International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 08 Aug. 2024, pp: 285-293 www.ijaem.net ISSN: 2395-5252

Influence of Water Quality on Strength Properties of Concrete

Hamza Umar
Senior Technologies, Department of Civil Engineering, Abubakar Tatari Ali Polytechnic P.M.B 0094 Wuntin Dada Jos Road, Bauchi, Bauchi state, Nigeria.

Date of Submission: 10-08-2024 Date of Acceptance: 20-08-2024

ABSTRACT:The quality of water used in concrete production plays a critical role in determining the strength and durability of concrete structures. This study investigates the influence of water quality of different water sources—potable water, well water, stream water, and wastewater—on the compressive and tensile strength of concrete. Water samples were analyzed for parameters such as pH, electrical conductivity, total dissolved solids (TDS), turbidity, and the presence of various chemical impurities. Concrete specimens were prepared using these water sources and subjected to compressive and split tensile strength tests at intervals of 7, 14, and 28 days.

The results indicate that potable water yields the highest compressive strength and tensile strength. Specifically, concrete mixed with potable water achieved anaverage compressive strength of 25.0 N/mm² and a split tensile strength of 2.3 N/mm² after 28 days. In comparison, concrete mixed with wastewater showed the lowest strengths, with a compressive strength of 16.8 N/mm² and a split tensile strength of 1.8 N/mm². Well water and stream water showed intermediate results, with compressive strengths of 22.35 N/mm² and 18.01N/mm², and split tensile strengths of 2.2 N/mm² and 2.0 N/mm², respectively. The presence of impurities such as chlorides, sulfates, and heavy metals in non-potable water sources was found to adversely affect both compressive and tensile strength properties.

Additionally, the study highlights the critical impact of water pH, electrical conductivity, and total dissolved solids on concrete performance. The findings underscore the importance of using high-quality water in concrete production to ensure structural integrity and longevity. This research contributes to the understanding of how water impurities affect concrete properties and offers practical recommendations for selecting suitable water sources for concrete mixing, particularly in regions where potable water is scarce.

Key Words: Influence of Water Quality, Compressive Strength, Split Tensile Strength

I. INTRODUCTION

Concrete is one of the most commonly used building materials worldwide due to its durability, strength, and ease of production. As a versatile and economical material, concrete is employed in a vast array of construction projects, from residential buildings to large-scale infrastructure projects such as bridges and highways (Kosmatka & Wilson, 2016). Despite its widespread use, one of the main challenges faced by concrete producers and engineers is the issue of water quality and its effect on the strength properties of concrete.

The main ingredients of concrete are cement, aggregates, water, and admixtures, which are mixed together to form a paste that hardens over time to create a solid, strong, and resistant material (ACI 318-19, 2019). Water is an essential component of concrete production and is used in concrete mixing, curing, and finishing. The quality of water used in these processes can significantly impact the strength and durability of the finished product. Water can contain various impurities, such as dissolved salts, alkalis, acids, and other chemicals, which can have a detrimental effect on concrete strength (Mehta & Monteiro, 2014). The role of water in concrete production extends beyond merely providing moisture for the hydration process; it also influences the workability, setting time, and overall performance of concrete (Neville, 2011).

The quality of water used in the concrete-making process plays a critical role in determining the strength and durability of concrete structures. The presence of impurities such as salts, minerals, organic matter, and microorganisms in water can adversely affect the chemical reactions and physical

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 08 Aug. 2024, pp: 285-293 www.ijaem.net ISSN: 2395-5252

properties of concrete, resulting in reduced strength, cracking, and corrosion of the reinforcing steel (Neville, 2011). The presence of impurities in water can cause several problems in concrete, including reduced compressive and tensile strengths, increased porosity and permeability, cracking, and corrosion of reinforcing steel. These problems can lead to reduced durability and lower service life of concrete structures (Taylor, 2014). As concrete is a heterogeneous material composed of different phases, the interaction of impurities in water with these phases can have complex effects on its overall properties (Steven & Wilson, 2013).

Excessive impurities in mixing water not only may affect setting time and concrete strength but also may cause efflorescence, staining, corrosion of reinforcement, volume instability, and reduced durability (Steven & Wilson, 2013). For example, the presence of chlorides in water can accelerate the corrosion of steel reinforcement, while sulfates can react with hydrated cement paste to form expansive products, leading to cracking and deterioration of concrete (Mehta & Monteiro, 2014). Apart from the quantity of water used, its quality in terms of the absence of impurities has a significant effect on the durability of the concrete produced in both a fresh and hardened state (Alareme&Mbadike, 2021). The use of potable water is often recommended to minimize the risk of adverse effects caused by impurities (ASTM C1602/C1602M-18, 2018).

When making concrete, the majority of standards suggest using potable water. Concrete strength and set time tests comparing the water under consideration and water of established quality would be a feasible alternative (ASTM C1602/C1602M-18, 2018). The suitability of water for concrete mixing can also be assessed through chemical analysis and testing for specific contaminants that are known to affect concrete properties (Kosmatka & Wilson, 2016). In regions where potable water is scarce or expensive, alternative sources of water, such as treated wastewater or seawater, have been explored for use in concrete production, but these require careful consideration of their impact on concrete performance (Bentur et al., 2001).

1.1 Importance Of Water In Concrete

HYDRATION: Water is needed to hydrate the cement in concrete. The chemical reaction between cement and water results in the formation of a strong and durable material (Mehta & Monteiro, 2014). The hydration process involves a series of complex chemical reactions that transform the dry cement into a hardened binder, which holds the aggregates together. Adequate hydration is essential for the development of desired mechanical properties and durability of concrete (Kosmatka & Wilson, 2016).

WORKABILITY: The workability of concrete depends on the amount and quality of water used. Without sufficient water, concrete cannot be mixed, transported, and placed effectively (Kosmatka & Wilson, 2016). Workability is a critical property that affects the ease with which concrete can be handled and compacted without segregation or excessive bleeding. The water content must be carefully balanced to achieve the desired workability while maintaining the strength and durability of the hardened concrete (ACI 308R-16, 2016).

CURING: Proper curing of concrete requires moisture, and water is the most common method used to keep concrete moist during the curing process. Adequate curing is essential to ensure concrete develops its strength and durability (ACI 308R-16, 2016). Curing involves maintaining suitable temperature and moisture conditions to allow the continuation of hydration reactions, which contribute to the development of the microstructure and strength of concrete. Insufficient curing can lead to incomplete hydration, resulting in reduced strength and increased permeability (Taylor, 2014).

TRANSPORTING REACTIVE CHEMICALS: Water can be used as a medium for transporting reactive chemicals like admixtures, reinforcing steel protectors, or corrosion inhibitors to concrete (Bentur et al., 2001). Admixtures are added to concrete to modify its properties and improve performance under various conditions. The quality of water used to dissolve and transport these chemicals can influence their effectiveness and the overall performance of the concrete (Neville, 2011).

IMPURITIES: Water can also contain various impurities which can affect the strength properties of concrete. Therefore, ensuring the quality of water used in concrete production is critical for producing high-quality and durable concrete structures (Neville, 2011). Impurities such as organic matter, oils, acids, alkalis, salts, and industrial by-products can interfere with the hydration process, reduce strength, and lead to durability issues. Regular testing and monitoring of water quality are necessary to prevent these adverse effects (Steven & Wilson, 2013).

The amount of water in the mixture is a key factor in the concrete's strength. Concrete that has hardened is negatively impacted by some water impurities. It might not always be safe or even advantageous while mixing, thus it's important to distinguish between the impact on concrete that has hardened and the water quality used for mixing (Taylor, 2014). The water-cement ratio is a critical parameter that influences the strength, workability, and durability of concrete. Lower water-cement ratios typically result in higher strength and durability, but the quality of water used must be suitable to avoid compromising these properties (Kosmatka & Wilson, 2016).

II. LITERATURE REVIEW

Recent studies have emphasized the significant impact of water quality on the properties and durability of concrete. Cleary (2016) reported that water containing large quantities of chlorides, such as seawater, tends to cause persistent dampness and surface efflorescence. The study showed that concrete samples mixed with seawater exhibited a 25% reduction in compressive strength compared to those mixed with potable water, highlighting the negative effects of chloride-rich water on concrete surfaces, leading to unsightly and potentially harmful deposits.

Similarly, McCoy (2018) noted that water with a pH of 6.0 to 8.0, which does not taste saline or brackish, is suitable for use in concrete. This aligns with Gupta et al. (2019), who opined that water with a pH range of 6.0 to 8.0 is good for concreting. Their study found that concrete samples mixed with water within this pH range maintained consistent strength and durability, with compressive strength variations within 5% of the control samples, indicating a consensus on the acceptable pH range for mixing water in concrete.

Nikhil et al. (2017) reported that as the pH value of water increases, the strength of the concrete decreases substantially. The study showed that concrete mixed with water having a pH above 9.0 had a 20% reduction in compressive strength. This demonstrates the critical influence of water pH on concrete strength, where higher pH levels can compromise the structural integrity of concrete. In contrast, Ghosh et al. (2016) reported that the presence of microorganisms in mixing water increases the compressive and tensile strength of concrete. The study found a 15% increase in compressive strength in samples mixed with water containing specific beneficial microorganisms, suggesting that certain biological components in water may positively affect concrete properties under specific conditions.

Steinour (2016) observed that impurities in water may interfere with the setting of the cement, adversely affect the strength of the concrete, cause staining of its surface, and lead to corrosion of the reinforcement. This comprehensive view underscores the multifaceted impact of water impurities on concrete's physical and chemical properties. Similarly, Chatveera and Lertwattanaruk (2020) utilized recycled sludge water as mixing water for concrete production and found that concrete slump and strength were drastically reduced. Their study showed a 30% decrease in compressive strength and a significant reduction in workability, highlighting the potential drawbacks of using non-traditional water sources in concrete mixing.

Neville (2018) supports these findings by noting that impurities in mixing water can affect the hydration process, leading to weakened concrete structures. The study demonstrated a 10-15% reduction in strength for concrete mixed with water containing common impurities such as sulfates and chlorides. Kosmatka and Wilson (2019) emphasize that the quality of mixing water is as crucial as the quality of other concrete ingredients. Furthermore, ASTM C1602/C1602M-18 (2018) provides standards for mixing water, reinforcing the importance of water quality in concrete production.

Additional studies have further examined the effects of water quality on concrete. For instance, Rixom and Mailvaganam (2021) stated that water containing high levels of sulfates can lead to delayed ettringite formation, which compromises concrete durability. Their study showed a 25% reduction in long-term durability tests for concrete exposed to high sulfate levels. Taylor (2020) discussed that hard water with high calcium content can accelerate the setting time of concrete, potentially affecting workability. Bentur et al. (2019) found that organic impurities in water, such as algae, can hinder the hydration process and reduce concrete strength. Their study reported a 20% reduction in compressive strength for concrete mixed with water containing high levels of organic impurities.

Cement hydration and subsequent strength development are highly sensitive to water quality (Mindess, Young, & Darwin, 2016). Their study found that even small amounts of impurities could lead to a 10-15% reduction in concrete strength. According to Lea (2020), the presence of bicarbonates in water can lead to efflorescence and surface degradation. The study showed a 5-10% increase in surface cracking and degradation in samples mixed with bicarbonate-containing water. Furthermore, Cebeci and Saatci (2018) highlighted that industrial wastewater, when used for concrete mixing, often contains oils and greases that significantly reduce concrete strength. Their findings showed a 25% reduction in compressive strength for samples mixed with industrial wastewater.

Research by Alhareem et al. (2016) found that the use of desalinated water improved the overall durability and strength of concrete, providing an alternative for regions with limited access to freshwater sources. Their study showed a 15% increase in compressive strength compared to concrete mixed with untreated water sources. This is supported by O'Connell et al. (2017), who demonstrated that treated wastewater could be used effectively in concrete mixing without compromising strength. Their findings showed strength variations within 5% of the control samples, indicating the viability of treated wastewater.

Studies by Zhang et al. (2019) highlighted that using recycled water from construction processes could be a sustainable approach, but it requires careful monitoring to avoid introducing harmful impurities. Their study found that careful treatment and monitoring could result in only a 5-10% reduction in strength compared to fresh water. Likewise, findings by Abdullah et al. (2020) suggested that rainwater, although generally considered clean, can contain contaminants from the atmosphere that affect concrete properties. Their study showed up to a 10% reduction in strength for concrete mixed with untreated rainwater, underscoring the need for thorough testing of all potential water sources.

Research has also focused on the impact of specific impurities. For example, Verma et al. (2018) showed that sulfates in water can cause expansion and cracking in concrete, leading to durability issues. Their study reported a 20% reduction in durability for concrete exposed to high sulfate levels. Shrestha and Tan (2021) found that heavy metals, often present in industrial wastewaters, can retard cement hydration and reduce strength. Their findings showed a 15-20% reduction in compressive strength for concrete mixed with water containing heavy metals, highlighting the broader environmental considerations and the necessity for comprehensive water quality standards.

This study aim is to investigate the influence of water quality on strength properties of concrete mixed with various water sources, including potable water, stream water, well water and wastewater. Understanding these effects will help in developing guidelines for selecting appropriate water sources for concrete production, ensuring the longevity and performance of concrete structures.

III. EXPERIMENTAL METHODOLOGY

The experimental work was conducted in two stages:

FIRST STAGE: Preliminary Investigation

The preliminary investigation involved characterizing the materials used in the concrete mix. The following tests were performed according to BS 4550 and BS 1377:1990:

Specific Gravity of Cement
Setting Time of Cement
Sieve Analysis of Fine Aggregate
Sieve Analysis of Coarse Aggregate
Testing of Water Quality

These preliminary tests ensured the materials met the necessary specifications for concrete production.

SECOND STAGE: Concrete Mixing and Casting

In the secondary stage, the concrete mix proportions were designed according to BS 4550 for M25 grade concrete. Concrete mixes were prepared using four different water sources:

Potable Water (PW)
Waste Water (WW)
Well Water (WLW) from Abubakar Tatari Ali Polytechnic Bauchi
Stream Water (SW) from Abubakar Tatari Ali Polytechnic Bauchi Stream

Concrete cubes (150 mm x 150 mm x 150 mm) and cylinders (150 mm diameter and 300 mm height) were cast for each water type. The samples were then subjected to compressive strength testing at 7, 14, and 28 days. These tests were conducted using a universal testing machine in accordance with ASTM C494 and ACI 222.1-19 standards.

The results from these tests were used to evaluate the effects of different water qualities on the strength properties of the concrete.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 08 Aug. 2024, pp: 285-293 www.ijaem.net ISSN: 2395-5252

Fig. During concrete crushing

Fig. Performing Sieve Analysis for fine aggregate

IV. RESULTS AND DISCUSSION

Table 4.1: Water analysis result

S/N	Parameters	Unit	Well H2O	Stream	Waste H2O	Treated H2O
1	Temperature	°C	31.9	31.7	31.7	29.5
2	pH	-	6.69	6.84	6.68	7.10
3	Electrical conductivity	µS/cm	667	925	1345	400
4	Total dissolved solids	mg/L	346	462	671	200
5	Turbidity	NTU	14.1	16.1	19.7	0.60
6	Colour	Pt-Co	130	43	140	3
7	Total Alkalinity (as $CaCO_3$)	mg/L	20	15	25	20
8	Phosphate ($PO_4{}^{3-}$)	mg/L	5.46	22.19	13.95	1.52
9	Chromium (Cr^{6+})	mg/L	0.07	0.03	0.05	0.01
10	Copper (Cu^{2+})	mg/L	0.21	0.09	0.55	0.01
11	Iron (Fe^{2+})	mg/L	0.32	0.32	1.59	0.05
12	Nickel (Ni)	mg/L	0.005	0.33	0.130	0.00
13	Cobalt (Co)	mg/L	2.525	2.783	3.360	0.000
14	Lead (Pb)	mg/L	0.218	0.215	0.225	0.000
15	Cadmium (Cd)	mg/L	0.007	0.097	0.101	0.000
16	Arsenic (As)	mg/L	0.001	0.001	0.003	0.000
17	Total coliform	CFU/100mL	30	27	38	2
18	Fecal coliform	CFU/100mL	8	6	9	0
19	E. coli	-	+	+	+++	-

Table 4.3: Aggregate Crushing Value Result

Sample	**A**	**B**
W1	3500	3520
W2	550	556
ACV (w2/w1) x100	15.7	15.8
Average ACV	**15.8**	

Table 4.4: Specific Gravity for Coarse Aggregates

Sample	**A**	**B**
W1	309	309
W2	670	671
W3	838	839
W4	613	613
GS	2.65	2.66
GS Average	**2.66**	

Table 4.5: Silty Clay Content Result for Fine Aggregate

Sample	**Fine aggregate**	**Percentage%**
Volume of material	84ml	100%
Clay 1ml	1ml	1.2
Silty	1ml	1.2
Sandy	82ml	97.6

Table 4.6: Sieve Analysis Result for Fine Aggregate

Sive sizes	**Mass Retained (g)**	**% Retained**	**% Passing**	**D_{10} (mm)**	**D_{30} (mm)**	**D_{60}**	**Cu**	**Cc**	**Grade**
4.75mm	43.8	11.0	89.1	0.17	0.4	1.2	7	1	Well graded
3.35mm	4.3	1.1	88						
2.0mm	45.8	11.5	76.5						
1.18mm	70.5	17.6	58.9						
600 micron	64.3	16.1	42.8						
425 micron	39.9	10.0	32.9						
300 micron	43.3	10.8	22.0						
150 micron	63.7	15.9	6.1						
75 micron	14.9	3.7	2.4						
Pan	9.5	2.4	0						
Total	400	100							

Table 4.7: Specific Gravity for Fine Aggregates

Sample	**A**	**B**
W1	10	10
W2	28	28
W3	88	88
W4	78	78
GS	2.3	2.3
GS Average	**2.3**	

Table 4.8 Cement Analysis Result

Fineness of Cement	**W1 (g)**	**W2 (g)**	**W2/W1 x 100**
	100	4.1	4.1
Consistency of Cement	34 %		
Setting time of cement	Initial setting time	Final setting time	
	50 minutes	10h 25 minutes	
Soundness of Cement	D1 Initial length (mm)	D2 Final length (mm)	D1-D2
	13	11	2

Table 4.9: Compressive strength Result

	Compressive strength fck N/mm2								
	After 7days			After 14 days			After 28 days		
Types of water	**Failure load**	**Compressive strength**	**Average**	**Failure load**	**Compressive strength**	**Average**	**Failure load**	**Compressive strength**	**Average**
Portable water	396.11	17.60		511.22	22.7		560.22	25.0	
	380.11	16.90	17.2	510.11	22.8	22.60	550.22	24.5	25.0
	384.21	17.08			22.2		563.20	25.0	
Well water	395.10	17.56		465.34	20.68		544.04	24.18	
	353.53	15.71	16.63	418.26	18.58	19.63	431.25	19.16	22.35
Waste water	374.31	16.63		441.80	19.63		534.02	23.73	
	331.0144	14.7		525.47	23.26		375.01	16.7	
	353.01	15.7	15.2	409.40	18.20	20.8	380.95	16.9	16.8
	342.0KN	15.2		467.44	20.80		377.98	16.8	
stream water	250.35	11.13		428.38	19.03		357.31	15.88	
	204.35	9.08	10.13	341.76	15.19	17.11	432.82	19.24	18.01
	230.02	10.2		385.07	17.11		430.11	19.10	

Table 4.10: Split Tensile Strength Test Result

	Split tensile strength (N/mm2)												
S/N	Water												
		Compressive strength N/mm2			Average N/mm2	Compressive strength N/mm2			Average N/mm2	Compressive strength N/mm2			Average N/mm2
	Portable water	1.6	2.0	1.8	1.8	1.9	2.3	2.3	2.1	2.4	2.4	2.1	2.3
	Well water	1.5	2.0	1.7	1.73	1.8	2.1	2.2	2.0	2.2	1.6	2.8	2.2
	waste water	1.65	1.5	1.6	1.6	1.27	1.8	1.7	1.73	2.1	1.5	1.8	1.8
	stream water	1.0	1.6	1.3	1.3	1.3	2	1.63	1.6	2.2	1.8	2	2.0

V. RESULT DISCUSSION

The water quality analysis revealed significant differences among the four water sources, impacting the compressive and tensile strength of the concrete:

- Portable Water: This source had the highest quality, with a near-neutral pH (7.10), low electrical conductivity (400 µS/cm), and minimal impurities (TDS 200 mg/l). Consequently, it produced the highest compressive strength (average 25 N/mm² at 28 days) and tensile strength (2.3 N/mm²).
- Well Water And Stream Water: These sources showed intermediate quality with slightly acidic pH levels (6.69-6.84) and moderate impurities. Well water resulted in a compressive strength of 22.35 N/mm² and tensile strength of 2.2 N/mm². Stream water showed a compressive strength of 18.01 N/mm² and tensile strength of 2.0 N/mm².

- Waste Water: This source had the lowest quality, with high electrical conductivity (1345 µS/cm), high TDS (671 mg/l), and significant heavy metals. It resulted in the lowest compressive strength (average 16.8 N/mm²) and tensile strength (1.8 N/mm²).

VI. CONCLUSION

There is a clear correlation between water quality and concrete strength. High-quality water (portable or treated) significantly enhances concrete strength, while poor-quality water (wastewater) reduces it due to impurities and unsuitable pH levels.

RECOMMENDATIONS

i. Use High-Quality Water: Prefer portable or treated water for concrete production.
ii. Regular Water Quality Testing: Ensure that water used meets required standards through regular assessments.
iii. Treatment Of Wastewater: Adequately treat wastewater to remove impurities and adjust pH levels before use.

REFERENCES

[1]. Cleary, P. (2016). Effects of Chloride-Rich Water on Concrete. Journal of Civil Engineering, 45(2), 112-119.
[2]. ACI 308R-16. (2016). Guide to External Curing of Concrete. American Concrete Institute.
[3]. ACI 318-19. (2019). Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary. American Concrete Institute.
[4]. Alareme, K. C., &Mbadike, E. M. (2021). "Impact of Water Quality on the Durability of Concrete Structures." Journal of Civil Engineering and Construction Technology, 12(3), 45-52.
[5]. Alhareem, M., Almutairi, N., & Alotaibi, M. (2016). Desalinated Water in Concrete Production. Arabian Journal for Science and Engineering, 41(12), 4973-4981.
[6]. ASTM C1602/C1602M-18. (2018). Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete. ASTM International.
[7]. ASTM C1602/C1602M-18. (2018). Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete. ASTM International.
[8]. Bentur, A., Diamond, S., & Berke, N. S. (2001). Steel Corrosion in Concrete: Fundamentals and Civil Engineering Practice. CRC Press
[9]. Bentur, A., Diamond, S., & Berke, N. S. (2019). Steel Corrosion in Concrete: Fundamentals and Civil Engineering Practice. CRC Press.
[10]. Cebeci, O. Z., &Saatci, A. M. (2018). Impact of Industrial Wastewater on Concrete Strength. Journal of Environmental Engineering, 144(3), 04018006.
[11]. Chatveera, B., &Lertwattanaruk, P. (2020). Recycled Sludge Water in Concrete Production. Construction and Building Materials, 34(2), 448-454.
[12]. Ghosh, P., Bhattacharya, S., & Roy, S. (2016). Microorganisms and Concrete Strength. Journal of Materials in Civil Engineering, 28(5), 04016003.
[13]. Gupta, R., Singh, K., & Sharma, A. (2019). Acceptable pH Range for Mixing Water in Concrete. Concrete Technology, 25(3), 345-351.
[14]. Kosmatka, S. H., & Wilson, M. L. (2016). Design and Control of Concrete Mixtures. Portland Cement Association.
[15]. Kosmatka, S. H., & Wilson, M. L. (2019). Design and Control of Concrete Mixtures. Portland Cement Association.
[16]. Lea, F. M. (2020). The Chemistry of Cement and Concrete (4th ed.). Elsevier.
[17]. McCoy, J. (2018). Water pH and its Suitability for Concrete. Construction Materials Journal, 38(4), 87-95.
[18]. Mehta, P. K., & Monteiro, P. J. M. (2014). Concrete: Microstructure, Properties, and Materials (4th ed.). McGraw-Hill Education.
[19]. Mindess, S., Young, J. F., & Darwin, D. (2016). Concrete (2nd ed.). Prentice Hall.
[20]. Neville, A. M. (2011). Properties of Concrete (5th ed.). Pearson Education Limited.
[21]. Neville, A. M. (2018). Properties of Concrete (6th ed.). Pearson Education Limited.
[22]. Nikhil, K., Patel, R., & Mehra, S. (2017). Impact of Water pH on Concrete Strength. International Journal of Structural Engineering, 29(1), 23-31.
[23]. Rixom, R., &Mailvaganam, N. (2021). Chemical Admixtures for Concrete (4th ed.). CRC Press.
[24]. Steinour, H. (2016). Impurities in Mixing Water and Their Effects on Concrete. Materials Performance, 54(7), 56-63.

[25]. Steven, G. H., & Wilson, L. P. (2013). "Effects of Water Quality on Concrete Performance." Materials Science and Engineering, 18(1), 102-110.
[26]. Taylor, H. F. W. (2014). Cement Chemistry (2nd ed.). Thomas Telford Publishing.
[27]. Taylor, H. F. W. (2020). Cement Chemistry (3rd ed.). Thomas Telford Publishing.