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# Effect of Silica Modulus on Concrete Maturity at Different Curing Temperatures

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**Abstract**

The variation in early-age strength development of concrete mixes containing locally produced OPC, cured at different temperatures throughout the seasons, has motivated many researchers to investigate this issue. This study analyzed how differences in the constituents of locally sourced OPC, particularly the silica modulus, affect strength development and its impact on concrete maturity at various temperatures. Concrete maturity was calculated using strength development over time to determine an equivalent age required to achieve a specific strength at a standard temperature. The equivalent age is a vital factor for determining the appropriate time to remove formwork at construction sites or to open roads to traffic. The study experimentally evaluated three different proportions of OPC constituents, producing three silica modulus (S.M.) values of 2.4, 2.7, and 3.0. It compared the effect of S.M. variation for two cement contents by assessing two groups of concrete with compressive strengths of 20 N/mm² and 35 N/mm², cured at temperatures of 7, 20, and 35 °C. The results revealed that strength increased with increasing curing temperature at all ages, while the rate of strength development decreased as S.M. increased for both strength levels. In contrast, the activation energy of concrete increased with increasing S.M., with the greatest increase observed in concrete with the higher cement content (35 N/mm²). The maturity function results, expressed in terms of equivalent age for concrete cured at non-standard temperatures (7 and 35 °C), showed that equivalent age was influenced by variations in the OPC S.M., with the effect being more pronounced at S.M. = 2.4 compared with S.M. values of 2.7 and 3.0.

*Keywords:* Concrete Maturity; Equivalent Age; Silica Modulus; Strength Development; Temperature.

## 1. Introduction

The components of cement and their proportions can affect concrete properties. One of the moduli that can affect concrete strength and the hydration process is silica modulus (S.M.), which is the mass ratio of silicon dioxide to the sum of alumina and ferric oxide ($SiO_2/Al_2O_3 + Fe_2O_3$) [1, 2]. The value of S.M., usually between 2 and 3 in the cement matrix, has an impact on the composition of the liquid phase within the clinker process. This liquid can change the function of $C_2S$ and $C_3S$ in cement, influencing concrete maturity and strength rate development [3-5]. The maturity concept of concrete relies on the relationship between concrete strength and both age and temperature sensitivity [6, 7]. Concrete maturity can produce a function to estimate the in-situ compressive strength at any age within the construction or estimate the equivalent age that is required for concrete to reach the specific strength at a standard temperature. These two outputs can assist in determining the proper time to remove a formwork in a construction site, open the roads for use, and end the protection of severe environments [6, 8]. Chindaprasirt et al. [9] investigated how the ratio of silica to

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alumina in geopolymers that contained fly ash (Type-C) affected the setting and hardening properties of geopolymers. The study tested a group of mixes that had silica-to-alumina ratios ranging from 2.87 to 4.79. Their results indicated that the increase in the silica/alumina ratio of cement reduces the setting time.

The researchers found that silica/alumina ratios between 3.20 and 3.70 have more impact on the early strength and setting time than other ratios. Yusuf et al. [10] examined the effect of silica ratio on the bonding and early strength of slag and fly ash concrete. The silica ratio that was examined was between 0.915 and 1.635. The results stated that within this range of *S.M.*, no significant effect was noticed on early strength; however, the microstructure of concrete containing higher *S.M.* was less homogenous compared to others. Ekinci et al. [11] investigated the effect of silica modulus, curing temperature, and liquid-to-binder (l/b) ratio on the compressive strength of geopolymer concrete containing volcanic tuff, which was used and activated with NaOH.

The study evaluated three temperatures of 90, 105, and 120°C and two l/b ratios of 0.5 and 0.6. Their results found that the silica modulus of 0.8, curing temperature of 105°C, and l/b ratio of 0.6 can produce the optimum performance of geopolymer concrete. Firdous & Stephan [12] assessed the influence of the silica modulus of geopolymers that had natural pozzolan on the rate of reaction. The study determined that the rate of reaction escalates with the decrease of silica modulus. Nonetheless, decreasing the silica modulus beyond a specific threshold adversely affects the mechanical characteristics of geopolymers. Salih et al. [13] statistically analyzed a study on the effect of different types of cement compounds and their oxides, along with a lime saturated factor (LSF) and silica modulus (*S.M.*), on the physical properties of cement and compressive strength. The study revealed that C3S, C3A, C4AF, and LSF have a positive impact on compressive strength, while C2S, CaO, SO3, and *S.M.* have a negative impact on compressive strength.

Luukkonen et al. [14] examined the influence of the varying silica modulus of sodium silicate powders on the mechanical and chemical characteristics of alkali-activated slag mortar. Their results indicated that a decrease in the silica modulus of solid sodium silicate exhibits a rise in the strength of alkali-activated slag over both 7 and 28 days. Kaze et al. [15] studied the impact of silica modulus on developing laterite-based alkali-activated binder. They found that the higher silica moduli (1.7 and 2) adversely affect the characteristics of the binder. Moreover, elevating the silica modulus from 1.3 to 2.0 causes an elongation of the setting time and a decrease in compression strength. Sivasakthi & Jeyalakshmi [16] have examined the impact of varying silica moduli from 0.6 to 1.6, along with increased temperatures of alkali solution, on the microstructure and strength of the fly ash geopolymer. The results revealed that increasing the silica modulus from 1.2 to 1.6 lowered the degree of reactivity and reduced strength development. In 2025, Ishaq et al. [17] examined the potential of *S.M.* ($Al_2O_3/SiO_2$) to affect the strength of concrete that had different percentages of glass powder as supplementary cementitious materials. The results found that silica modulus has a vital role on concrete strength, and it increases with increasing curing age.

A literature review reports that the majority of studies have focused on the impact of the silica modulus on geopolymer performance and alkali activators in the presence of some pozzolana materials. Research on concrete cured at different temperatures and with different amounts of cement is limited. This study, therefore, intends to address these research gaps. The study has focused on evaluating the impact of varying proportions of local OPC constituents that produce three silica modules (S.M.) of 2.4, 2.7, and 3.0 in terms of concrete maturity at various curing temperatures of 7, 20, and 35°C, which simulate seasonal temperatures. This evaluation included two quantities of cement represented by two groups of concrete with strengths of 20 and 35 N/mm².The study calculated the maturity of concrete assessing the strength gained over time and determined an equivalent age required to achieve the specific strength at the standard temperature. The resulting equivalent age is vital to identify the time to remove the formwork at the construction site or utilize open roads.

## 2. Experimental Program

### 2.1. Materials

***Ordinary Portland cement (OPC)***, produced from Almas Factory, in the grade of 32.5, was utilized for all the mixes. All chemical and physical characteristics of OPC are compatible with the specifications of IQS: 5, 2019 [18], and listed in Tables 1 and 2, respectively. All tests were performed in the Construction Materials Testing Lab of the Civil Engineering Department at the University of Mosul.

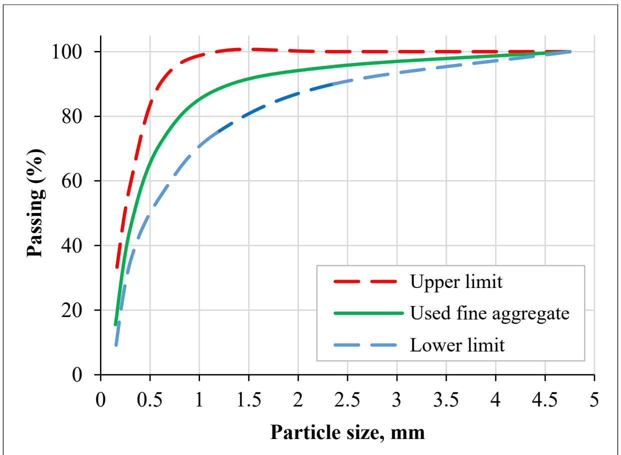
**Table 1. Chemical characteristics of OPC**

| Chemical Composition % | Results | | | Specifications IQS 5 (2019) [18] |
|---|---|---|---|---|
| | OPC 1 | OPC 2 | OPC 3 | |
| CaO | 61.19 | 61.82 | 61.16 | |
| $SiO_2$ | 19.72 | 20.65 | 21.29 | |
| $AL_2O_3$ | 4.20 | 4.11 | 3.85 | |
| $Fe_2O_3$ | 4.00 | 3.51 | 3.25 | |
| $SO_3$ | 1.72 | 1.82 | 1.85 | ≤ 2.8% |
| MgO | 2.05 | 2.27 | 2.47 | ≤ 5% |
| Insoluble residue | 1.00 | 0.90 | 0.90 | ≤ 1.5% |
| Loss of ignition | 3.18 | 2.90 | 2.82 | ≤ 4% |
| Free CaO | 1.35 | 1.49 | 1.12 | |
| **Total** | **98.41** | **99.47** | **98.70** | |
| ***Main Compounds*** | | | | |
| $C_2S$ | 9.31 | 23.06 | 26.04 | |
| $C_3S$ | 62.79 | 49.24 | 46.79 | |
| $C_3A$ | 3.83 | 4.95 | 5.04 | |
| $C_4AF$ | 12.17 | 10.68 | 9.28 | |

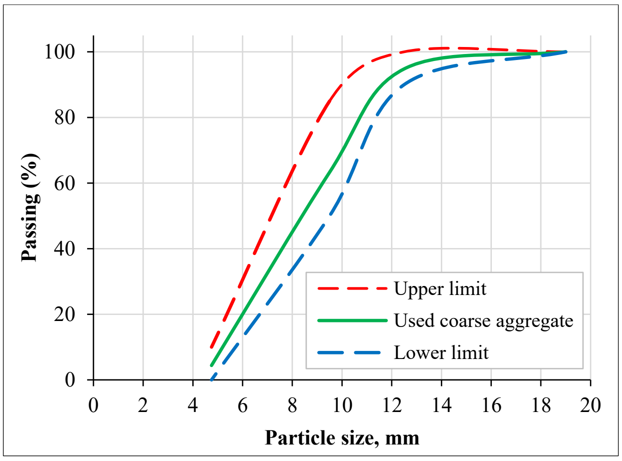
**Table 2. Physical characteristics of OPC**

| Physical characteristics | Results | | | Specifications IQS 5 (2019) [18] |
|---|---|---|---|---|
| | OPC 1 | OPC 2 | OPC 3 | |
| Initial setting time (min.) | 135 | 120 | 105 | |
| Final setting time (min.) | 270 | 255 | 240 | |
| Water to achieve consistency (g) | 106 | 103 | 101 | |
| Specific gravity | 3.15 | 3.15 | 3.15 | |
| Autoclave (%) | 0.23 | 0.22 | 0.25 | ≤ 0.8 |
| Blaine fineness ($cm^2/g$) | 3308 | 3300 | 3288 | |
| Color | Grey | Grey | Grey | |
| ***Compressive strength ($N/mm^2$)*** | | | | |
| 2-day | 12.3 | 13.6 | 15.3 | ≥ 10 $N/mm^2$ |
| 28-day | 39.5 | 38.1 | 37.5 | ≥ 32.5 $N/mm^2$ |

***Fine Aggregate***: River sand, produced from the Kanhash in Iraq/Mosul, was used as fine aggregate and had a maximum size aggregate of 2.36 mm (No. 8). The water absorption rate of sand is 1.5%, as determined by ASTM C128 [19]. According to ASTM C29 [20], the specific gravity of sand is 2.68, and its density is 1680 kg/m³. The gradation of sand matches with the specification of IQS [21], as shown in Figure 1-a, and the fineness modulus is 2.75.




(a)




(b)

**Figure 1. Sieve analysis of (a) fine aggregate & (b) coarse aggregate**

***Coarse Aggregate***: Natural coarse aggregate, obtained from Kanhash in Iraq/Mosul, was used as coarse aggregate. It has a specific gravity and absorption of 2.67 and 0.8%, respectively. Its gradation meets the specification of IQS [21], as shown in Figure 1-b, and the maximum size is 19 mm (¾ in.). The fine and coarse aggregates used in all the mixes were in a saturated surface dry (SSD) state.

***Water***: Potable water is used for mixing and curing of all mixes.

## 2.2. Methodology

The methodology of the study consists of three phases; the first is testing the final setting time of cement pastes that had different silica moduli. Second is determining the compressive strength of concrete mixes that had different silica moduli at different ages and temperatures. Third, calculate the concrete maturity function to determine the equivalent age of concrete cured at nonstandard temperatures. Figure 2 illustrates all phases of the methodology.

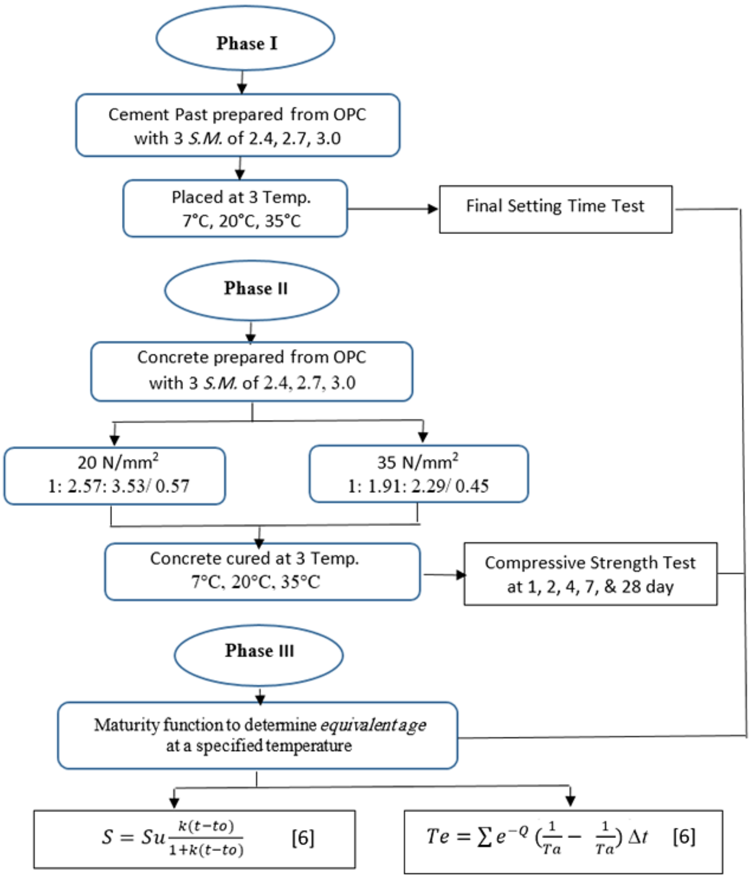



**Figure 2. Three phases of the research methodology**

***Final setting time test***: To calculate the strength gain (*k-value*), the final setting time required to safely demold the concrete was measured using the Vicat Needle Test, following ASTM C191 [22], as seen in Figure 3-a. The test was conducted on two groups of paste that had two different amounts of cement; each group included three pastes with three silica moduli. The specimens were subjected to testing at three temperatures of 7°C, 20°C, and 35°C.


(a) (b)

**Figure 3. (a) Final setting test of cement pasts, (b) Compressive strength test of concrete specimens**

***Compressive strength test***: The experimental work included two groups of mixes designed for 20 and 30 N/mm². The mix proportions of the first group were 1:2.57:3.53/0.57, and the second was 1:1.91:2.29/0.45, as illustrated in Table 3. Each group was applied to cast forty-five cubic specimens in standard dimensions of 150×150×150 mm and placed for curing at three temperatures of 7°C, 21°C, and 34°C. All specimens were tested for compressive strength, following the BS EN 12390-4 [23], at 1, 2, 4, 7, and 28 days, as shown in Figure 3-b.

**Table 3. Material measurements of all mixes**

| Strength (MPa) | Materials weight (kg/m³) | | | |
|---|---|---|---|---|
| | Cement | Fine. Agg. | Coarse Agg. | Water |
| 20 | 300 | 770 | 1060 | 170 |
| 34 | 420 | 800 | 960 | 190 |

***Maturity function***: Following ASTM C1074 [6], this study used a maturity function to identify the equivalent age required for concrete to reach maturity at a standard temperature, which is comparable to the maturity achieved during a curing period at a non-standard temperature, as shown in Equation 1.

$$Te = \sum e^{-Q}\left(\frac{1}{Ta} - \frac{1}{Ta}\right)\Delta t \qquad (1)$$

where, *Te* is an equivalent age at a standard temperature *Ts*, days, Q is activation energy/gas constant (8.31 J/K.mol), *Ta* is concrete temperature within time period Δt, °K, and *Ts* is specified temperature, °K, & Δt = time period, days.

The activation energy, Q, needed for Equation 1, was calculate using Equation 2. The last was used to determine the strength gain (*k-value*) based on the actual compressive strength of all concrete specimens, including three silica moduli and curing temperatures. The correlation between the logarithm of the *k-value* and the inverse of curing temperatures is plotted to identify the Q value to use in the previous equation (Equation 1) of each silica modulus and for two strengths.

$$S = Su\frac{k(t-to)}{1+k(t-to)} \qquad (2)$$

where, *S* is compressive strength of cube at age t, *t* is age of the test, *Su* is ultimate strength, *to* is age when strength start gaining, and k is the rate of strength gaining.

## 3. Experimental Results and Discussion

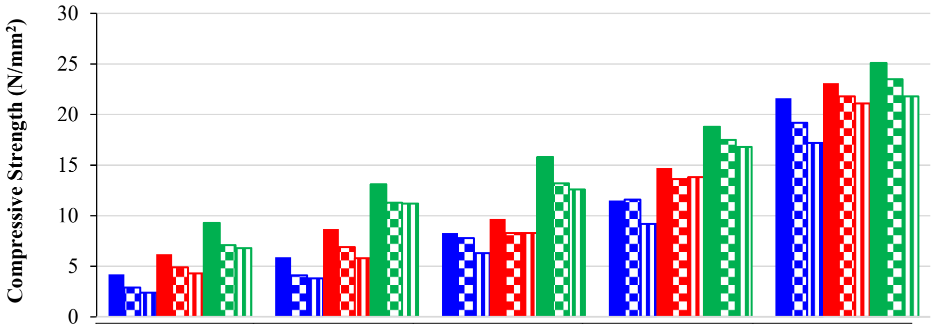
***Final setting time***: The final setting time (F.S.T.) was determined for two groups of OPC pastes; each group had varying silica modulus (*S.M.*) and was placed at three temperatures. The amounts of cement in the paste were 300 and 420 kg/m³, respectively, for the first and second groups. The results of the test are listed in Table 4 and show that the F.S.T. reduced when the *S.M.* for the pastes increased. Since *S.M.* contributes to accelerating cement hydration and slightly decreases F.S.T., this output is compatible with the finding of Chindaprasirt et al. [9] Adewumi et al. [24], and Ramanathan et al. [25]. In addition, the F.S.T. was reduced for the paste placed at higher temperatures because of the impact of temperature on the acceleration of the hydration process, shortening setting time [24-26]. Furthermore, the F.S.T. was less for the group of pastes that contained a higher amount of cement (420 kg/m³) compared with the other, since the first had a lower *w/c* ratio (0.45), resulting in a reduction in F.S.T.

**Table 4. Final setting time of cement pastes had varying silica modulus at temperatures**

| Cement amount (kg/m³) | Silica modulus | Final setting time (min.) | | |
|---|---|---|---|---|
| | | Curing temperature (°C) | | |
| | | 7 | 20 | 35 |
| 300 | 2.4 | 300 | 270 | 240 |
| | 2.7 | 285 | 255 | 225 |
| | 3.0 | 285 | 240 | 225 |
| 420 | 2.4 | 255 | 240 | 225 |
| | 2.7 | 255 | 225 | 210 |
| | 3.0 | 240 | 225 | 210 |

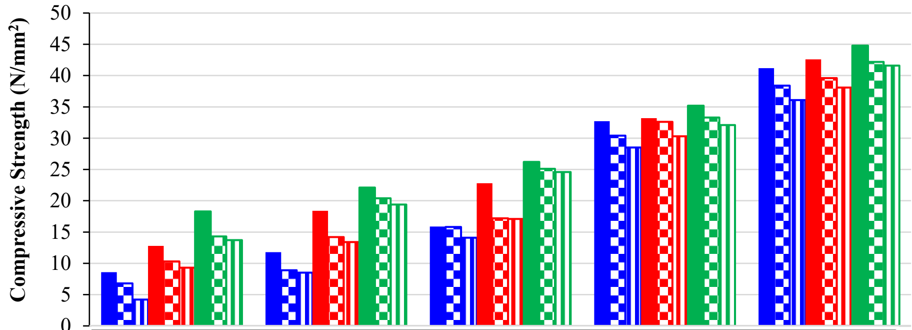
***Compressive strength***: The compressive strength was examined for two groups of concrete specimens (20 N/mm² and 35 N/mm²) at ages of 1, 2, 4, 7, and 28 days. Each group prepared from OPC with varying silica modulus (*S.M.*) and cured at three temperatures. The results of all specimens were plotted in Figures 4 and 5 for concrete strengths of

20 N/mm$^2$ and 35 N/mm$^2$, respectively, at all ages. The results indicated that the compressive strength increased as the curing temperature was raised, especially at early ages. The reason for the finding is that high curing temperature generates more crystallized hydration product (C-S-H) to induce a compact microstructure and enhance the matrix adhesion and strength development of concrete; this trend is compatible with previous studies [24, 26-28]. However, the compressive strength decreases with the increase of *S.M.* at all curing temperatures and all ages. The reduction in strength was more observed when S.M. increased from 2.4 to 2.7, while the reduction in strength was diminished between *S.M.* of 2.7 and 3.0. This reduction can be attributed to the role of *S.M.* (silica to alumina ratio) in the composition of the liquid phase during the clinker process. This liquid can change the function of $C_2S$ and $C_3S$ in cement, influencing concrete maturity and strength rate development [3, 4]. The nature of the alkali solution, the binding material, and the curing temperature can all have an impact on this strength ratio [29]. Previous studies [11, 24] revealed similar findings, indicating that the *S.M.* of cement could negatively impact the compressive strength of concrete.




| | 1-day | 2-day | 4-day | 7-day | 28-day |
|---|---|---|---|---|---|
| S.M 2.4,T 7°C | 4.2 | 5.9 | 8.3 | 11.5 | 21.6 |
| S.M 2.7,T 7°C | 2.9 | 4.1 | 7.8 | 11.6 | 19.2 |
| S.M. 3,T 7°C | 2.4 | 3.8 | 6.3 | 9.2 | 17.2 |
| S.M 2.4,T 21°C | 6.2 | 8.7 | 9.7 | 14.7 | 23.1 |
| S.M2.7,T 21°C | 4.9 | 6.9 | 8.3 | 13.6 | 21.8 |
| S.M. 3,T 21°C | 4.3 | 5.8 | 8.3 | 13.8 | 21.1 |
| S.M 2.4,T 35°C | 9.3 | 13.1 | 15.8 | 18.8 | 25.1 |
| S.M.2.7,T 35°C | 7.1 | 11.3 | 13.2 | 17.5 | 23.5 |
| S.M. 3,T 35°C | 6.8 | 11.2 | 12.6 | 16.8 | 21.8 |

**Figure 4. Compressive Strength of concrete contained varying S.M. and curing temperatures at different ages for concrete strength design of 2035 N/mm$^2$**




| | 1-day | 2-day | 4-day | 7-day | 28-day |
|---|---|---|---|---|---|
| S.M 2.4, T 7°C | 8.6 | 11.8 | 15.9 | 32.7 | 41.2 |
| S.M 2.7, T 7°C | 6.8 | 8.9 | 15.8 | 30.4 | 38.4 |
| S.M. 3, T 7°C | 4.2 | 8.5 | 14.1 | 28.5 | 36.1 |
| S.M 2.4, T 21°C | 12.8 | 18.4 | 22.8 | 33.2 | 42.6 |
| S.M2.7, T 21°C | 10.3 | 14.2 | 17.2 | 32.6 | 39.6 |
| S.M. 3, T 21°C | 9.3 | 13.4 | 17.1 | 30.3 | 38.1 |
| S.M 2.4, T 35°C | 18.3 | 22.1 | 26.2 | 35.2 | 44.8 |
| S.M.2.7, T 35°C | 14.3 | 20.4 | 25.1 | 33.3 | 42.2 |
| S.M. 3, T 35°C | 13.7 | 19.4 | 24.6 | 32.1 | 41.6 |

**Figure 5. Compressive Strength of concrete contained varying S.M. and curing temperatures at different ages for concrete strength design of 35 N/mm$^2$**

The strength gain rate (*k-value*) for concrete was determined using its compressive strength for three silica moduli and curing temperatures. The results are shown in Table 5, Figure 6 for 20 N/mm$^2$, and Figure 7 for 35 N/mm$^2$. The results indicated that the rate of strength gain increased as the curing temperature rose, for the same reason mentioned above [24, 26-28]. At the same temperature, the *k-value* was the highest for concrete with a silica modulus (*S.M.)* of 2.4, while the k-value was approximately the same for concrete with *S.M.* values of 2.7 and 3 for both strengths of 20 N/mm² and 35 N/mm². Thereafter, the *k-value* logarithm was plotted against the inverse of curing temperatures in °K for all silica moduli and temperatures. Figure 8 shows this for 20 N/mm² concrete, and Figure 9 shows this for 35 N/mm² concrete. The value of Q, which equals the activation energy/gas constant (8.3 J/k.mole) [6], was found for each silica modulus, as listed in Table 5.

The outputs showed that the activation energy increased with the increase of silica modulus, and this increase was more pronounced in concrete containing a high amount of cement (35 N/mm²). These results indicated that the amount of cement can influence activation energy rather than the strength gain. This value of Q was then used in Equation 1 to figure out the equivalent age of concrete, with different silica moduli, that was poured at a non-standard temperature. The findings of the equivalent age, at a standard condition, for concrete cured at non-standard temperatures of 7°C and 35°C are listed in Tables 6 and 7, respectively. The results depicted that the equivalent age is influenced by the silica modulus of OPC; the increased silica modulus increases the variation between the equivalent age and the actual test age. This variation increased for concrete cured at a higher temperature of 35°C, and it ranged between 32% and 52% when the silica modulus was between 2.4 and 3.0. The finding additionally showed that the amount of cement could impact an equivalent age, specifically with a silica modulus of 2.7, as seen in Figure 10.

**Table 5. Strength gain rate (*k-value*) and activation energy ($E_a$) of concrete**

| S.M. | Strength gaining rate (*K –value*), (1/day) | | | | | | *Activation energy* ($E_a$), (J/mol) | |
|---|---|---|---|---|---|---|---|---|
| | Strength design, N/mm$^2$ | | | | | | Strength design (N/mm$^2$) | |
| | 20 | | | 35 | | | | |
| | Curing temperature (°C) | | | | | | 20 | 35 |
| | 7 | 20 | 35 | 7 | 20 | 35 | | |
| 2.4 | 0.45 | 0.64 | 0.81 | 0.43 | 0.61 | 0.84 | 14,856 | 16,852 |
| 2.7 | 0.27 | 0.50 | 0.56 | 0.29 | 0.47 | 0.66 | 18,768 | 20,958 |
| 3.0 | 0.24 | 0.41 | 0.57 | 0.22 | 0.46 | 0.65 | 21,766 | 27,656 |

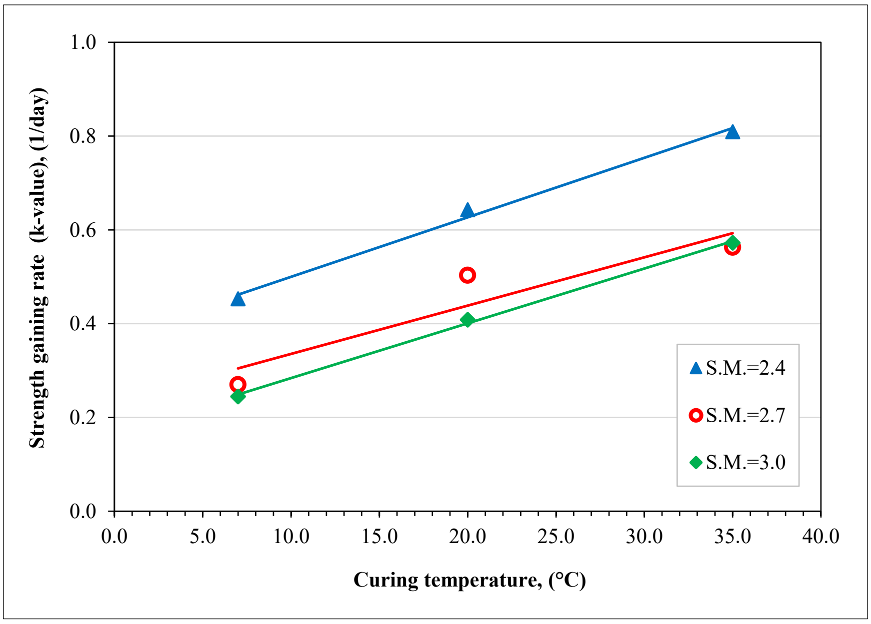



**Figure 6. Strength gain rate (*k-value)* versus curing temperature for specimens of (20 N/mm$^2$)**

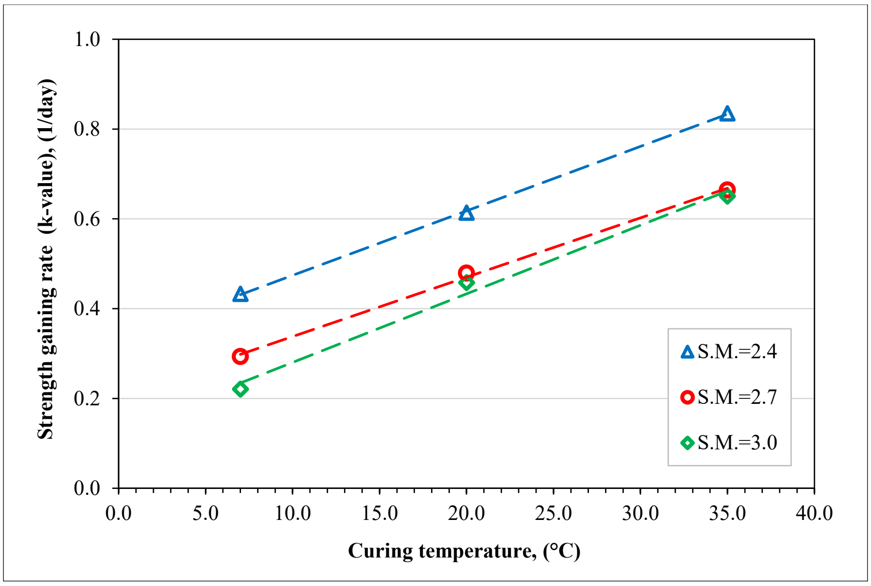



**Figure 7. Strength gain rate (*k-value)* versus curing temperature for specimens of (35 N/mm$^2$)**

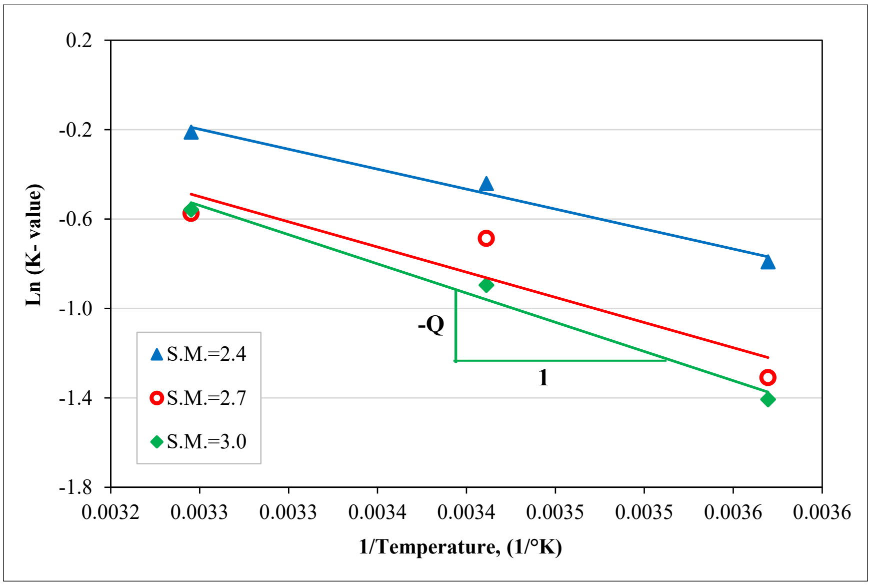



**Figure 8. *K-value* logarithm versus curing temperature invers to determine Q for specimens (20 N/mm$^2$)**

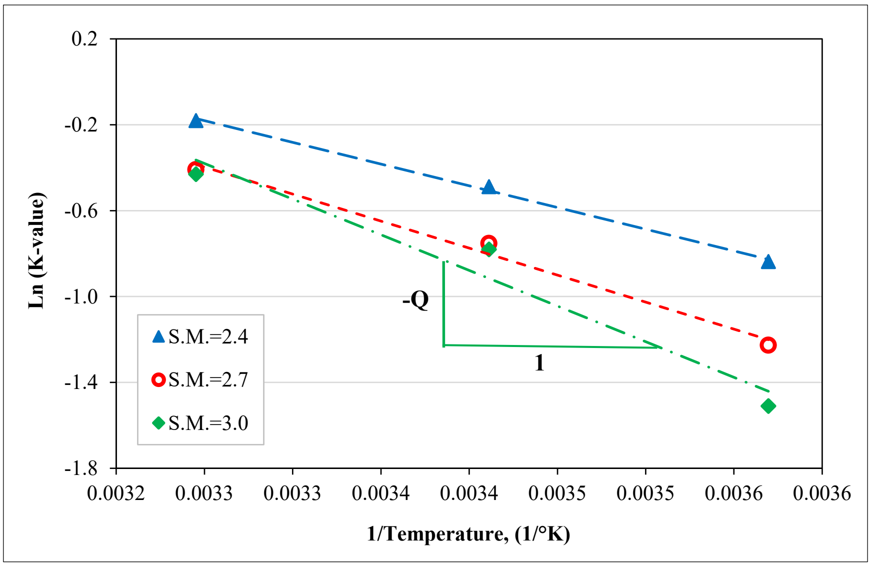



**Figure 9. *K-value* logarithm versus curing temperature invers to determine Q for specimens of (35 N/mm$^2$)**

**Table 6. Equivalent age at standard temperature (20°C) for different silica modulus for concrete strength design of 20 N/mm²**

| Curing temp., (°C) | S.M. | Actual test Age Δ*t*,(day) | Equivalent age *Te*, (day) | Diff.% | S.M. | Equivalent age *Te*, (day) | Diff.% | S.M. | Equivalent age *Te*, (day) | Diff.% |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 2.4 | 1 | 0.7 | -26 | 2.7 | 0.7 | -32 | 3.0 | 0.6 | -36 |
| | | 2 | 1.5 | -26 | | 1.4 | -32 | | 1.3 | -36 |
| | | 4 | 3.0 | -26 | | 2.7 | -32 | | 2.6 | -36 |
| | | 7 | 5.2 | -26 | | 4.8 | -32 | | 4.5 | -36 |
| | | 28 | 20.7 | -26 | | 19.1 | -32 | | 18.0 | -36 |
| 35 | | 1 | 1.3 | 32 | | 1.4 | 42 | | 1.5 | 50 |
| | | 2 | 2.6 | 32 | | 2.8 | 42 | | 3.0 | 50 |
| | | 4 | 5.3 | 32 | | 5.7 | 42 | | 6.0 | 50 |
| | | 7 | 9.2 | 32 | | 9.9 | 42 | | 10.5 | 50 |
| | | 28 | 36.9 | 32 | | 39.7 | 42 | | 41.9 | 50 |

**Table 7. Equivalent age at standard temperature (20°C) for different silica modulus for concrete strength design of 35 N/mm²**

| Curing temp., (°C) | S.M. | Actual test Age Δ*t*,(day) | Equivalent age *Te*, (day) | Diff. % | S.M. | Equivalent age *Te*, (day) | Diff.% | S.M. | Equivalent age *Te*, (day) | Diff.% |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 2.4 | 1 | 0.7 | -26 | 2.7 | 0.6 | -35 | 3.0 | 0.6 | -37 |
| | | 2 | 1.5 | -26 | | 1.3 | -35 | | 1.3 | -37 |
| | | 4 | 3.0 | -26 | | 2.6 | -35 | | 2.5 | -37 |
| | | 7 | 5.2 | -26 | | 4.5 | -35 | | 4.4 | -37 |
| | | 28 | 20.6 | -26 | | 18.1 | -35 | | 17.7 | -37 |
| 35 | | 1 | 1.3 | 33 | | 1.5 | 48 | | 1.5 | 52 |
| | | 2 | 2.7 | 33 | | 3.0 | 48 | | 3.0 | 52 |
| | | 4 | 5.3 | 33 | | 5.9 | 48 | | 6.1 | 52 |
| | | 7 | 9.3 | 33 | | 10.4 | 48 | | 10.6 | 52 |
| | | 28 | 37.3 | 33 | | 41.6 | 48 | | 42.6 | 52 |

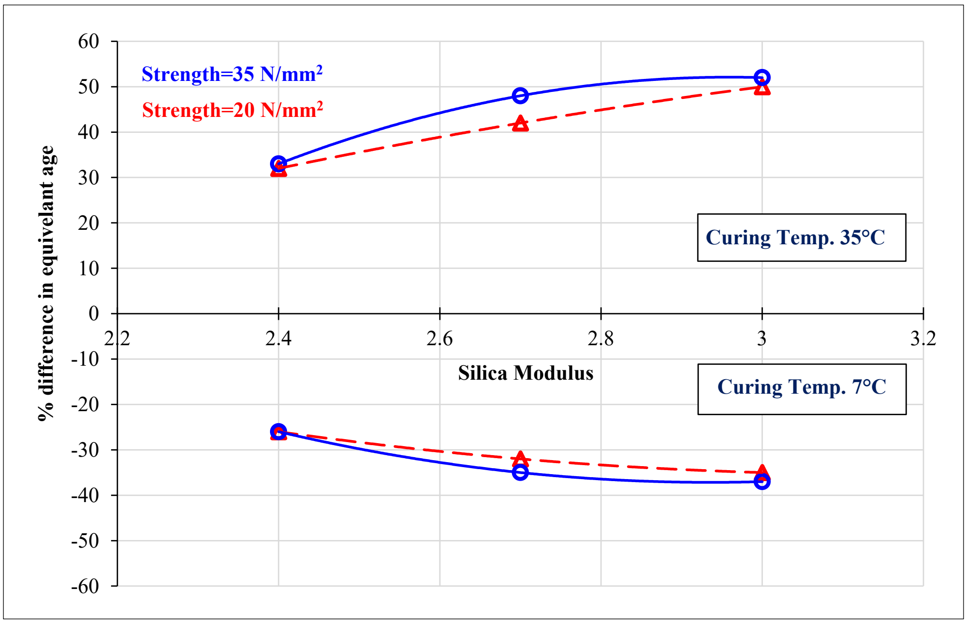



**Figure 10. The percentages difference in equivalent age with varying silica modulus at 7 °C and 35 °C for concrete strengths design of 20 N/mm² and 35 N/mm²**

# 4. Conclusions

The test results were used to determine the impact of silica modulus on the maturity of concrete, in terms of equivalent age, at different temperatures and for two different strengths (20 and 35 N/mm²). The following outputs can be explored:

- The silica modulus has an impact on the final-setting time of cement paste; the higher the silica modulus, the less the final setting time of the paste under all temperatures. In addition, the higher amount of cement accelerates the final setting time.
- The silica modulus can influence the concrete compressive strength; the increase of silica modulus reduces the compressive strength at all temperatures and all ages. This reduction was more pronounced for concrete containing OPC with a silica modulus of 2.4.
- The activation energy (*Ea*) of concrete increases in parallel with the raising silica modulus, and this increase is particularly noticeable in concrete that contained a higher amount of cement (35 N/mm²), indicating that the amount of cement significantly impacts the *Ea*.
- The silica modulus of cement affects the equivalent age; as the silica modulus rises, the difference between the equivalent age and the actual test age widens. This difference increases for the concrete cured at a higher temperature of 35°C. In addition, the amount of cement, particularly when silica modulus is present at 2.7, may influence the equivalent age.

# 5. Declarations

## 5.1. Author Contributions

Conceptualization, E.K.I. and S.Y.A.; methodology, S.Y.A.; software, O.A.S.; validation, E.K.I., S.Y.A., and O.A.S.; formal analysis, E.K.I. and S.Y.A.; investigation, E.K.I. and S.Y.A.; resources, O.A.S.; data curation, S.Y.A.; writing—original draft preparation, E.K.I.; writing—review and editing, E.K.I. and S.Y.A.; visualization, E.K.I. and O.A.S.; supervision, S.Y.A.; project administration, E.K.I. and S.Y.A.; funding acquisition, E.K.I., S.Y.A., and O.A.S. All authors have read and agreed to the published version of the manuscript.

## 5.2. Data Availability Statement

The data presented in this study are available in the article.

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## 5.5. Conflicts of Interest

The authors declare no conflict of interest.

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