimum range for blending water salinity for the physical properties of high strength concrete.

Meanwhile, in terms of the mechanical results, the use of sea salt in blending water had a positive influence on both the compressive strength and the flexural strength of high strength concrete in the early stages. Besides that, 35.0 g/L was the optimum blending water salinity for both of the compressive strength (86 MPa) and the flexural strength (9 MPa) which can be classified as high strength concrete. Hence, 35.0 g/L can be concluded as the optimum blending water salinity due to the performance of the physical and mechanical properties of high-strength concrete reported in this study.

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