

CORRELATION BETWEEN NORMAL AND ACCELERATED CURING STRENGTH OF CONCRETE MIXTURES

Shanmugasundaram Imran Khan^{1,*}, Sivapregassame Palani², and Sivanandam Kodandaraman³

Received: September 19, 2024; Revised: July 14, 2025; Accepted: July 22, 2025

Abstract

Indian cement industries produce various types of cement. Among them, the most prevalently used general-purpose cements are ordinary Portland cement (OPC), Portland pozzolana cement (PPC), and Portland slag cements (PSC). Today modern construction and advanced construction techniques bring a sharp focus on the evaluation of strength parameters at an early age. This will enable quality control measures from time to time and in taking quick decisions on corrective measures. Prediction of the early age strength of concrete is essential, particularly for the manufacture of structural precast components. There are different methods available to predict the strength of concrete at an early stage. The scope investigation of the present correlation equation given in IS: 9013 was released in 1978, and is based on the age-old cement of Indian cement industries. Today the morphology of Indian cements has undergone a sea change with different chemical and mineralogical compositions. In the present investigation, the relation between the 28-day strength of normally cured concrete and accelerated cured concrete strength by boiling water techniques has been evaluated. Six ranges of water cement ratios have been used. The linear regression analysis has been carried out to establish the relationship between the actual 7-28 days strength with accelerated strength. A linear relationship has been found to fit very closely between the accelerated and the actual compressive strength of concrete made out of different brands and types of cement. In all the cases the coefficient of regression is found to be greater than 0.90. Further, a comparison has been made with the relation recommended by IS: 9013.

Keywords: Accelerated Curing Strength; Boiling Water Technique; Concrete Strength; OPC-43 Grade; OPC-53 grade; PPC; PSC; Regression Analysis

¹ Department of Civil Engineering, Kamala Nehru Institute of Physical & Social Sciences, Engineering College, Sultanpur, Uttar Pradesh, India. Email: ashok4094@gmail.com*

² Former Executive Engineer, Public Works Department, Puducherry, India. Email: erpalani59@gmail.com

³ Former Principal, Pondicherry Engineering College, Puducherry, India. Email: skramane@gmail.com

* Corresponding author

DOI: <https://doi.org/10.55766/sujst6711>

Suranaree J. Sci. Technol. 33(1):010393(1-11)

Introduction

India is the second largest producer of cement in the world, accounting for more than 7 percent of the global installed capacity. In the financial year (FY) 2022, domestic production of cement stood at 356 million tons, up from 296 million tons in FY 2021 (Akhnoukh and Buckhalter 2020). The general-purpose cement, such as ordinary Portland cement (OPC), Portland pozzolana cement (PPC), and Portland slag cement (PSC) are prevalently produced in India (Salih and Aldikheeli, 2020). Currently, blended cement, PPC, and PSC put together account for 73 percent of total cement production in India, compared to 27 percent for OPC (Hoy *et al.*, 2024a). Compressive strength after 28 days is the traditional measure used to determine the quality of concrete used in construction projects (Abadel *et al.*, 2022). It takes too long to be useful for controlling concrete construction or implementing immediate corrective measures because this approach requires 28 days of curing in moisture before testing (Kantatham *et al.*, 2024). If the quality of the concrete is discovered to be questionable after 28 days, it will have hardened significantly by then and may have also been covered by later building (Vineel *et al.*, 2018). It becomes extremely difficult and frequently impractical to replace the concrete mass of dubious qualities as a result (Dong *et al.*, 2022). However, in the case that the concrete turns out to be stronger than needed, it will be too late to stop the unnecessary usage of cement in an unfeasible mix proportioning (Moelich and Combrinck, 2020). For quality control, it is therefore not possible to test concrete using the normal 28 day cube method (Samingthong *et al.*, 2023).

In order to evaluate the controlled concrete quality, an acceptance test is employed, which can yield results while the concrete is still flexible and enough vibrant to allow for practical removal in about 24 hours following casting (Hong *et al.*, 2021). Concrete's compressive strength may now be quickly tested, allowing for the estimation of whether or not the material will likely attain the desired strength after 28 days (Hoy *et al.*, 2024b). This is made possible by dependable test methods that use accelerated curing procedures (Bahmani and Mostofinejad, 2022). An accelerated curing process approved by the Bureau of Indian Standards and detailed in IS 9013:1978 (1978) is required for the fast and dependable evaluation of controlled concrete in the field. This standard (Huang *et al.*, 2021) describes the "warm water method" and the "boiling water method," two techniques. Apart from the aforementioned two techniques, the American

Society for Testing and Materials (ASTM C 684), offers two further accelerated testing methods: "autogenous" and "high temperature and pressure" (Harith *et al.*, 2022).

Problem Formulation

Two regression equations corresponding to the boiling water and warm water methods are presented in IS 9013:1978 (1978). These equations have been developed in the 1970s during which time the use of PPC and PSC was extremely scanty. Though many parameters of concrete mixture influence the strength gain during the accelerated curing the chemical composition of cement must have a significant bearing in imparting the accelerated strength. Cement types vary significantly in their proportions of clinker, pozzolanic or slag content, and gypsum. These variations affect the hydration rate, heat evolution, and strength gain, especially under elevated temperatures used in accelerated curing methods. For instance, the pozzolanic reaction in PPC and the latent hydraulic reaction in PSC are slower than the hydration of OPC, which can result in different strength gain profiles under accelerated conditions. Recognizing these differences, an exhaustive study was undertaken to evaluate the accelerated strength development of concrete mixtures incorporating Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC). Based on the outcomes, it was contemplated to propose separate correlation equations for each cement type, if the data supports that a unified approach is insufficient for accurate prediction.

Proposed Methodology

A significant amount of the strength that would normally take 28 days to accomplish is reached in a shorter amount of time when concrete is cured more quickly because it speeds up the cement's hydration process. In order to correlate the results of compressive strength measurements on specimens cured by both normal and accelerated curing methods, it is essential to take into account the cement's chemical composition, the ratio of water to cement, as well as mix proportions. These factors determine the cement's rate and extent of water intake under a given curing regime. In addition to thermally triggering the chemical reactions involved in cement hydration, the accelerated cure regime

itself introduces additional variable in that the greater temperature used may change the shape of the hydration products.

This study examines the relationship among the strength after 28 days of regularly cured concrete and the accelerated strength achieved by boiling water procedures. Ratios of cement to water have been employed in six ranges. Establishing the association between the actual 7-28 day strength and accelerated strength has been done through the use of linear regression analysis. By comparing the accelerated and actual compressive strengths of concrete built with various cement brands and types, a linear connection has been found to fit quite closely.

Experimental Programme

Materials

Four types of cements, OPC-43 Grade IS 8112 (2013), OPC-53 grade IS 12269 (1987), PPC IS

1489 Part 1:1991 (1991), and PSC IS 455 (1989) were used in the present study. In each type, different brands or called samples were used. To find the physical and chemical properties, composite samples were prepared from each brand and tested. The chemical composition and physical properties of cement are given in Table 1.

Aggregates

Crushed stone aggregates, fine and coarse procured from the Perumakkal quarry were used in this investigation. The required quantity was estimated and procured in single bulk and stored in bins. They were tested in accordance with IS 383 (1970) for gradation. The test results are presented in Table 2.

Coarse aggregates of maximum size 20mm and 12.5mm were separately procured and tested for gradation separately. Based on the gradation, a mixture of 60% of 20mm and 40% of 12.5mm graded aggregates satisfied the requirements for 20mm graded aggregates as stipulated in IS 4031 (1988).

Table 1. Physical properties and chemical analysis of cement

Properties	Cement type			
	OPC		PPC	PSC
	43 Grade	53 Grade		
Physical:				
Density (g/cm ³)	3.16	3.17	3.14	3.11
Specific surface:				
Blaine (m ² /kg)	335	365	350	372
Setting time:				
Initial (min)	190	210	180	220
Final (min)	320	360	290	280
Mechanical				
Compressive strength:				
3 Days (MPa)	25.62	25.64	18.42	17.42
7 Days (MPa)	36.52	36.33	26.54	23.45
28 Days (MPa)	48.42	58.63	37.48	37.32
Chemical composition:				
Oxide (%):				
CaO	65.32	71.23	61.87	60.92
SiO ₂	20.63	13.30	20.20	21.84
Al ₂ O ₃	4.22	3.65	4.54	3.85
Fe ₂ O ₃	3.85	4.65	4.80	5.02
MgO	1.42	1.82	2.01	1.65
CaO (free)	1.86	1.02	2.48	2.24
Insoluble residue (%)	0.52	0.85	1.10	1.25
Loss on ignition (%)	0.86	1.10	1.22	1.22

Table 2. Gradation of aggregates - Cumulative aggregate passing.

IS Sieve size, mm	20	16	12.5	10	4.75	2.36	1.18	0.60	0.30	0.15
Fine aggregate	100	100	100	100	99	98	81	40	22	1
Coarse aggregate, 20mm max.	100	33	10	2	0	0	0	0	0	0
Coarse aggregate, 12.5mm max.	100	100	99	85	1	0	0	0	0	0

Note: Fineness modulus of fine aggregate = 2.57
 Fineness modulus of 20mm size aggregate = 8.97
 Fineness modulus of 12.5 mm aggregate = 6.15

Concrete mixture designation

Three basic mixture proportions were decided in this study. Alphanumeric designations were given for the concrete mixtures. The alphabet, namely.

- A. stands for a mixture with a cement content of 300kg/m³ of concrete,
- B. stands for a mixture with a cement content of 400kg/m³ of concrete, and
- C. stands for a mixture with a cement content of 500kg/m³ of concrete.

Cement samples/brands were identified in the respective Tables of test results for concrete mixture details as per the IS 10262 (2009).

Table 3 shows the Concrete mixture details. The cement-to-water ratio is one of the most critical factors affecting the properties of concrete. The respective water cement ratio was included in the above designations. Water cement ratios of 0.58, 0.55, 0.50, 0.45, 0.40, and 0.35 were considered in this study. For example, 58 stands for a mixture with a water cement ratio of 0.58, 50 stands for a mixture with a water cement ratio of 0.50, and so on. For instance, mixtures A58 and A55 contain 300 kg/m³ of cement, with water contents of 174 kg/m³ and 165 kg/m³, yielding w/c ratios of 0.58 and 0.55, respectively. Similarly, mixtures B50 and B45 each include 400 kg/m³ of cement, with 200 kg/m³ and 180 kg/m³ of water, leading to w/c ratios of 0.50 and 0.45. Lastly, mixtures C40 and C35 contain 500 kg/m³ of cement, with water contents of 200 kg/m³ and 175 kg/m³, corresponding to w/c ratios of 0.40 and 0.35, respectively.

Specimen preparation

The required quantity of materials was accurately weighed/measured and kept in separate containers. Pan-type mixture machine was used for mixing the concrete. All the dry materials required for the mixtures were added to the pan mixture and mixed in the dry state for 30 seconds. Required water was added then and thoroughly mixed for 3 minutes. All the test specimens were prepared on steel moulds. The specimens were consolidated using a table vibrator as per IS 516 (1959), 100 mm size cubes were prepared for all the samples of

cement. For each category twelve specimens were prepared for finding accelerated strength by (i) warm water, (ii) boiling water, (iii) actual 7 day and (iv) actual 28 day strength of concretes. Total 216 concrete cube specimens were tested in this study. For Grade 53 concrete, Brand 1 included 6 different mixtures, with 3 specimens tested at each of one curing ages (AS-3, N7-3, N28-3), totaling 18 specimens. Brand 2 and Brand 3 under Grade 53 followed the same pattern, contributing 18 specimens each, resulting in 54 specimens for Grade 53 overall. Grade 43 concrete was tested using 4 different brands, each with 6 mixtures and 3 specimens per curing age, totaling 72 specimens. PPC cement was evaluated using 4 brands, with the same testing scheme, contributing 72 specimens. PSC cement was tested using one brand, with 6 mixtures and 3 specimens per curing age, totaling 18 specimens.

Curing

a) Accelerated curing - Boiling water method: The test specimens were kept at ambient temperature for 23 hours from the time of the addition of water to the dry ingredients (Ozioko and Ohazurike 2019). The specimens then be gently lowered into the boiling water tank and kept immersed for a period of 3½ hours ± 5 minutes (Anand *et al.*, 2023). The temperature of the water in the curing tank was maintained at boiling (100°C) throughout the curing period.

After boiling for 3½ hours ± 5 minutes the specimens were shifted to cold water maintained at 27 ± 2°C for a period of not less than one hour. Accelerated curing approach involves immersing the specimens in warm water maintained at a constant temperature, after an initial rest period at ambient conditions. The immersion duration depending on the target strength and cement type. The warm water method provides a less aggressive thermal profile, reducing the risk of micro cracking due to thermal stress while still achieving accelerated strength development.

b) Normal curing - water curing: The test specimens were kept at ambient temperature for 24 hours from the time of the addition of water to the dry ingredients. The specimens were demoulded

Table 3. Concrete mixture details

Mixture designation	Materials, kg/m ³ of concrete			Water cement ratio	
	Cement (C)	Fine aggregate	Coarse aggregate	Water (W)	(W/C)
A58	300	730	1245	174	0.58
A55	300	735	1250	165	0.55
B50	400	645	1205	200	0.50
B45	400	655	1215	180	0.45
C40	500	525	1225	200	0.40
C35	500	530	1240	175	0.35

and immersed in water baths with a temperature maintained at $27 \pm 2^\circ\text{C}$ till testing the specimens for compressive strength. Three specimens were tested for each of 7-day and 28-day strength in accordance with IS 9013:1978 (1978).

Samples images of the accelerated curing process is illustrated in the above given Figure 1. Accelerated concrete curing is a method that uses elevated temperatures, often in the form of steam or hot water, to speed up the hydration process of cement, resulting in concrete reaching a significant portion of its ultimate strength within a significantly shorter timeframe compared to traditional curing. Specifically the boiling water method, which enables rapid assessment of early-age compressive strength of cement-based materials. In this setup, moulded specimens are carefully placed into a boiling water bath after an initial resting period at ambient temperature, simulating conditions that accelerate hydration reactions. Based on the process, the cement types such as OPC-43 Grade, OPC-53 grade, PPC and PSC are processed with the accelerated curing to find out the compressive strength of the cement with different water cement ratio. It highlights safety considerations and the importance of maintaining consistent timing and temperature conditions to ensure repeatable and standardized results.



Figure 1. Sample images of the Accelerated curing process

Compressive strength

After appropriate curing the specimens were tested for compressive strength in accordance with IS 516 (1959) using a 2MN capacity compression testing machine. Three specimens were tested for each category and the average values are reported in Tables 4 - 7.

Table 4 (a)-(c) illustrates the compressive strength for 53 grade with 3 different brands. Normal concrete strength is designated as N7/N28 and accelerated strength is designated as AS. The N7 describes the concrete strength for 7 days and N28 determines the concrete strength for 28 days.

According to the compressive strength for 53 grade based on brand 3, the N28 with the PC35 mixture designation has the highest compressive strength of 44.13 MPa and the AS with the PC35 has 24.20 MPa. Thus, the 53 grade with brand 3 has the highest compressive strength compared to the brand 1 and 2.

Table 4(a). Compressive strength (53 Grade)-Brand 1 IS 12269 (1987)

Mixture designation	Compressive strength, MPa			Slump, mm
	AS	N7	N28	
PA58	11.83	19.13	24.93	40
PA55	12.10	21.73	25.13	0
PB50	12.23	24.93	27.67	80
PB45	17.83	30.13	36.27	40
PC40	16.47	29.80	37.77	80
PC35	20.30	31.67	41.47	20

Table 4(b). Compressive strength (53 Grade)-Brand 2

Mixture designation	Compressive strength, MPa			Slump, mm
	AS	N7	N28	
PA58	08.97	14.87	25.53	50
PA55	12.07	19.67	26.73	0
PB50	12.33	21.53	28.20	140
PB45	17.07	24.13	37.60	70
PC40	19.53	27.00	38.27	130
PC35	21.13	29.80	38.67	50

Table 4(c). Compressive strength (53 Grade)-Brand 3

Mixture designation	Compressive strength, MPa			Slump, mm
	AS	N7	N28	
PA58	10.07	20.70	29.67	60
PA55	12.87	21.93	30.00	20
PB50	13.60	24.07	32.67	190
PB45	16.67	25.53	34.27	35
PC40	17.53	27.00	39.67	120
PC35	24.20	32.27	44.13	20

Compressive strength for 43 grade with 4 different brands are illustrated in the table 5 (a)-(d). According to the compressive strength for 43 grade based on brand 1, the N28 with the PC35 mixture designation has highest compressive strength of 48.67 MPa. And for 43 grade based on brand 4, the AS with the PC35 has 25.23 MPa. Thus, the mixture of PC35 for brand 1 and brand 4 has the highest compressive strength for AS and N28 than the other brands.

Table 5(a). Compressive strength (43 Grade)-Brand 1 IS 8112 (2013)

Mixture designation	Compressive strength, MPa			Slump, mm
	AS	N7	N28	
PA58	12.57	19.40	23.53	40
PA55	14.80	19.80	30.60	20
PB50	17.70	27.60	32.67	190
PB45	17.97	29.73	42.20	35
PC40	19.47	32.40	43.27	150
PC35	22.73	36.30	48.67	45

Table 5(b). Compressive strength (43 Grade)-Brand 2

Mixture designation	Compressive strength, MPa			Slump, mm
	AS	N7	N28	
PA58	9.87	19.13	25.27	0
PA55	10.87	19.40	26.13	0
PB50	11.33	21.47	30.07	115
PB45	15.37	23.87	33.93	45
PC40	18.30	28.13	39.13	80
PC35	22.07	33.93	43.27	20

Table 5(c). Compressive strength (43 Grade)-Brand 3

Mixture designation	Compressive strength, MPa			Slump, mm
	AS	N7	N28	
PA58	10.10	17.47	21.67	55
PA55	11.47	18.53	23.33	20
PB50	11.77	19.40	25.07	190
PB45	13.47	23.53	26.53	40
PC40	18.17	28.20	35.13	140
PC35	21.03	32.47	37.07	20

Table 5(d). Compressive strength (43 Grade)-Brand 4

Mixture designation	Compressive strength, MPa			Slump, mm
	AS	N7	N28	
PA58	12.00	18.30	23.2	40
PA55	12.37	22.40	27.40	20
PB50	12.87	24.27	32.4	190
PB45	16.77	27.27	35.27	40
PC40	18.80	29.53	39.67	120
PC35	25.23	34.60	42.53	20

Compressive strength for PPC with 4 different brands is illustrated in Table 6 (a)-(d). Based on the evaluation of the compressive strength for PPC based on different brands, the mixture designation of the ZA35 for brand 1 has the highest compressive strength for N28 and AS. The attained compressive strength of the ZA35 with brand 1 for N28 and AS are 44.93 and 18.17.

Table 6(a). Compressive strength (PPC)-Brand 1 IS 1489 Part 1:1991 (1991).

Mixture designation	Compressive strength, MPa			Slump, mm
	AS	N7	N28	
ZA58	7.70	15.07	21.80	40
ZA55	10.90	15.40	25.13	20
ZA50	11.67	18.73	24.80	55
ZA45	14.30	25.93	35.13	45
ZA40	16.40	27.80	36.93	55
ZA35	18.17	31.53	44.93	0

Table 6(b). Compressive strength (PPC)-Brand 2

Mixture designation	Compressive strength, MPa			Slump, mm
	AS	N7	N28	
ZA58	8.53	14.60	20.27	75
ZA55	10.17	19.07	25.93	25
ZA50	10.33	19.73	26.13	155
ZA45	12.07	21.27	29.87	95
ZA40	14.70	19.33	30.80	95
ZA35	17.50	27.07	37.40	0

Table 6(c). Compressive strength (PPC)-Brand 3

Mixture designation	Compressive strength, MPa			Slump, mm
	AS	N7	N28	
ZA58	7.17	12.33	18.93	20
ZA55	8.30	12.83	19.40	0
ZA50	9.20	15.47	23.60	70
ZA45	10.27	16.83	26.80	40
ZA40	10.70	19.33	29.07	30
ZA35	17.73	26.87	32.60	20

Table 6(d). Compressive strength (PPC)-Brand 4

Mixture designation	Compressive strength, MPa			Slump, mm
	AS	N7	N28	
ZA58	7.23	13.47	21.33	0
ZA55	7.67	13.90	22.87	0
ZA50	7.97	16.73	26.80	80
ZA45	10.40	20.20	28.53	20
ZA40	13.13	22.73	30.80	40
ZA35	16.83	26.33	37.27	20

Table 7 illustrates the compressive strength for different mixture designations and brands. From the above mentioned table, the mixture designation of the SA35 with AS and N28 attains the highest compressive strength as 20.07 MPa and 39.20 MPa.

Table 7. Compressive strength (PSC) IS 455 (1989)

Mixture designation	Compressive strength, MPa			Slump, mm
	AS	N7	N28	
SA58	9.87	17.27	30.20	40
SA55	11.57	18.67	30.67	0
SA50	11.67	19.87	31.93	80
SA45	14.07	20.33	37.47	40
SA40	16.90	25.73	38.33	80
SA35	20.07	33.33	39.20	20

1. Justification

Based on the compressive strength of the different cement type and brands, the cement type of 43 grade based on brand 1, the N28 with the PC35 mixture designation has highest compressive strength of 48.67 MPa. Likewise, the 43 grade based on brand 4 for AS with PC35 has 25.23 MPa. Thus, the cement type of 43 grade with the mixture designation of PC35, which has the water cement ratio of 0.35 (Nematollahzade *et al.*, 2020) has the highest compressive strength than the other cement type and brands.

Discussion

1. Correlation relation

In this investigation, it has been decided to propose a separate correlation equation for each type of cement to predict the 7-day and 28-day strength. In order to increase the degree of confidence maximum number of brands of cement samples have been used in this study. The very

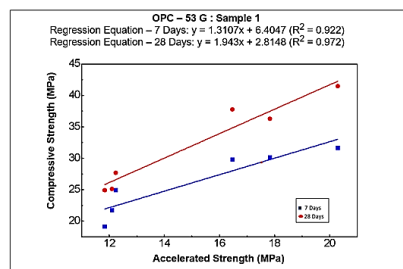
objective of assessing the strength with reliability is that in quality control it is preferable to assess the strength of concrete as quickly as possible such that both speed of construction and economy could be achieved. In IS 9013:1978 (1978) two accelerated techniques are proposed. These techniques involve time bound activities with the usage of a water bath maintained at the appropriate temperature. In the warm water technique, a prolonged period of warm water exposure is stipulated whereas in the boiling water technique, relatively a shorter duration (3½) is enough. Further, the boiling water technique is ideally suited for the Indian system of working.

Correlation relations between the accelerated strength at 7 and 28 days for various types of cement are presented below:

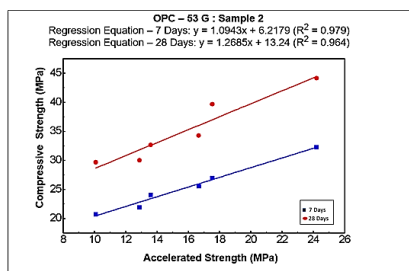
OPC - 53 Grade: IS 12269 (1987) linear regression analysis was carried out between the accelerated strength versus 7-day and 28-day strengths separately for 3 samples. The regression

equations are plotted and presented in Figures 2 (a) - (c). For each equation, six samples with different w-c ratios have been accounted. The coefficient of regression for all the cases was very close to 1.0, the minimum being 0.922 and the maximum being 0.991.

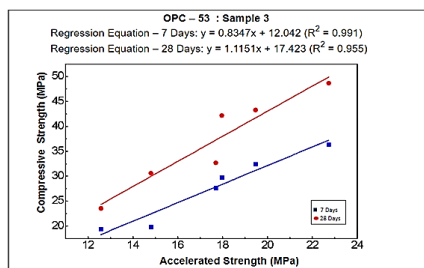
OPC - 43 Grade: IS 8112 (2013) Three samples of 43 Grade OPC was used. Linear regression equations are presented in Figures 3 (a) - (d). The coefficient of regression for all the cases was very close to 1.0, the minimum being 0.900 and the maximum being 0.991.



(a)

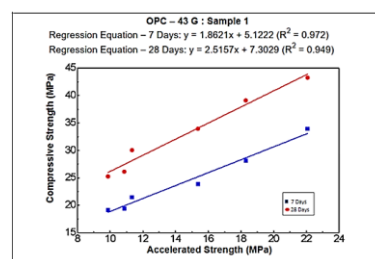


(b)

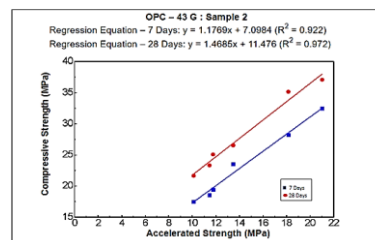


(c)

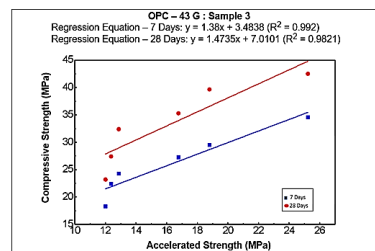
Figure 2. (a) - (c). Accelerated and actual compressive strength of OPC 53



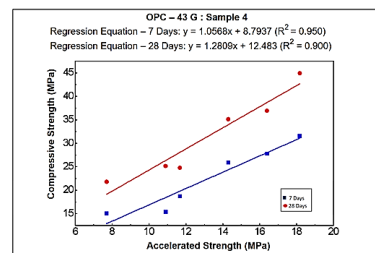
(a)



(b)



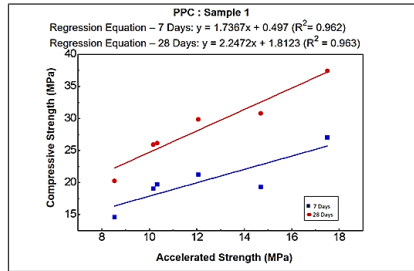
(c)



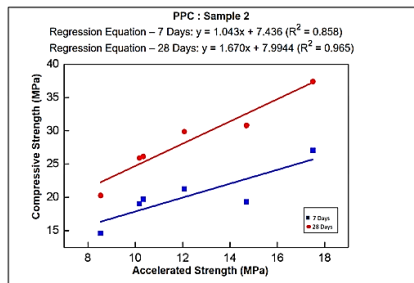
(d)

Figure 3. (a) - (d). Accelerated and actual compressive strength of OPC 43

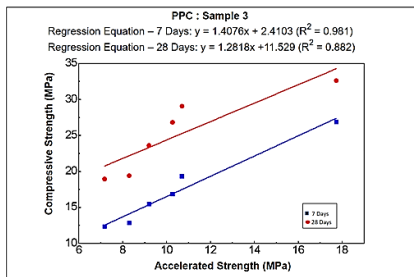
PPC: IS 1489 Part 1:1991 (1991) Four samples of PPC were used and their linear regression equations are presented in Figures 4 (a) - (d). The coefficient of regression for all the cases was very close to 1.0, the minimum being 0.858 and the maximum being 0.981.



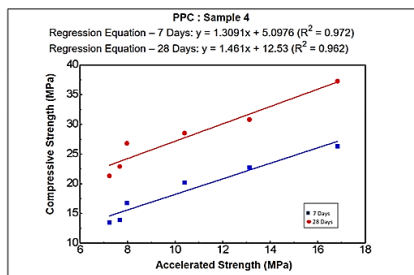
(a)



(b)



(c)



(d)

Figure 4. (a) - (d). Accelerated and actual compressive strength of PPC

PSC: IS 455 (1989). One sample of PSC was used and its linear equation is presented in Figure 5. The coefficient of regression is 0.908 0.974 for 28 day and 7 day strength respectively.

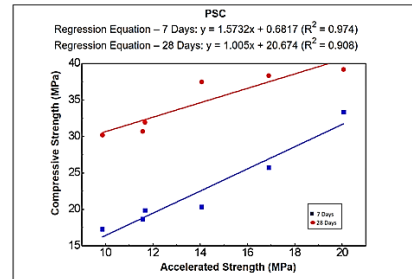


Figure 5. Accelerated and actual compressive strength of PSC

In the present study, all the samples and types of cement were employed with six ranges of w/c ratio, 0.58 to 0.35. From the behavior of the regression equations and the high range of regression coefficient, it is inferred that the w/c ratio has little significance in influencing the accelerated strength of concrete.

i) Combined regression analysis:

A number of samples of OPC and PPC were used and regression analysis has been carried out independently. Now consider the types of samples the results of the respective samples were pooled together and regression analysis was carried out and presented in Figures 6 (a) - (f). As only one sample of PSC was used it is not accounted for combined analysis. The combined analysis has yielded a very close fitting with a minimum regression coefficient of 0.903 and a maximum of 0.978. This behavior confirms that amongst the types of cement, the variation between a particular type of cement samples and the variation of accelerated strength of concrete is hardly affected.

However, comparing the types of cement the variation is significant. Comparing the equations of the variation between the correlation equations is in the range of 10% to 15%. Therefore, it is preferable to employ separate equations for predicting the most probable compressive strength of concrete from the accelerated strength.

Figure 7 illustrates the regression equation (for 28 day strength) for each type of cement compared with the equation suggested in IS: 9013. The proposed regression equation is dotted line and the IS regression equation is straight line. The figure shows the OPC 53, OPC 43, PSC and PPC. It shows the strength of the cement.

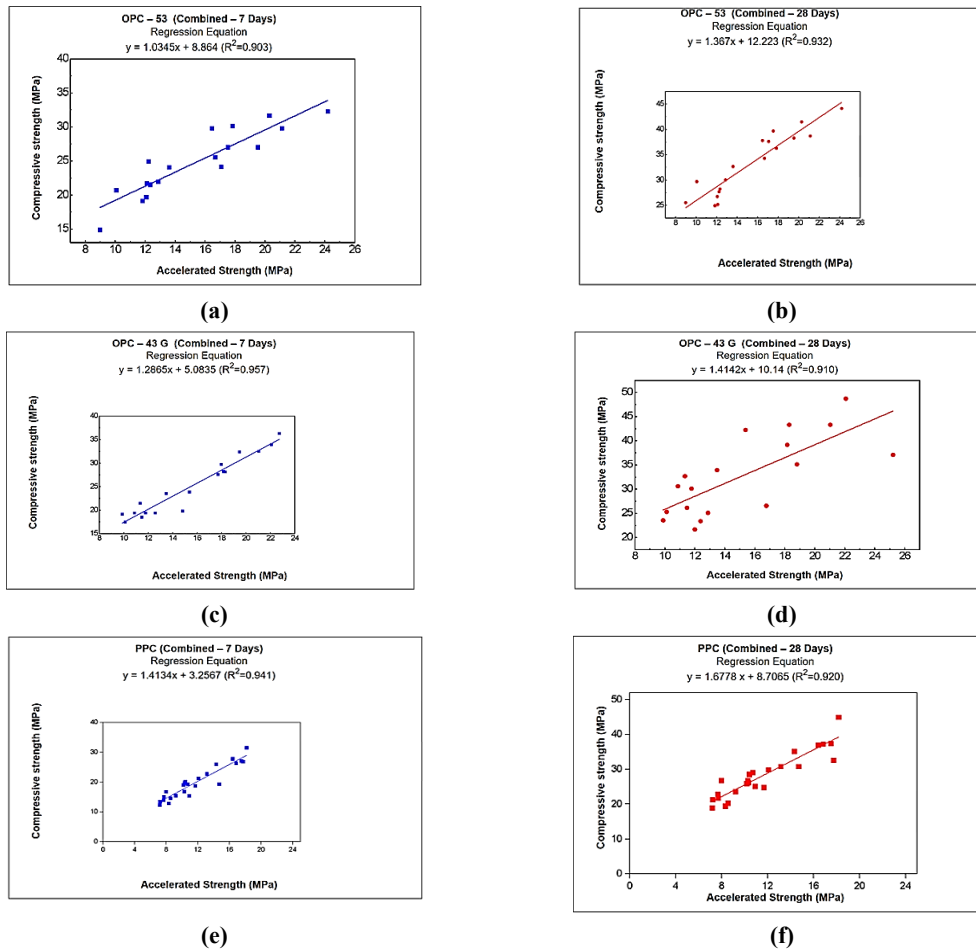


Figure 6. (a) - (f). Combined regression analysis for OPC53, OPC43 and PPC

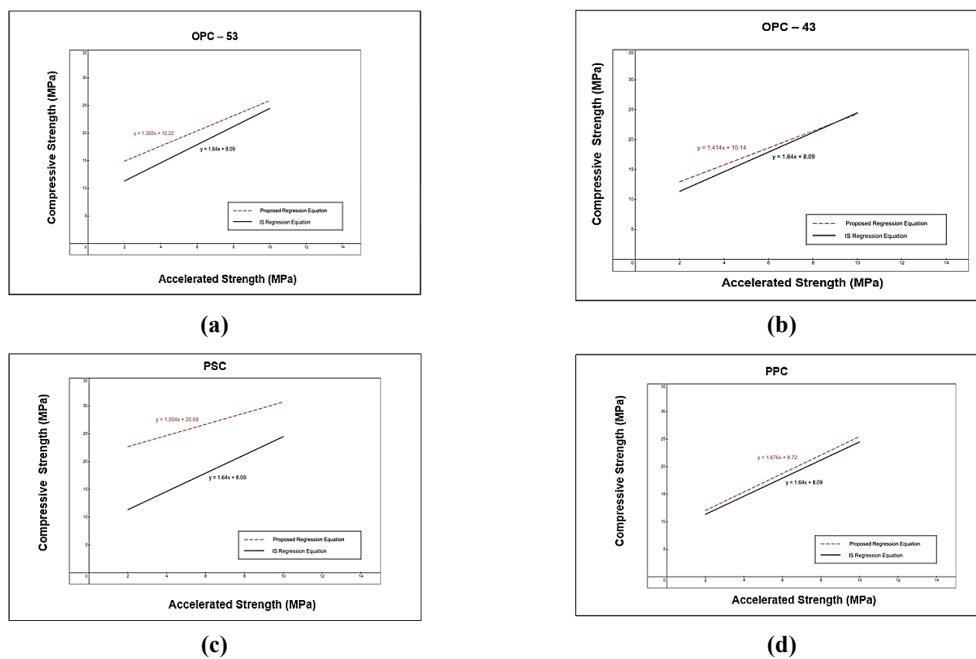


Figure 7. (a) - (d). Comparison between proposed and IS equation

Table 8. Compressive strength (PPC)-Brand 1 IS 1489 Part 1:1991 (1991)

Methods	Curing Duration	Curing Temperature	Ambient temperature	Relative Humidity
Proposed	28 days	100°C	27 ± 2°C	-
Fe-SEM	24 hrs	50°C	-	65% ± 10%
(Wang <i>et al.</i> , 2023)				
SIFCON	28 days	200 - 400°C	-	-
(Ali <i>et al.</i> , 2022)				

Table 9. Statistical analysis for the proposed method

Type	Statistical test	AS	N7	N28	Slump
OPC-53	F-Value	0.0408	2.3845	0.0004	1.1038
	P-Value	0.8434	0.1375	0.9836	0.3194
	T- test	0.8434	0.1561	0.9836	0.3194
OPC-43	F-Value	2.9535	3.9331	5.7417	0.6232
	P-Value	0.0557	0.0197	0.0038	0.6051

This Table 8 presents the curing parameters used for different experimental methods in a materials or concrete-based study. Each method involves distinct curing durations, temperatures, and environmental conditions, which are critical for evaluating the performance and microstructural properties of cementitious or composite materials.

Table 9 shows the statistical analysis of the proposed methods. It has cement types such as OPC 53, OPC 43, PPC and PSC. Normal concrete strength 7 days and 28 days is designated as N7/N28, slump is a workability of concrete and accelerated strength is designated as AS.

Conclusions

Thus, the analysis of different cement types such as OPC-43 Grade IS 8112 (2013), OPC-53 grade IS 12269 (1987), PPC IS 1489 Part 1:1991 (1991), and PSC IS: 455 - 1989 are evaluated based on the normal and accelerated curing methods. The physical and chemical properties of cement do not influence the accelerated strength of concrete significantly. The study also developed regression equations to predict the compressive strength of concrete based on accelerated curing, which proved to be highly reliable, with correlation coefficients ranging from 0.9 to 1.0 for different cement types. The water cement ratio has very little impact on the compressive strength of concrete. The W/C ratio are 0.58, 0.55, 0.50, 0.45, 0.40 and 0.35. According to that, the proposed strength equation for OPC-53 grade yields 25% higher strength compared to IS equation. Then, the proposed strength equation for OPC-43 grade yields a little higher (12.5%) strength at a lower strength range but nearly merges with IS code. Likewise, the proposed strength equation PPC is in close agreement with IS equation and the variation

between both equations is hardly 7%. Finally, the proposed strength equation for PSC is a significant variation of IS equation due to the equations are not parallel. In the smaller strength range the variation is more than 30% on the higher side. Whereas, it is about 12% lower at the higher strength (50MPa) range. Thus the proposed strength equation for different cement types are better compared to the IS equation. In future, this proposed strength equation can be used in different cement types that can enhance the concrete strength. Likewise, based on the evaluation of the concrete strength using different water cement ratio, physical and chemical properties, the structural elements can be developed and simulated to identify the compressive strength.

Acknowledgement

Funding: The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Conflict of Interest: The authors declared that they have no conflicts of interest to this work. We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

Availability of data and material: Not applicable

Code availability: Not applicable

Author contributions: The corresponding author claims the major contribution of the paper including formulation, analysis and editing. The co-authors provides guidance to verify the analysis result and manuscript editing.

Compliance with ethical standards: This article is a completely original work of its authors; it has not been published before and will not be sent to other publications until the journal's editorial board decides not to accept it for publication.

References

- Abadel, A., Abbas, H., Almusallam, T., Alshaikh, I. M., Khawaji, M., Alghamdi, H., & Salah, A. A. (2022). Experimental study of shear behavior of CFRP strengthened ultra-high-performance fiber-reinforced concrete deep beams. *Case Studies in Construction Materials*, 16, e01103. <https://doi.org/10.1016/j.cscm.2022.e01103>
- Akhnoukh, A. K., & Buckhalter, C. (2021). Ultra-high-performance concrete: Constituents, mechanical properties, applications and current challenges. *Case Studies in Construction Materials*, 15, e00559. <https://doi.org/10.1016/j.cscm.2021.e00559>
- Ali, M. H., Atiş, C. D., & Al-Kamaki, Y. S. S. (2022). Mechanical properties and efficiency of SIFCON samples at elevated temperature cured with standard and accelerated method. *Case Studies in Construction Materials*, 17, e01281. <https://doi.org/10.1016/j.cscm.2022.e01281>
- Anand, P., Sinha, A. K., & Rajhans, P. (2023). Enhancing the performance of aerated concrete through accelerated curing and waste material integration. *Advances in Cement Research*, Advance online publication, 1-21.
- Bahmani, H., & Mostofinejad, D. (2022). Microstructure of ultra-high-performance concrete (UHPC): A review study. *Journal of Building Engineering*, 50, 104118. <https://doi.org/10.1016/j.jobbe.2022.104118>
- Bureau of Indian Standards. (1959). *Method of tests for strength of concrete (IS 516:1959, reaffirmed 2004)*. Bureau of Indian Standards.
- Bureau of Indian Standards. (1970). *Specification for coarse and fine aggregates from natural sources for concrete (IS 383:1970, reaffirmed 2002)*. Bureau of Indian Standards.
- Bureau of Indian Standards. (1978). *Method of making, curing and determining compressive strength of accelerated cured concrete test specimens (IS 9013:1978)*. Bureau of Indian Standards.
- Bureau of Indian Standards. (1987). *Ordinary Portland cement, 53 grade: Specification (IS 12269:1987)*. Bureau of Indian Standards.
- Bureau of Indian Standards. (1988). *Methods of physical tests for hydraulic cement (IS 4031, various parts, 2nd ed., reaffirmed 2000)*. Bureau of Indian Standards.
- Bureau of Indian Standards. (1989). *Portland slag cement: Specification (IS 455:1989, 4th rev., reaffirmed 1995)*. Bureau of Indian Standards.
- Bureau of Indian Standards. (1991). *Portland-Pozzolana cement: Specification, Part 1: Fly ash based (IS 1489 Part 1:1991, 3rd rev., reaffirmed 2005)*. Bureau of Indian Standards.
- Bureau of Indian Standards. (2009). *Guidelines for concrete mix design proportioning (IS 10262:2009)*. Bureau of Indian Standards.
- Bureau of Indian Standards. (2013). *Ordinary Portland cement, 43 grade: Specification (IS 8112:2013)*. Bureau of Indian Standards.
- Dong, E., Yu, R., Fan, D., Chen, Z., & Ma, X. (2022). Absorption-desorption process of internal curing water in ultra-high-performance concrete (UHPC) incorporating pumice: From relaxation theory to dynamic migration model. *Cement and Concrete Composites*, 133, 104659. <https://doi.org/10.1016/j.cemconcomp.2022.104659>
- Harith, I. K., Amanah, B. H., & Naser, M. H. (2022). Effect of proposed accelerated curing method on high volume fly ash concrete. *Key Engineering Materials*, 924, 213-222. <https://doi.org/10.4028/p-97s10r>
- Hong, G., Oh, S., Choi, S., Chin, W. J., Kim, Y. J., & Song, C. (2021). Correlation between the compressive strength and ultrasonic pulse velocity of cement mortars blended with silica fume: An analysis of microstructure and hydration kinetics. *Materials*, 14(10), 2476. <https://doi.org/10.3390/ma14102476>
- Hoy, M., Ro, B., Horpibulsuk, S., Suddeepong, A., Buritatum, A., Arulrajah, A., Yaowarat, T., Chinkulkijniwat, A., & Horpibulsuk, J. (2024a). Flexural fatigue performance of hemp fiber-reinforced concrete using recycled concrete aggregates as a sustainable rigid pavement. *Journal of Materials in Civil Engineering*, 36(11), 04024378. <https://doi.org/10.1061/JMCEE7.MTENG-18367>
- Hoy, M., Tonueng, C., Horpibulsuk, S., Suddeepong, A., Buritatum, A., Yaowarat, T., & Arulrajah, A. (2024b). Enhancing concrete pavement performance using refuse-derived fuel fly ash as a sustainable cementitious material. *International Journal of Pavement Engineering*, 25(1), 2431601. <https://doi.org/10.1080/10298436.2024.2431601>
- Huang, H., Gao, X., & Teng, L. (2021). Fiber alignment and its effect on mechanical properties of UHPC: An overview. *Construction and Building Materials*, 296, 123741. <https://doi.org/10.1016/j.conbuildmat.2021.123741>
- Kantatham, K., Hoy, M., Sansri, S., Horpibulsuk, S., Suddeepong, A., Buritatum, A., Yaowarat, T., Ro, B., & Phunpeng, V. (2024). Natural rubber latex-modified concrete with bottom ash for sustainable rigid pavements. *Civil Engineering Journal*, 10(8), 2485-2501. <https://doi.org/10.28991/CEJ-2024-010-08-05>
- Moelich, G. M., & Combrinck, R. (2020). A weather data analysis method to mitigate and prevent plastic shrinkage cracking. *Construction and Building Materials*, 253, 119066. <https://doi.org/10.1016/j.conbuildmat.2020.119066>
- Nematollahzade, M., Tajadini, A., Afshoon, I., & Aslani, F. (2020). Influence of different curing conditions and water-to-cement ratio on properties of self-compacting concretes. *Construction and Building Materials*, 237, 117570. <https://doi.org/10.1016/j.conbuildmat.2019.117570>
- Ozioko, H. O., & Ohazurike, E. E. (2019). Accelerated curing of concrete cubes using warm water. *International Journal of Research and Innovation in Applied Science*, 4(3), 33-36.
- Salih, M. A., & Aldikheeli, M. R. (2020). Evaluation of factors influencing the compressive strength of Portland cement statistically. *IOP Conference Series: Materials Science and Engineering*, 737, 012059. <https://doi.org/10.1088/1757-899X/737/1/012059>
- Samingthong, W., Hoy, M., Ro, B., Horpibulsuk, S., Yosthasaen, T., Suddeepong, A., Buritatum, A., Yaowarat, T., & Arulrajah, A. (2023). Natural rubber latex-modified concrete with PET and crumb rubber aggregate replacements for sustainable rigid pavements. *Sustainability*, 15(19), 14147. <https://doi.org/10.3390/su151914147>
- Vineel, C. H., Vineeta, M., & Saravani, S. (2018). Strength comparison between normally cured and accelerated cured concrete with partial replacement of sand with pond ash. *Journal of Emerging Technologies and Innovative Research*, 5(9), 143-147.
- Wang, W. C., Duong, H. T. H., & Zhang, C. H. (2023). Influence of accelerating admixtures on high early strength cement performance using heat curing method. *Case Studies in Construction Materials*, 18, e01746. <https://doi.org/10.1016/j.cscm.2022.e01746>