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DEVELOPMENT OF SUSTAINABLE CONCRETE BY USING NON-POTABLE AND SANITARY WATER IN THAILAND

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ABSTRACT: This study investigated the effects of various water types in concrete mixes to minimize freshwater consumption and combat scarcity. River water, sea water, estuary water, domestic wastewater, and fresh water were assessed, analyzing concrete properties such as water absorption, compressive, flexural, and splitting tensile strengths. Results indicated comparable failure modes across different water types in compression, flexure, and splitting. Estuary water decreased compressive strength by 8%, while other water types enhanced it, with domestic wastewater showing the most improvement. Splitting tensile strength saw no significant reductions; domestic wastewater exhibited the highest enhancement (24.39%), followed by estuary and river water, whereas estuary water led in flexural strength improvement. Domestic wastewater reduced absorption and increased slump by up to 60%. To summarize, domestic wastewater positively influenced compressive and splitting tensile strengths, decreased water absorption, and increased slump. River water exhibited properties akin to fresh water, implying its suitability; further exploration into reinforced concrete using these water sources is suggested.

Keywords: Water replacement, Concrete, Compressive strength, Splitting tensile strength, Water absorption, Slump

1. INTRODUCTION

Owing to shifts in climate patterns and the impact of deforestation, this reliance on water could potentially trigger a scarcity of freshwater resources. Notably, the concrete industry emerges as a significant consumer of water, underscoring its role as one of the foremost sectors contributing to extensive water usage [1,2]. Global industrial activities are projected to escalate water consumption to 1,500 billion cubic meters by the year 2030, a substantial increase from the 800 billion cubic meters recorded in 2009 [3,4]. In Thailand, groundwater holds significant importance as a water source. Groundwater serves as the primary water supply for approximately 20 percent of the country's 220 towns and cities, as well as for half of its 700 sanitary districts. Estimates indicate that around 75 percent of the domestic water demand is met through groundwater extraction [5]. Due to excessive historical and ongoing groundwater usage, Thailand is currently undergoing its most severe drought in four decades. Substituting freshwater or tap water with alternative sources like river water (RV), estuary water (EW), and sea water (SW) in concrete production could alleviate water scarcity. Repurposing these water sources for concrete not only promotes sustainable construction practices but also helps conserve and recover drinking water, addressing Thailand's water shortage [6]. Roughly one trillion cubic meters of freshwater are annually consumed in the construction sector, with approximately 500 liters of freshwater needed to produce each cubic meter of concrete [7]. Chemical impurities in water are detrimental to the resulting concrete and therefore, several limits are imposed by current codes [8–10]..

Recently, several researchers have observed the utilization of various water types in the production and curing of concrete. The compressive strength of specimens crafted with reclaimed wastewater exhibited an increase of 8%–17% when utilizing 25%–100% reclaimed water. Another study by Su et al. [11] delved into the use of different water sources (tap water, underground water, and wash water) for concrete mixing. This research unveiled a direct influence of mixing water quality on concrete's fresh and hardened attributes, encompassing workability, setting time, strength development, and overall durability. Younis et al. [12] investigated seawater as a sustainable alternative for mixing concrete. Seawater's chemical composition indicated TDS of around 30,300 mg/l and chloride and sulfate levels of 18,600 mg/l and 2359 mg/l, respectively. Findings showed minimal impact on density and air content, but workability and initial setting time were significantly affected. In terms of mechanical properties, a decline of 7%–10% was noted in compressive and tensile strength. Aldossary et al. [13] explored the impact of Total Dissolved Solids (TDS) found in the mixing water on concrete properties in both its fresh and hardened states. Various experimental evaluations were carried out, encompassing workability, initial setting time, air content, compressive strength, water absorption, water permeability, chloride permeability, and electrical resistivity. The outcomes demonstrated a clear trend: as TDS concentration increased, workability and initial setting time decreased. When TDS concentrations were higher, the air content and water absorption of the concrete reduced by around 31% and 6%, respectively.

The ongoing discussion suggests that the production of concrete utilizes massive amount of fresh water estimated at 500 liters for each cubic meter of concrete [7]. The numbers are alarming and water resources other than fresh water must be investigated to produce concrete. At present, no experimental work is conducted to investigate the behavior of concrete that employed non-potable water to produce concrete in Thailand. There is a need to explore the use of water resources other than the fresh water in Thailand for concrete production, especially when Groundwater serves as the primary water supply for approximately 20 percent of the country's 220 towns and cities [5].

2. RESEARCH SIGNIFICANCE

This study evaluates how sea, estuary, river, and dishwashing water affect concrete's compressive strength, flexural strength, splitting tensile strength, and water absorption when replacing tap water entirely. This is a preliminary study that explores the utilization of various water resources in Thailand for concrete production. The results are compared to those of control concrete. The research presents a solution to alleviate drinking water scarcity by repurposing these otherwise wasted water sources. Amid increasing global challenges in securing safe drinking water, utilizing these resources for concrete production holds a dual benefit: fostering sustainable construction practices and concurrently conserving and reclaiming water used in concrete. Depending on the construction area—be it coastal, urban, or rural—optimal water sources like sea, estuary, river, or dishwashing water was selected for this purpose. In Thailand, two major sources of water are river and sea. Therefore these two sources were included. Water was also collected at the mouth of river (Estuary water) to see the effect of water with combined properties of river and sea. Further, according to statista statics approximately 49% population in Thailand is dining out and huge amount of waste water is generated during washing the dishes. Therefore domestic waste water was also considered in this research. Finally, fresh water was also considered to compare the mechanical properties of concrete made with non-potable water with the concrete made with potable water.

3. METHODOLOGY

3.1. Specimen Details

A total of 60 specimens were tested in the present study to assess the properties of compressive strength, flexural strength, tensile strength, and water absorption. Cylindrical specimens of 150×300 mm to determine the concrete strength in compression and tension, the prismatic specimens 100×100×500 mm to determine the concrete flexural, and the square specimens of 150×150×150 mm to determine the water absorption of the concrete were cast in accordance with ASTM C192/C192M-19 [14]. Thus, 15 specimens were tested to determine each of the above-mentioned properties of concrete. Fifteen specimens were categorized depending on the type of mixing water, mainly fresh water (FW), estuary water (EW), river water (RW), sea water (SW), and domestic wastewater (DWW). It is noted that river water was collected from Chao Phraya River and sea water from Bang Saen Beach. Thus, five different types of water were utilized, whereas three specimens were tested for each water type, making 15 specimens against a particular concrete property.

3.2. Material Properties

Type I Portland cement was used. The coarse aggregates were crushed rocks (water absorption was between 1-2%). Natural sand was used as fine aggregates rocks (water absorption was between 2-4%). The target strength of the concrete at 21 days (f_c) was 20 MPa and every mix was allotted a mixing time of 1 minute and 20±5 seconds. The mix design procedure was carried out in accordance with ACI 211 [15] using a water/cement ratio of 0.69. The mixing proportions are presented in Table 1. The mixing of concrete was performed by using a rotating mixer. The maximum aggregate size was 20 mm. Each mix was prepared by using the same amount of water. The slump corresponding to control, SW, EW, RW, and DWW was 75 mm, 15 mm, 15 mm, 20 mm, and 120 mm, respectively. Typical specimens are shown in Fig.1.


(a)


(b)

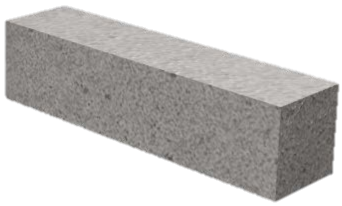

(c)

Fig. 1 Typical specimens for (a) compression, (b) water absorption, and (c) flexural and splitting testing.

Table 1 Mix design proportions

Cement (kg/m^3)	Fine Aggregates (kg/m^3)	Coarse Aggregates (kg/m^3)	Water (kg/m^3)
276	966	966	193

3.3. Specimen Preparation and Test Setup

Concrete ingredients were mixed in rotary mixer and subjected to rotations for a period of 80 seconds approximately. Steel molds were used to cast specimens. Each mold was filled with three equal layers of concrete, whereas each concrete layer was subjected to a uniform compaction. A complete process for specimen fabrication is shown in Fig. 2. A Universal Testing Machine was used to apply loads, as shown in Fig. 3. The capacity of Universal Testing Machine was 500 kN. The water absorption test was performed in accordance with ASTM C1585-20 [16]. Specimens were over-dried for a period of 24 hours, weighed, and immersed in water for a period of 48 hours. Then, specimens were weighed again to complete the process, as shown in Fig. 4. Proper care was ensured during placement of specimens to avoid damage to the concrete specimens. All specimens were properly marked with suitable numbers.

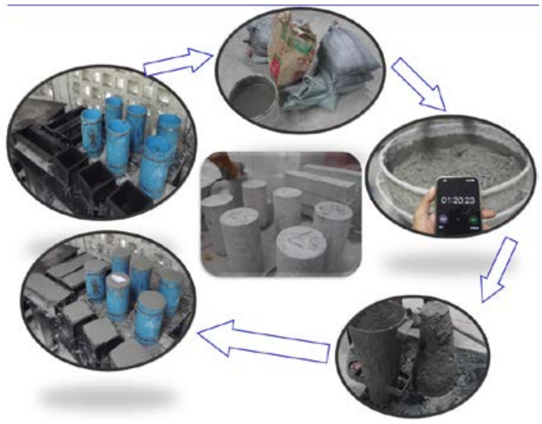
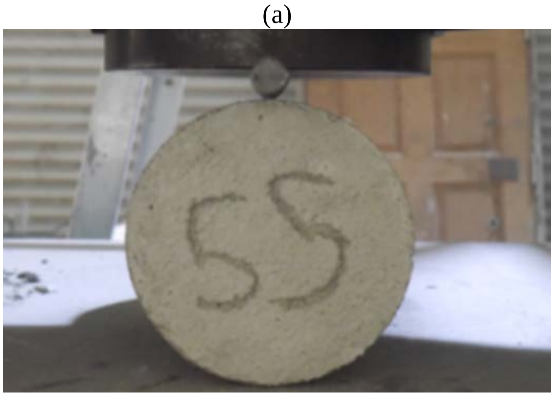


Fig. 2 Specimen fabrication.


(a)



(b)

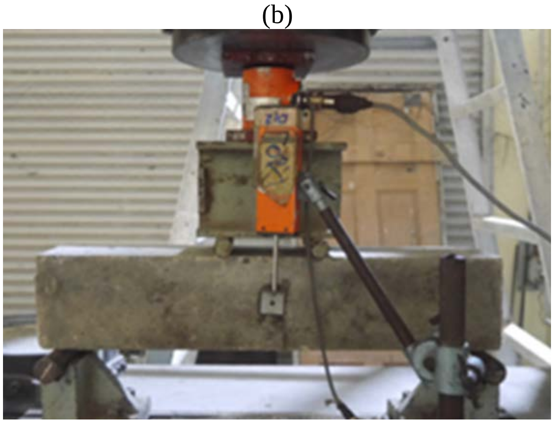

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Fig. 3 Typical tests for (a) compression, (b) splitting tensile, and (c) flexural strength by using Universal Testing Machine.

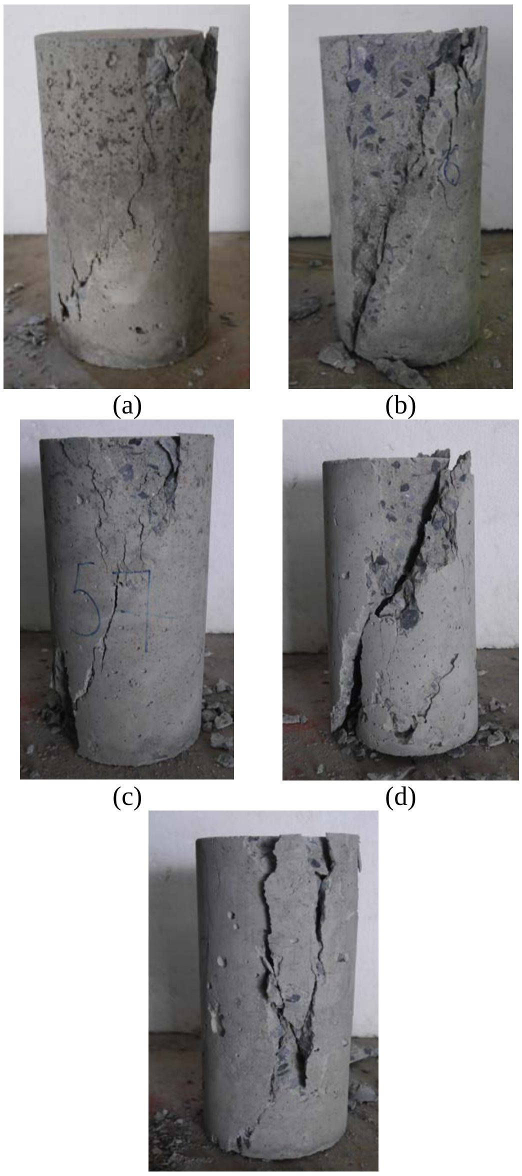
Fig. 4 Typical cycle in water absorption test.

4. EXPERIMENTAL RESULTS

4.1. Failure Modes

The failure modes of concrete specimens under compression, flexure, and splitting are well known. In this section, the impact of different waters on physical behavior of concrete is discussed, particularly with the focus on compressive, flexure, and splitting tensile behavior.

The failure modes in compression are shown in Fig. 5. The failure of all specimens was typical, i.e., accompanied by crushing of concrete and splitting along the longitudinal axes of cylinders. The splitting cracks propagated within the whole length of all specimens. Characteristically, the failure of specimens was not notably different from the failure of Specimen FW. In a similar way, the flexure failure of all specimens is shown in Fig. 6. All specimens demonstrated splitting in a direction perpendicular to longitudinal axis beams. The failure modes in splitting are shown in Fig. 7. It can be observed that all specimens failed in a similar manner under splitting. In general, different water types did not impact the failure modes of concrete under compression, flexure, and splitting.



(a) (b) (c) (d) (e)

Fig. 5 Failure modes in compression for concrete fabricated with (a) fresh water, (b) sea water, (c) estuary water, (d) river water, and (e) domestic wastewater.

4.2. Compressive Strength

The compressive strength was evaluated from the measured maximum load that each specimen experienced before crushing. It is to be noted that three representative specimens were tested for each type of water. However, the results presented in these sections correspond to the average results of representative specimens.

Fig. 6 Failure modes in flexure for concrete fabricated with (a) fresh water, (b) sea water, (c) estuary water, (d) river water, and (e) domestic wastewater.

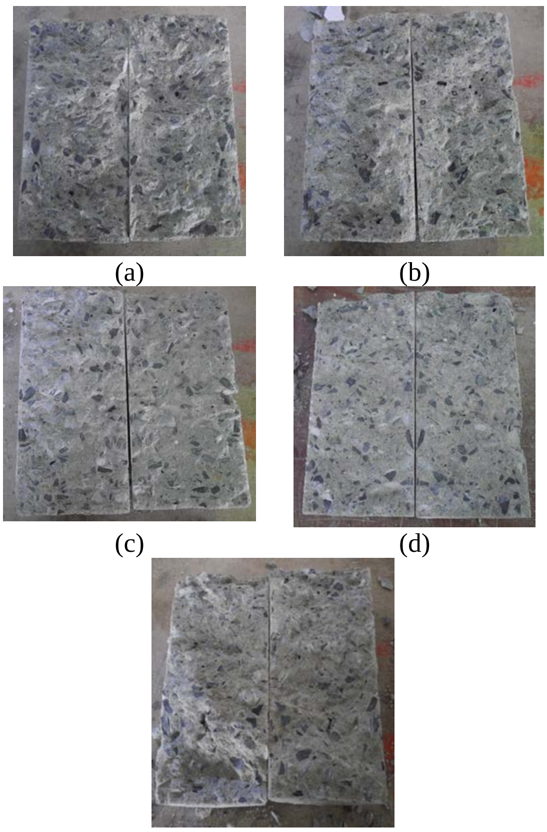


Fig. 7 Failure modes (a) fresh (b) sea water, (c) estuary water, (d) river, and (e) domestic water.

Fig. 8 shows a comparison of compressive strength of concrete for each water type. Table 2 summarizes the measured compressive strengths and their variation with respect to the control specimen. The average compressive strength of Specimen FW was 15.99 MPa. Specimen SW demonstrated a 10.38% increase in compressive strength, corresponding to a compressive strength of 17.65 MPa. Similarly, specimens RW and DWW registered 16.75% and 16.98% higher compressive strengths than control specimens. The results suggest that the use of estuary water in concrete has detrimental effects on compressive strength of concrete, as reflected by 8.02% decrease in compressive strength. Moreover, the maximum improvement in compressive strength was imparted using river water (RW) that was closely followed the use of domestic wastewater.

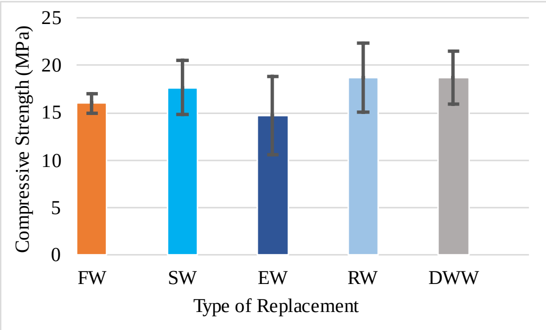


Fig. 8 Compressive strength of concrete.

Table 2 Summary of compressive strength

Specimen	Compressive Strength (MPa)	Variation from FW (%)
FW	15.99	-
SW	17.65	+10.38
EW	14.71	-8.02
RW	18.67	+16.75
DWW	18.71	+16.98

4.3. Splitting Tensile Strength

The comparison of splitting tensile strength (i.e., averaged over three specimens) is shown in Fig. 9. Table 3 shows the corresponding numerical values and their variations with respect to control Specimen FW. It can be noted that all types of water used in the present study yield similar or higher splitting tensile strengths than control specimen. In particular, Specimen DWW yielded a 24.39% higher increase in splitting tensile strength than control specimen. It is recalled that the same specimen had also yielded a 16.98% higher compressive strength than control specimen. Specimen RW had also exhibited a 16.75% higher compressive strength than control specimen.

However, it failed to improve the splitting tensile strength by a significant margin to match the improvement by Specimen DWW. Specimen SW did not show any improvement in splitting tensile strength, despite exhibiting a 10.38% improvement in the compressive strength. Furthermore, Specimen EW, that exhibited an 8.02% reduction in compressive strength, was able to improve the splitting tensile strength by 7.84%.

4.4. Flexural Strength

The comparison of flexural strength for various water types is shown in Figure 10, whereas Table 4 presents the corresponding numerical values and their comparison to the control specimen.

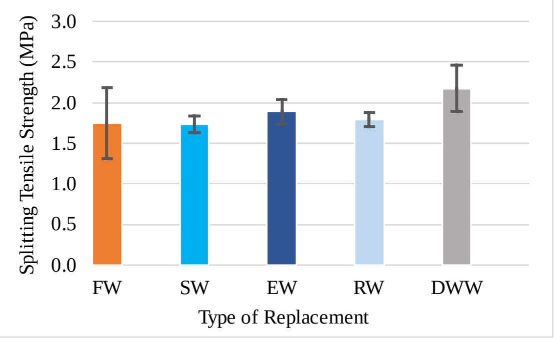


Fig. 9 Splitting tensile strength of concrete.

Table 3 Summary of splitting tensile strength

Specimen	Splitting Tensile Strength (MPa)	Variation from FW (%)
FW	1.75	-
SW	1.74	-0.67
EW	1.89	+7.84
RW	1.79	+2.05
DWW	2.18	+24.39

Interestingly, Specimen SW demonstrated a 27.06% reduction in flexural strength, and it was the only specimen with flexural strength lower than control specimen. It may be recalled that this specimen did not exhibit significant degradation in compressive and splitting tensile strengths. The maximum increase in flexural strength was observed in the case of Specimen EW, i.e., exhibiting a 21.18% improvement. The same Specimen EW had an 8.02% reduction in compressive strength while improving the splitting tensile strength by 7.84%. Specimen RW demonstrated an 8.24% improvement in flexural strength, whereas the same water had imparted 16.75% and 2.05% improvements in compressive and splitting tensile strengths, respectively. Finally, Specimen DWW exhibited the least improvement in flexural strength, i.e., by 3.53% only. From the ongoing discussion, it can be observed that a particular type of water did not necessarily improve all concrete properties by similar margins and there was always a tradeoff between different concrete characteristics. In particular, estuary water could be beneficial in improving flexural and splitting tensile strengths, but it could prove to be detrimental for the compressive strength of concrete. Similarly, domestic wastewater yielded significant improvements in compressive and splitting tensile strengths but resulted in only a 3.53% improvement in flexural strength.

4.5. Water Absorption

The comparison of water absorption (i.e., averaged over three specimens) is shown in Fig. 11. Table 5 shows the corresponding numerical values and their variations with respect to control Specimen FW.

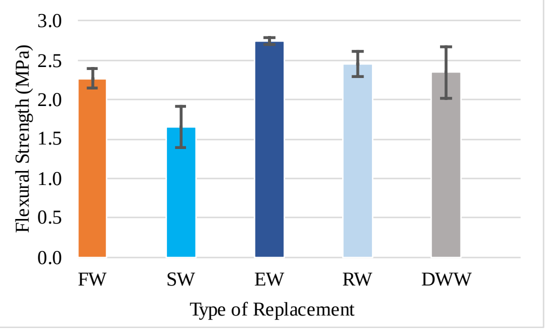


Fig. 10 Flexural strength of concrete

Table 4 Summary of flexural strength

Specimen	Flexural Strength (MPa)	Variation from FW (%)
FW	2.27	-
SW	1.65	-27.06
EW	2.75	+21.18
RW	2.45	+8.24
DWW	2.35	+3.53

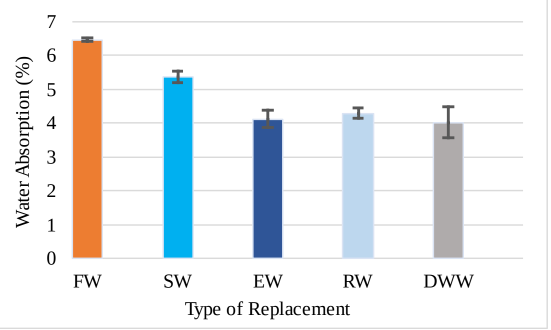


Fig. 11 Water absorption of concrete

In general, all specimens depicted a decrease in water absorption characteristics with respect to control Specimen FW. Concrete constructed with sea water resulted in the least amount of reduction in water absorption, whereas the highest reduction in water absorption was imparted by domestic wastewater. This is partly reflected in the mechanical properties of concrete fabricated by using domestic wastewater. The reduction in water absorption of concrete by using estuary and river water was slightly lower than the reduction by domestic wastewater.

4.6. Slump

Fig. 12 shows the slump values for each water type. Table 6 shows the corresponding slumps values and their variation from control specimen. It may be noted that sea water, estuary water, and river water negatively impacted slump by reducing it by 80%, 80%, and 73.33%, respectively. On the other hand, domestic wastewater increased the slump by 60% over the control specimen.

Table 5 Summary of water absorption test results

Specimen	Water Absorption (%)	Variation from FW (%)
FW	6.47	-
SW	5.38	-16.80
EW	4.13	-36.19
RW	4.30	-33.56
DWW	4.02	-37.78

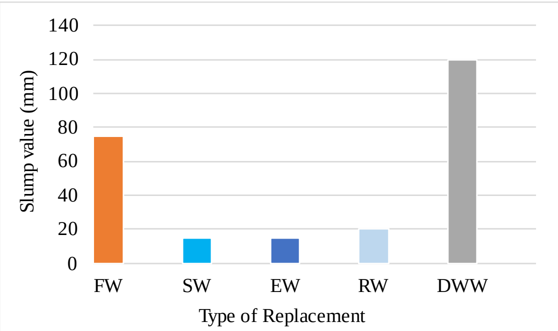


Fig. 12 Slump values of concrete

Table 6 Summary of slump in concrete

Specimen	Slump (mm)	Variation from FW (%)
FW	75	-
SW	15	-80.00
EW	15	-80.00
RW	20	-73.33
DWW	120	+60.00

5. CONCLUSIONS

This study aimed to explore the effects of different water types in the concrete mix to reduce the usage of fresh water and prevent its scarcity. Four water types, including river, sea, estuary, and domestic wastewater, were considered in addition to the normal fresh water. Water absorption, compressive, flexural, and splitting tensile strengths of concrete were compared. The following conclusions were drawn from experimental results.

The failure modes of concrete fabricated with different water types under compression, flexure, and splitting could not be differentiated from that of control specimen.

The compressive strength of concrete was reduced by the addition of estuary water (i.e., a reduction of around 8% in compressive strength was observed). The other water types resulted in the improvement of compressive strength, with the highest improvement imparted by domestic wastewater. A significant reduction in splitting tensile strength was not observed for all water types. The highest improvement in splitting tensile strength was imparted by domestic wastewater (i.e., 24.39%), followed by estuary and river water, respectively. On the contrary, estuary water imparted the highest improvement in flexural strength. The water absorption was significantly reduced by wastewater, whereas an increase of up to 60% in slump was imparted by the wastewater.

In summary, the additional of domestic wastewater imparted significant enhancements in compressive and splitting tensile strengths. It reduced water absorption and increase concrete slump significantly. In the case of river water, significant enhancements in concrete properties were not observed. However, the properties of concrete made with river water were close to the properties of fresh water concrete. Therefore, river or domestic waste water can be recommended to produce concrete. However, the performance of RW or DWW reinforced concrete needs to be explored.

6. ACKNOWLEDGMENTS

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7. REFERENCES

1. Miller S.A., Horvath A., and Monteiro P.J.M., Impacts of Booming Concrete Production on Water Resources Worldwide, Nature Sustainability 1(1), 2018, pp. 69–76.
2. Rodsin K., Joyklad P., Hussain Q., Mohamad H., Buatik A., Zhou M., Chaiyasarn K., Nawaz A., Mehmood T., and Elnemr A., Behavior of Steel Clamp Confined Brick

Aggregate Concrete Circular Columns Subjected to Axial Compression, Case Studies in Construction Materials, 16, 2022.
3. De Matos P.R., Prudêncio L.R., Pilar R., Gleize P.J.P., and Pelisser F., Use of Recycled Water from Mixer Truck Wash in Concrete: Effect on the Hydration, Fresh and Hardened Properties, Construction and Buildings Materials 230, 2020.
4. Joyklad P., Nawaz A., and Hussain Q., Effect of Fired Clay Brick Aggregates on Mechanical Properties of Concrete, Suranaree Journal of Science and Technology, 25, 2018, pp. 349–362.
5. Sethaputra S., Thanopanuwat S., Kumpa L., and Pattanee S., Thailand's Water Vision: A Case Study, From Vision to Action: A Synthesis of Experiences in Southeast Asia, 2001, pp. 71–97.
6. Saingam P., Ejaz A., Ali N., Nawaz A., Hussain Q., and Joyklad P., Prediction of Stress-Strain Curves for HFRP Composite Confined Brick Aggregate Concrete under Axial Load, Polymers, 15, 2023.
7. Peighambarzadeh F.S., Asadollahfardi G., and Akbardoost J., The Effects of Using Treated Wastewater on the Fracture Toughness of the Concrete, Australian Journal of Civil Engineering, 18, 2020, pp. 56–64.
8. ASTM C94/C94M, Standard Specification for Ready-Mixed Concrete, ASTM International, West Conshohocken, PA, 2018.
9. ASTM C1602/C1602M, Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete, ASTM International, West Conshohocken, PA, 2018.
10. ACI 318-19, Building Code Requirements for Structural Concrete and Commentary; Farmington Hills, MI, USA, 2019.
11. Su N., Miao, B., Liu, and F.S., Effect of Wash Water and Underground Water on Properties of Concrete. Cement and Concrete Research 32, 2002, pp. 777–782.
12. Younis A., Ebead U., Suraneni P., and Nanni A. Fresh and Hardened Properties of Seawater-Mixed Concrete. Construction and Building Materials 190, 2018, pp. 276–286.
13. Aldayel A.M.H., Ahmad S., Bahraq A.A., Effect of Total Dissolved Solids-Contaminated Water on the Properties of Concrete, Journal of Building Engineering, 32, 2020.
14. ASTM C192/C192M-19, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory, ASTM International, West Conshohocken, PA, 2019.
15. ACI Committee 211, Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete, Farmington Hills, MI, USA, 2022.
16. ASTM C1585-20, Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes, ASTM International, West Conshohocken, PA, 2020.