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Impact of Alkaline Water on Concrete Properties: Setting Time and Compressive Strength Analysis

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ABSTRACT

Water serves as the medium in the cement hydration reaction process. The characteristics of Alkaline Water in concrete production are still not widely understood. This study determines the effect of Alkaline Water on the normal consistency, setting time, and compressive strength. The research uses Alkaline Water with pH levels of 8 and 9 for the mixture matrix and water with a pH level of 7 as a comparison. The normal consistency and setting time of the cement are measured using a Vicat apparatus. The compressive strength of the matrix is tested using cube samples of 50 × 50 × 50 mm at the ages of 3, 7, 14, 21, and 28 days, and they are cured using Alkaline Water at each respective pH level. The normal consistency of the matrix mixtures with water at pH 8 and pH 9, compared to pH 7, shows no significant influence from the higher pH levels, with consistency ranging from 27% to 28%. The setting time of the cement with water at pH 8 and pH 9 results in relatively similar outcomes, though it sets 30 minutes faster than with pH 7 water. The compressive strength of the matrix with water at pH 8 and pH 9 shows a decreasing pattern at 28 days, whereas pH 7 results in increasing compressive strength with age. For concrete casting that requires a quicker initial set, Alkaline Water (with a pH higher than 7) can be used.

1. INTRODUCTION

The primary constituents of concrete mixtures include cement, water, sand, and gravel. Mortar is composed of cement, water, and sand, whereas the matrix consists of cement and water. The analysis begins with an examination of the matrix mixture to investigate the influence of water in concrete mixtures [1]. The matrix serves as a critical component of mortar. According to Walker and Bloem, the strength of concrete is determined by the strength of the mortar, the bond between the mortar and the coarse aggregate, and the strength of the coarse aggregate itself [2]. Consequently, in this study, the assessment of matrix strength is isolated from the influence of other component strengths.

Cement is a hydraulic binder that requires water for the hydration process [3, 4]. The amount of water needed for hydration dramatically depends on the composition of the compounds in the cement and the fineness of the cement [5]. If the water for the hydration process is insufficient, not all the cement particles will hydrate; similarly, if there is too much water, the strength of the cement paste will decrease. Therefore, it is crucial to determine the optimal amount of water needed to ensure the hydration process proceeds perfectly, allowing the cement to achieve its maximum strength. The consistency testing is conducted using the Vicat apparatus to determine the optimal amount of water required, according to SNI or ASTM standards [6]. When cement is mixed with water, the hydration process begins, leading to initial setting and eventual hardening [4]. The duration of the setting process is highly dependent on the composition of the compounds in the cement and the ambient temperature. Notably, there are two types of setting times in cement paste: initial setting time and final setting time [7].

Water is a primary component in the concrete-making process [8-11]. The water content in each region exhibits different physical and chemical properties, as well as pH values, depending on environmental conditions [12]. Consequently, both the quantity and quality of water must be carefully considered when used in concrete mixtures [13]. Then, the pH level of water significantly affects the performance of concrete and has a notable impact on its durability by influencing the hydration reactions of cementitious materials [14]. Moreover, different pH values of water will affect concrete characteristics such as workability, compressive strength, cement hydration process, setting time, and curing time [13, 15-17].

Alkaline Kangen Water is distinguished by its alkaline pH level and is characterized by unique properties, including softness, energy, and cleansing capabilities. It also demonstrates micro-properties, showcasing unparalleled absorption abilities within the body. Enriched with alkaline minerals, it contributes to the neutralization of acidic conditions within the body. With an abundance of available electrons, Alkaline Kangen Water facilitates cell-mediated neutralization of harmful free radicals [18, 19].

According to Shirahata's research, ionized Alkaline Water is characterized by its alkaline nature, richness in hydrogen components, low water molecule content, and negative redox potential. This water is known for its antioxidant activity as it can reduce free radicals or reactive oxygen species (ROS) within the body. One of the Alkaline Water products is Kangen Water, with a pH of 9, obtained through the ionization process using Enagic machines. The water entering the machine is first filtered through three layers of high-efficiency filters to remove substances such as rust, lead, chlorine, bacteria, and odors [20]. The use of alkaline pH water for concrete mixing and maintenance can affect its compressive strength. The higher the pH of the water used, the lower the compressive strength of the resulting concrete compared to normal concrete compressive strength [21]. However, it has also been found that strength increases with an increase in the pH of the mixing water [22].

Apart from its role in concrete mixing, water serves a crucial function in the concrete curing process, aimed at preserving the concrete's temperature to attain the desired quality [23-25]. Alongside the quality of the concrete's constituent materials, the method employed in executing the concrete curing process significantly affects the anticipated quality [24, 26-28]. Syaifudin's study found that employing a mixture of Co(NH2)2 or urea in concrete samples with a compressive strength of fc' 20 MPa during the curing process enhanced compressive strength at 7 days but exhibited a decline at 28 days [29]. Meanwhile, Bakir's research conducted the curing process for mortar samples under two distinct environmental conditions: hot conditions at 40°C with 0% humidity and 100% humidity. The results indicated that hot climates notably impact mortar resistance to compression. Wet curing is regarded as the most effective method compared to alternative preservation techniques, primarily due to its ability to restrict water evaporation, hasten the hydration process, and minimize crack formation [30].

Normal consistency is a characteristic of the amount of water in the cement hydration process, as shown in Eq. 1. The cement hydration process is influenced by various factors such as temperature, humidity, and environmental influences [31-34]. Meanwhile, the setting time of cement is the moment when the cement hydration process occurs, bonding begins, and the cement starts to harden [7].

$$Consistency = \frac{weight\ of\ water}{weight\ of\ cement}\ x\ 100\% \quad (1)$$

The bond strength of cement significantly influences the success of a matrix mixture and mortar or concrete mixture. The mixture or blend must be promptly cast. Hence, it is crucial to determine the duration of cement bonding that will occur [4].

The initial setting time is the duration required from the moment the cement mixes with water, transitioning from a plastic state to a non-plastic state. In contrast, the final setting time is the duration required from the moment the cement mixes with water, transitioning from a plastic state to a hardened state. The hardening referred to in the final setting time signifies only the rigid form, yet the cement matrix should not yet be subjected to any load, whether from its own weight or external loads [7].

In Dutta's research, concrete specimens were fabricated utilizing four different water pH levels (5, 7, 10, and 13) as the mixing water during the concrete casting process. The findings indicate a notable enhancement in compressive strength, approximately 25%, at the 90-day mark for concrete specimens with a pH of 13 compared to those cast with water at pH 7 (considered normal) [14].

A study on cement properties utilizing alkaline mixing water (pH 10 - pH 14) was conducted by Çomak [35]. It was concluded that Alkaline Water is effective in enhancing the workability of the mixture. Additionally, compressive strength increases with the rising pH of the mixing water, except for pH 14 [35]. Similar findings were reported by Sobhnamayan et al. [36], indicating that acidic water up to a specific pH level also increases the compressive strength of cement mortar. Furthermore, in the study conducted by Kucche et al. [9], it was concluded that water pH below 3 reduces the compressive strength of concrete [37, 38].

Numerous prior studies have highlighted the prevalent utilization of water in concrete mixtures by researchers globally, often entailing the direct fabrication of concrete specimens without a comprehensive consideration of the inherent characteristics of the concrete constituents. However, the mechanical strength of concrete is markedly contingent upon and influenced by the initial attributes of its constituent materials [39]. Predominant causes of concrete degradation stem from fluctuations in humidity and pH levels. Hence, it is imperative to scrutinize the pH potential within the initial mixing water to furnish pivotal insights into the production of high-quality concrete [40, 41].

In this study, the approach of utilizing a matrix mixture differs from the conventional method employed by previous researchers, who predominantly utilized concrete or mortar mixtures to assess the influence of Alkaline Water. Furthermore, this study utilizes Alkaline Water obtained from the Enagic machine process (Kangen Water).

Considering that the hydration process of cement occurs through the mixing of cement with normal water, the utilization of Alkaline Water in this study is anticipated to affect the normal consistency, setting time, and compressive strength of the matrix. Conversely, when Alkaline Water is used in concrete mixtures, its strength will be influenced by the aggregate materials, sand, and the interaction between the aggregate and mortar. It may potentially lead to biased outcomes.

The study utilized an experimental approach involving Alkaline Water with pH levels of 8 and 9 as mixtures and for matrix treatment. The outcomes obtained from this investigation serve to elucidate the impact of Alkaline Water on the normal consistency and setting time of the mixture, along with the compressive strength of the matrix. Additionally, water with a pH of 7 was employed as a comparative control.

The selection of pH 8 and pH 9 was based on Boyd's research concerning brackish water found at river estuaries. Brackish water, a blend of freshwater and seawater, typically exhibits pH levels ranging from 6.5 to 9 [42]. Consequently, this study aims to investigate the effects of incorporating brackish water into concrete mixtures.

2. RESEARCH METHOD

The water utilized consists of pH 8 and pH 9 water derived from the Enagic machine product (Kangen Water) [18]. In contrast, pH 7 water originates from tap water and the cement used is a product from the Tiga Roda brand.

The research steps comprise: firstly, testing the normal consistency of the cement and water mixture. The testing is conducted with six variations of water volume for pH 7, pH 8, and pH 9. The percentage of water volume used is 20%, 22%, 24%, 26%, 28%, and 30%, with a cement weight of 300 grams. Subsequently, the slump is measured using a Vicat apparatus for each mixture over 30 seconds. The testing results are depicted graphically to illustrate the relationship between normal consistency and vicat needle penetration.

Secondly, testing the setting time of the cement. The setting time testing involves using 300 grams of cement and 84 mm of water (pH 7, pH 8, and pH 9 water) using a vicat apparatus to determine the initial and final setting times of the cement. The initial setting time is when the penetration needle reaches a depth of 25 mm in the cement paste/matrix, while the final setting time is when the penetration needle cannot penetrate the cement matrix or reaches 0 mm.

Thirdly, fabricating concrete matrix test specimens with a mixture of 3300 grams of cement and 930 ml of water for each pH 7, pH 8, and pH 9. The moulds used are cubes measuring 50 × 50 × 50 mm. The test specimens are cured by immersion using water corresponding to each pH mixture (pH 7, pH 8, and pH 9) [25]. Subsequently, compressive strength testing of the matrix is conducted at ages 3, 7, 14, 21, and 28 days using a compression testing machine [43]. A total of 3 samples are produced for each pH mixture and age, resulting in a total of 45 test specimens.

Fourthly, analyze the development of matrix strength by calculating the average compressive strength of the matrix and creating a graphical representation of its progress.

Finally, the achieved matrix strength by converting its compressive strength to the age of 28 days. The standard deviation is calculated, and the results are determined. The conversion factors for age are 0.4, 0.65, 0.88, 0.95, and 1.0 for ages 3, 7, 14, 21, and 28 days respectively [44, 45].

3. RESULTS AND DISCUSSIONS

3.1 Cement consistency testing

Testing the consistency of Portland cement refers to SNI 03-6826-2002, where a slump of 10±1 mm is measured over 30 seconds. The test results are presented in Table 1.

Table 1. Cement consistency testing

No	Cement (gram)	Water Precentage (%)	Water Volume (mm)	Needle Penetration (mm) pH 7	pH 8	pH 9
1	300	0.2	60	3	4	2
2	300	0.22	66	5	5	4
3	300	0.24	72	6	7	5
4	300	0.26	78	8	9	7
5	300	0.28	84	11	10	10
6	300	0.3	90	14	11	12

From Table 1, a graphical representation illustrating the correlation between water percentage and needle penetration values was generated to ascertain the normal consistency of the cement. As depicted in Figure 1, the normal consistency is determined by a slump of 10 mm, constituting 28% for the water mixtures of pH 8 and pH 9, and 27.3% for pH 7 water.

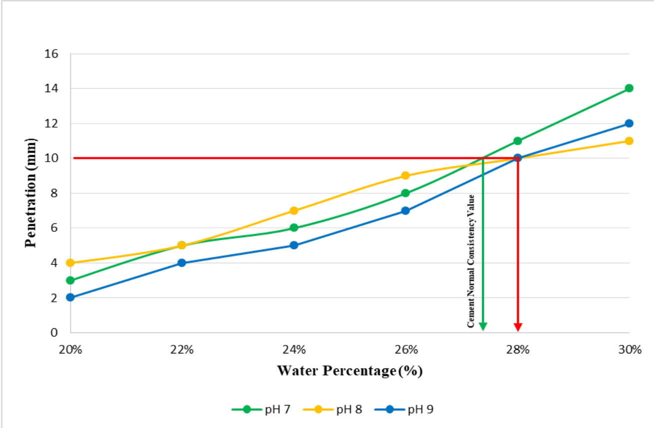

Figure 1. Comparison of cement consistency

From Figure 1, it is evident that the normal consistency values of the cement mixture using pH 8 and pH 9 water show no significant difference compared to pH 7 water.

3.2 Cement setting time testing

Table 2. Comparison cement setting time

Penetration Time (minutes)	Needle Penetration (mm) pH 7	pH 8	pH 9
0			
15	48	43	45
30	44	38	38
45	41	33	33
60	38	25	29
75	34	18	25
90	29	14	16
105	25	8	12
120	21	4	0
135	17	0	0
150	11	0	0
165	0	0	0

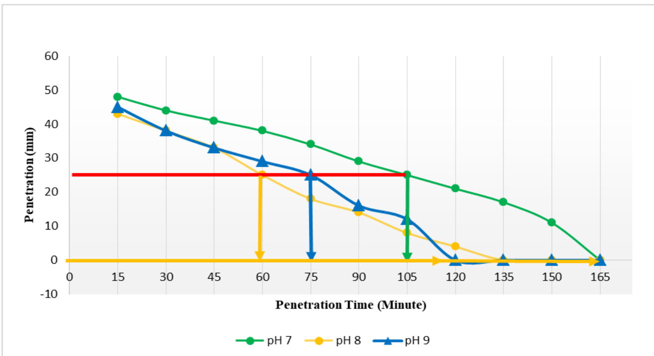

Figure 2. Comparison of setting time

Based on Table 2 and Figure 2, the comparison of the cement setting time testing results reveals that for Kangen Water pH 8, the normal setting time of cement occurs at 60 minutes with a Vicat needle penetration of 25 mm, and the final setting time occurs at 135 minutes with a Vicat needle penetration of 0. For Kangen Water pH 9, the normal setting time of cement occurs at 75 minutes with a Vicat needle penetration of 25 mm, and the final setting time occurs at 120 minutes with a Vicat needle penetration of 0. Conversely, for normal water (pH 7), the normal setting time of cement occurs at 105 minutes with a Vicat needle penetration of 24 mm, and the final setting time occurs at 160 minutes with a Vicat needle penetration of 0 mm. Therefore, it can be stated that both the normal setting time and final setting time of cement using Kangen Water (pH 8 and pH 9) are faster compared to using normal water (pH 7). It aligns with the findings of previous researchers, indicating that the use of Alkaline Water can accelerate the cement setting time [13, 15-17].

3.3 Matrix compressive strength testing

The results of the compressive strength testing of the matrix can be observed in Table 3, as well as in Figure 3, which illustrates a graphical comparison of the matrix's compressive strength.

Table 3. Compressive strength of matrix (MPa)

Days	pH 7	pH 8	pH 9
3	37.15	36.96	43.18
7	48.32	43.12	51.23
14	53.49	46.20	66.13
21	61.27	53.51	74.60
28	64.08	46.82	66.25

Based on the result shown in Table 3, the compressive strength of the matrix can be used to calculate the percentage (%) change in compressive strength of the matrix from ages 3, 7, 14, 21, and 28 days as follows:

1. For normal water (pH 7), there is an increasing trend in matrix compressive strength from age 3 days to 7 days by 30%, from 7 days to 14 days by 11%, from 14 days to 21 days by 15%, and from 21 days to 28 days by 5%.
2. For pH 8 water, there is an increasing trend in matrix compressive strength from age 3 days to 21 days. The percentage change in compressive strength from 3 days to 7 days is 17%, from 7 days to 14 days is 7%, and from 14 days to 21 days is 16%. However, there is a decrease in strength at 28 days by -13%.
3. Moreover, for pH 9 water, the matrix compressive strength increases by 19% from age 3 days to 7 days, by 29% from 7 days to 14 days, and by 13% from 14 days to 21 days. However, there is a decrease in strength by -11% from 21 days to 28 days.

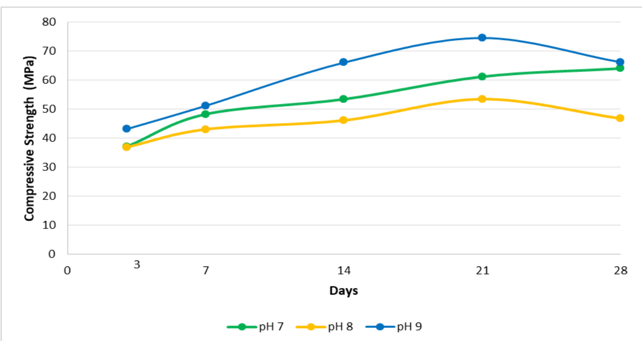

Figure 3. Comparison of compressive strength of matrix

Based on Figure 3, the graph illustrates that the use of pH 7 water shows a consistent increase in matrix compressive strength at each age from 3 days to 28 days. In contrast, pH 8 and pH 9 water influence the strength pattern with an increasing trend from 3 days to 21 days, followed by a decrease at 28 days.

The comparison of matrix compressive strength between pH 7, pH 8, and pH 9 water is presented in Table 4. The results indicate that the compressive strength using pH 8 water, compared to pH 7 water, shows a difference ranging from -0.50% to -26.94%, with an average of -12.90%. The highest deviation in compressive strength occurs at 28 days, with a value of -26.94%.

On the other hand, the compressive strength of the matrix using pH 9 water, compared to pH 7 water, shows a deviation ranging from 3.38% to 23.64%, with an average of 14.21%. The highest deviation occurs at 14 days, with a value of 23.64%.

Table 4. Percentage comparison

Days	pH 8 (%)	pH 9 (%)
3	-0.50	16.25
7	-10.77	6.01
14	-13.63	23.64
21	-12.66	21.76
28	-26.94	3.38

Table 5. Compressive strength pH 7

No	Days	Xi (MPa)	
		Initial	Conversion
1	3	39.43	98.58
2	3	40.70	101.75
3	3	31.31	78.27
4	7	42.36	65.18
5	7	55.96	86.09
6	7	46.64	71.76
7	14	59.88	68.05
8	14	50.73	57.64
9	14	49.85	56.65
10	21	64.16	67.54
11	21	60.48	63.66
12	21	59.17	62.28
13	28	63.69	63.69
14	28	62.97	62.97
15	28	65.59	65.59

Table 6. Compressive strength pH 8

No	Days	Xi (MPa)	
		Initial	Conversion
1	3	28.45	71.14
2	3	46.05	115.13
3	3	36.38	90.95
4	7	45.57	70.11
5	7	39.87	61.34
6	7	43.91	67.55
7	14	47.75	54.27
8	14	47.00	53.41
9	14	43.83	49.81
10	21	57.46	60.49
11	21	48.47	51.02
12	21	54.61	57.48
13	28	46.76	46.76
14	28	45.93	45.93
15	28	47.75	47.75

The compressive strength of the matrix using pH 9 water, which is higher than that using pH 7 water, aligns with the findings of Dutta, who observed that the use of Alkaline Water can enhance the compressive strength of concrete compared to water with a pH of 7. Additionally, according to Çomak [35], Alkaline Water is efficacious in improving the workability of the mixture.

The compressive strength data for each test specimen and its conversion to 28 days can be seen in Tables 5, 6, and 7.

Table 7. Compressive strength pH 9

No	Days	Xi (MPa)	
		Initial	Conversion
1	3	40.11	100.26
2	3	41.29	103.24
3	3	48.15	120.38
4	7	49.38	75.97
5	7	59.72	91.88
6	7	44.58	68.59
7	14	70.51	80.13
8	14	55.71	63.31
9	14	72.17	82.01
10	21	70.34	74.05
11	21	79.42	83.60
12	21	74.03	77.93
13	28	73.24	73.24
14	28	65.35	65.35
15	28	60.16	60.16

Table 8. Standard deviation pH 7

No	(Xi)	Xi - $\bar{X}$	(Xi - $\bar{X}$)^2
1	98.58	27.27	743.48
2	101.75	30.44	926.42
3	78.27	6.96	48.40
4	65.18	-6.14	37.66
5	86.09	14.78	218.33
6	71.76	0.45	0.20
7	68.05	-3.27	10.67
8	57.64	-13.67	186.84
9	56.65	-14.66	214.91
10	67.54	-3.77	14.25
11	63.66	-7.65	58.59
12	62.28	-9.03	81.56
13	63.69	-7.63	58.18
14	62.97	-8.34	69.57
15	65.59	-5.73	32.78
∑Xi	1069.69		983.52

Subsequently, to determine the actual matrix strength, the following equation is used [46, 47].

Compression strength average

$$\bar{X} = \frac{\sum Xi}{n} \quad (2)$$

Standard Deviation (s)

$$s = \sqrt{\frac{\sum(Xi-\bar{X})^2}{n-1}} \quad (3)$$

Compressive strength range achieved:

$$fc' = \bar{X} \pm (1.16 \times s) \quad (4)$$

where,

Xi = Compressive Strength
∑Xi = Number of Compressive Strength Data
n = Number of Data
$\bar{X}$ = Compressive Strength Average
s = Standard Deviation
1.16 = Coeficient for 15 Sample

The calculation of average strength and standard deviation can be seen in Table 8.

$$\sum Xi = 1069.69$$
$$n = 15$$
$$\sum(Xi - X)^2 = 983.52$$

$$\bar{X} = \frac{1069.69}{15} = 71.31$$

$$s = \sqrt{\frac{983.52}{14}} = 8.38$$

Lower bound $fc' = \bar{X} - (1.16 \times s)$
$= 71.31 - (1.16 \text{ x } 8.38)$
= 61.59 MPa

Upper bound $fc' = \bar{X} + (1.16 \times s)$
$= 71.31 + (1.16 \times 8.38)$
= 81.04 MPa

The average compressive strength of the concrete is 71.31 MPa, with the range of compressive strength achieved between 61.59 and 81.04 MPa. Subsequently, the results of the compressive strength calculations for each pH can be seen in Table 9.

Table 9. Compressive strength results

Sample	($\bar{X}$)	(s)	Variation (MPa)
pH 7	71.31	8.38	61.59 – 81.04
pH 8	62.88	9.86	51.43 – 74.32
pH 9	81.34	10.24	69.45 – 93.22

Based on the findings, it is evident that the compressive strength of the matrix with alkaline pH 9 reached its peak at 81.34 MPa, representing a notable increase of 14.06% compared to the pH 7 matrix. Conversely, the pH 8 variant experienced a decrease of 11.83%. Consequently, Alkaline Water with a pH of 9 exhibits superior potential for enhancing compressive strength in concrete mixtures [35].

4. CONCLUSION AND SUGGESTION

4.1 Conclusion

Based on the research findings, it can be concluded that the use of pH 8 and pH 9 water has a relatively insignificant impact on the consistency of cement.

Furthermore, based on the analysis mentioned above, it can be inferred that the utilization of pH 8 and pH 9 water significantly affects the initial and final setting times of the cement. Although not markedly significant, this indicates that the process of initial and final setting occurs more rapidly when compared to pH 7 water.

The compressive strength attained at the age of 28 days for pH 7 is 64.08 MPa, for pH 8 is 46.82 MPa, and for pH 9 is 66.25 MPa. The relationship between compressive strength and age demonstrates an increasing trend with age for pH 7. Conversely, there is a trend of decreasing strength at the age of 28 days for pH 8 and pH 9.

In comparing the compressive strengths of pH 7 with pH 8, there is a decrease in average strength by 12.90%, while for pH 7 with pH 9, there is an increase in average strength by 12.27%.

The utilization of alkaline pH 9 water in matrix mixtures can yield an increased compressive strength of 14.06% compared to pH 7 water.

4.2 Suggestion

The next step is to conduct research on the influence of Alkaline Water on the compressive strength of the matrix for a minimum age of 90 days in order to determine the strength impact according to age development.

In addition to researching matrix mixtures, further studies are also needed regarding concrete mixtures, including their strength development and other related strength factors.

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NOMENCLATURE

pH	Potential of Hydrogen
f'c	Required Concrete Compressive Strenght
MPa	Mega Pascal
Xi	Compressive Strength
$\sum$Xi	Number of Compressive Strength Data
n	Number of Data
$\bar{X}$	Compressive Strength Average
s	Standard Deviation