

CONSTRUCTION MANAGEMENT BY CONTROLLING THE DESIGN AND CURING TIME OF A CONCRETE MIX

Hamid Reza DARVISHVAND¹, Seiyed Ali Haj Seiyed TAGHIA^{2*}, Navid AFSHARI³

Abstract

The interval of time after pouring concrete is an important factor, which directly affects the timing and cost of construction. The case study that was investigated in this research, is a tunnel project located in Iran. Eighteen mix designs were prepared using properties such as different water-cement ratios and the use of two types of superplasticizer with different dosages. The optimal mix designs among the samples were separately specified.

Concrete mix designs with different curing ages were made to specify the minimum curing time in which the concrete could gain the required compressive strength. Moreover, the concrete's compressive strength was measured for different ages in order to determine the minimum time interval. For a better insight, two mathematical equations were derived to estimate the minimum curing time and time interval. Finally, a statistical analysis was conducted in order to determine the proper time intervals. Moreover, the analysis specified the impact rate of the research parameters (i.e. the type and dosage of superplasticizer, curing time, and water-cement ratio) on the compressive strength

Address

- ¹ Dept. of Civil Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran, (hr.darvishvand@qiau.ac.ir), ORCID number: 0000-0003-2042-2043.
- ² Dept. of Civil and Environmental Engineering, University of Hawaii at Manoa, Honolulu, USA, (taghia@hawaii.edu), ORCID number: 0000-0002-9304-7427.
- ³ Dept. of Civil Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran, navidafshari1@gmail.com

* **Corresponding author:** taghia@hawaii.edu

Key words

- Time interval;
- Mix design;
- Water-cement ratio;
- Superplasticizer;
- Compressive strength;
- Statistical analysis.

1 INTRODUCTION

Reducing the time and cost of construction projects is one of the main goals of each on-going project. One of the causes that prolong the construction of concrete structures is the time interval for the curing process in order to gain adequate concrete strength. The curing of concrete is crucial regarding its strength and durability characteristics (Felekoglu et al. 2014; Hui et al. 2014; Wu et al. 2012; Yildirim et al. 2015; Zhu et al. 2014). The curing process includes the moisture-curing and curing temperatures (Yu et al. 2015; El-Ashkar et al. 2007).

Kim et al. (1998) studied a change in strength regarding the effect of the curing time at specific temperatures. The results indicated that concrete under a high temperature at an early stage gains higher early-age strength, but actually gains

a lower later-age strength. Concrete under a low temperature at an early age shows lower early-age strength, but nearly the same later-age strength. They suggested a model for concrete to gain strength.

Elmoaty et al. (2016) investigated the effects of the curing time and temperature on geopolymer concrete. The results indicated that concrete properties are notably affected by curing conditions.

Haghighatnejada et al. (2016) examined the properties of concrete made with a substitution of natural sand with recycled aggregate subjected to different curing conditions. The results revealed that an irregular curing condition often decreases concrete characteristics, whereas regular water curing provides appropriate curing conditions and improves concrete properties.

Zhu et al. (2016) studied the effect of the curing time on the mechanical properties of engineered cementitious composites (ECCs). The compressive and flexural strengths rise, as the curing time increases. Suitable mechanical properties are gained for cement substituted by 80% fly ash and a water curing time of 7 days.

Da et al. (2017) studied the mechanical behavior of concrete at different curing days (3, 7, 14 and 28 days) subjected to different confining stresses. The curing time lowers with an increase in confinement. They proposed a curing time model.

Madandoust et al. (2019) evaluated the effect of steel and polypropylene fibres on lightweight concrete properties. The specimens were cured subject to different curing conditions. The results showed that the mix designs cured under a 90°C vapour curing reach the highest mechanical strength.

Fang et al. (2020) examined the effect of the curing time (7, 28, 90 and 180 days) on flexural and compressive strengths. Regular curing after 28 days can notably enhance the mechanical properties of concrete with alkali contents of 2–3%.

Formworks should be removed when the concrete is able to bear effective stresses and deformations within a given tolerance. According to the ACI 318-19 standard, no construction loads should be placed on nor should any formwork removed from any part of a structure under construction except when that portion of the structure in combination with the remaining formwork has sufficient strength to safely support its weight and the loads placed thereon and without impairing serviceability.

With reference to these issues, a case study called the Manjil tunnel project was investigated in this article. The main purpose of this research is to adjust concrete curing time and the time intervals to continue concrete work so that a structure can be able to withstand all load types.

1.1 Case Study: Manjil Tunnel Project (Qazvin-Rasht Highway)

The project site is located between the cities of Manjil and Rudbar in the Gilan province of Iran. The 7 km long-project site consists of two separate runways, 5 tunnels, two valley bridges, one ramp bridge (Zeytoun Bridge) and a 4 km-open trench, which commenced in 2015 and was completed in March 2017. This project had a direct impact on reducing traveling and transport times. Therefore, it was of the essence to promptly complete this job. In this project, the conventional and new generations of superplasticizer (SP) that are available on the Iranian market were used to facilitate the concrete works. The other purpose of this research was to separately clarify the optimal mix designs among samples containing both types of SPs. In the following section, the role of SPs utilized in the concrete production of this project is discussed.

1.2 Superplasticizer (SP)

SPs are broadly used to produce workable, strong, and durable mortars and concrete. The hydration role of cement in the presence of an SP has been studied by many researchers. SPs can disperse cement particles and improve the workability, compactness, permeability and carbon resistance of concrete (Yamda et al. 2000; Carazeanu et al. 2002; Kreppelt et

al. 2002; Yu et al. 2013; Chen et al. 2016). Two types of SPs are available on the Iranian market and are discussed in this research:

1. Conventional SPs based on polynaphthalene-sulfonate (PNS), melamine (PMS) or lignosulfonate (LS) disperse particles by means of electro sterics.
2. A new generation of SPs such as polycarboxylate-ether (PCEs) disperse particles by forming a steric obstacle.

1.3 Polynaphthalene Sulfonate (PNS)

The PNS is a polymeric molecule formed by the condensation of naphthalene sulfonic acid and formaldehyde in which the hydrophilic groups are mainly sulfonic groups, whereas the hydrophobic part is naphthalene. A PNS can reduce water consumption by up to 20% (Uchikawa et al. 1992).

1.4 Polycarboxylate-Ether (PCE)

The effects of PCE in order to reduce water consumption and raise the workability of concrete have been investigated by many researchers (Mollah et al. 2000; Yamada et al. 2000; Golaszewski and Szwabowski 2004; Puertas et al. 2005; Palacios et al. 2009; Ferrari et al. 2010; Toledano-Prados et al. 2013; Adjoudj et al. 2014; Lange et al. 2014; Li et al. 2014; Cartuxo et al. 2015). In addition, it has been proved that PCE can reduce the plastic shrinkage of concrete (Baghabra et al. 2014). (Zhang and Kong (2014)) and (Perrot et al. (2013)) investigated the role of PCE on the porosity of concrete and understood that SP apparently decreases permeability and increases the compressibility of hardened concrete.

1.5 Significance of Research

Most of the aspects and novelties of the current study can be addressed as follows:

- Determining the optimal mix design regarding two generations of superplasticizer
- Specifying the minimum curing time to meet the required compressive strength
- Estimating the minimum time interval for concrete at different ages
- Deriving mathematical equations to capture the findings of the research
- Conducting parametric studies on the roles of research parameters

2 EXPERIMENTAL PROCEDURE

In this section, the material types, mix design, and sample preparation are separately described.

2.1 Material types

Ordinary Portland cement was used for all the specimens. The class of this cement is 42.5, indicating that it should

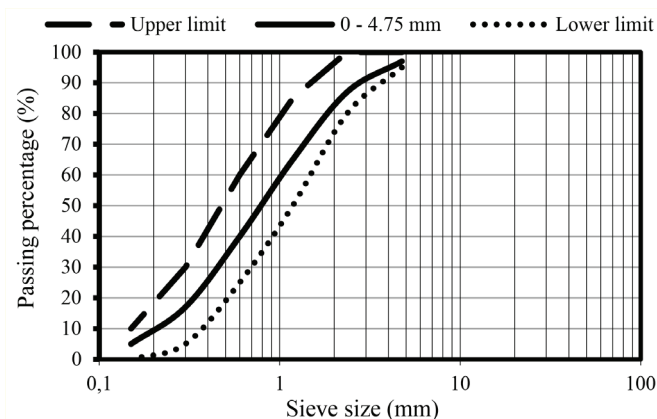


Fig. 1 Sieve analysis and grading curve and its limits for sand

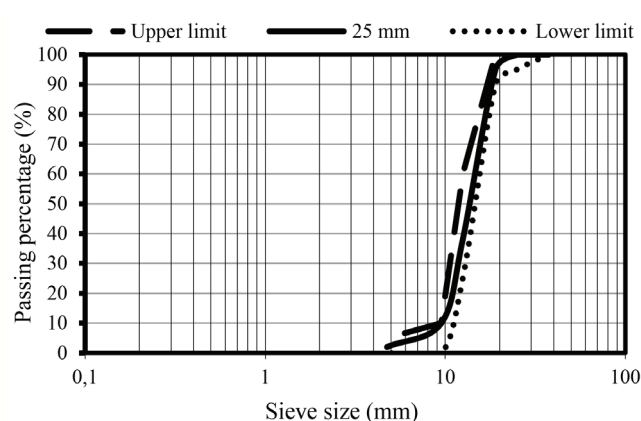


Fig. 2 Sieve analysis and grading curve and its limits for gravel

achieve a minimum compressive strength of 42.5 MPa at 28 days. The specimens were made according to ASTM C150 (2004) and the gravel and sand aggregates consisted of river types (available construction materials at the project site) in accordance with ASTM C33 (2003). The sand grain sizes ranged from 0 to 4.75 mm with an apparent weight of 2700 kg/m³ in the saturated surface dry (SSD) state. A sieve analysis, the grading curves, and their limits for sand and gravel are provided in Figs. 1 and 2, respectively. ASTM C33 (2003) was applied to evaluate the analysis and grading. The lower and upper limits of this standard are specified in these figures.

Data from the figures suggest that all the aggregates satisfy the grading requirement because they fall within the allowable limits of ASTM C33 (2003). Therefore, they are appropriate for the production of concrete. As mentioned above, two types of SPs based on PNS and PCE have been used. The technical specifications for the SPs are given in Table 1.

Tab. 1 The specifications of SPs

Properties	PNS	PCE
Ingredient	Polynaphthalene sulfonate	Polycarboxylate
Color	Dark green	Dark brown
State	Liquid	Liquid
Density g/ml (20°C)	1.2 ± 0.02	1.1 ± 0.02
PH (20°C)	8	7
Total chloride (%)	<0.1	<0.1
Ionic nature	Anion	Anion

Tab. 2 Mix design characteristics

Code	Cement (kg/m ³)	Sand (kg/m ³)	Gravel (kg/m ³)	Water-cement ratio	SP (%)	
					PCE	PNS
W4P2	400	910	1080	0.4	0.2	-
W4P4	400	910	1080	0.4	0.4	-
W4P6	400	910	1080	0.4	0.6	-
W5P2	400	910	1080	0.5	0.2	-
W5P4	400	910	1080	0.5	0.4	-
W5P6	400	910	1080	0.5	0.6	-
W6P2	400	910	1080	0.6	0.2	-
W6P4	400	910	1080	0.6	0.4	-
W6P6	400	910	1080	0.6	0.6	-
W4N2	400	910	1080	0.4	-	0.2
W4N4	400	910	1080	0.4	-	0.4
W4N6	400	910	1080	0.4	-	0.6
W5N2	400	910	1080	0.5	-	0.2
W5N4	400	910	1080	0.5	-	0.4
W5N6	400	910	1080	0.5	-	0.6
W6N2	400	910	1080	0.6	-	0.2
W6N4	400	910	1080	0.6	-	0.4
W6N6	400	910	1080	0.6	-	0.6

2.2 Mix design

In this study, eighteen mix designs, which are summarized in Table 2, were prepared. The sequence of mixing the materials was as follows: First, the mixture of sand and gravel was mixed with three-fourths of the required water for 15 minutes. Then, cement was added to the mixture, and lastly, one-fourth of the remaining water, which was previously mixed with the superplasticizer, was gradually added to the mixture. Each mix design includes three samples. Tab. 2 provides the abbreviations for all the specimens.

In the nomenclature of the mixing design, numbers 4, 5, and 6 following the letter W indicate the water-cement ratios (W/C ratios) of 0.4, 0.5, and 0.6, respectively. The letters P and N represent the polycarboxylate-ether and polynaphthalene sulfonate (the SPs), respectively. Also, the numbers 2, 4, and 6 after P and N show the SP dosage as a fraction of the cement's weight (equal to 0.2, 0.4, and 0.6 percent, respectively). Generally, SPs are used to compensate for a low W/C ratio and increase the workability of concrete. However, in this study, a higher W/C ratio of 0.6 was studied to simulate the operational faults during concrete production.

2.3 Preparation of the Sample

The concrete was initially prepared and followed by inserting it into the pre-prepared molds. The samples were then set to harden. The shape of a cubic mold was used with each 15 cm dimension (Fig 3). After 24 hours, the molds were removed, and the samples were cured for a duration of 1, 3, 7, 14, and 28 days. The curing time for concrete highly depends on the weather conditions and varies at different project sites. The ambient conditions in this field study were a temperature of 17°C, humidity of 65%, and a wind speed of 20 . In order to simulate the curing conditions of the samples with the real situations at the site, the curing process was performed in open air by covering them with gunny sacks together with watering them daily.



Fig. 3 Preparing the samples on site

3 RESULTS AND DISCUSSION

This research was conducted in two steps:
1: Dealing with the effect of the curing time on the concrete's compressive strength at the age of 28 days. Also,

the optimal mix designs were determined. Afterwards, the concrete's strength was studied at different ages (1, 3, 7, 14, and 28 days). In this way, for a quantification of the results, two mathematical equations have been proposed.
2: Conducting the statistical analysis to reach a comprehensive conclusion on this research.

3.1 The effect of the curing time on the concrete's compressive strength at the age of 28 days

The compressive strength of the cubic samples cured at different ages of 1, 3, 7, 14, and 28 days are provided in Table 3. The compressive strength tests were performed at the age of 28 days according to ASTM C39 (2014). As presented in Table 2, samples W4P4 (W/C ratio= 0.4 and PCE=0.4%) and W5N6 (W/C ratio= 0.5 and PNS= 0.6%) resulted in the highest level of compressive strength. These samples are defined as the optimal mix designs with two different types of SPs.

In Figures 4 to 9, the compressive strength of the 28-day concrete is depicted for different W/C ratios and various SP percentages (obtained from Table 3). The increasing rates of the compressive strength are plotted with reference to the corresponding samples with a one-day curing time. The data presented in these figures were extracted from Table 3. As expected, Figs. 4 to 9 show an increase in the 28-day compressive strength due to the increase in the curing time. However, its growth rate declines by increasing the curing time. In other words, the required strength in the concrete can be gained be-

Tab. 3 Compressive strength of the samples for different curing periods at the age of 28 days (MPa)

No.	Mix design code	Period of curing (days)				
		1	3	7	14	28
1	W4P2	24.1	25.6	26.2	28	30
2	W4P4	28.9	31.2	32.5	33.2	34
3	W4P6	26.1	28	28.9	29.7	32
4	W5P2	23.4	24.8	25.8	27.4	29
5	W5P4	27.2	29.5	30	31	32.5
6	W5P6	24.2	25.8	26.2	27.5	30
7	W6P2	21.7	22.9	24.4	25.2	27
8	W6P4	21.8	22.2	24	26	29.5
9	W6P6	18.2	19.1	20.4	21.5	26
10	W4N2	21	22.5	23.1	24.5	27
11	W4N4	22.9	24.4	25.8	26.9	29
12	W4N6	24.6	26.1	27.5	28.4	30.5
13	W5N2	23	24.8	25.6	26.4	28.5
14	W5N4	25.5	27.4	28.3	29.2	31
15	W5N6	26.8	28.8	29.7	30.8	31.8
16	W6N2	21.2	22.5	23.6	24	26.5
17	W6N4	23.4	25	25.9	26.5	28
18	W6N6	21	24.3	26.2	27.1	29.5

fore the age of 28 days, without any significant reduction in the characteristic strength.

In order to quantify the effect of the curing time on the 28-day concrete's strength, the following equation is proposed for the two optimal mix designs of W4P4 and W5N6 by adding the curve fitting of the data provided in Table 3:

$$C = 0.044 \ln(d_r) + 1 \quad (1)$$

C is the reduction coefficient of the 28-day strength of the concrete, and d_r are the normalized curing days (the number of curing days divided by 28 days as related to the full curing time). The diagram of Eq. (1) is shown in Fig. 10 along with the data for the W4P4 and W5N6 optimal mix designs.

The graph shows good agreement between Eq. 1 and the experimental results (correlation coefficient: R^2 is 0.99). As shown in Fig. 10, the concrete reaches 90% of its characteristic strength in $d_r=0.1$, which is equivalent to $0.1 \cdot 28$ days ≈ 3 days. Therefore, 3 days of curing is appropriate for time management of the project and achieving the required strength at 28 days.

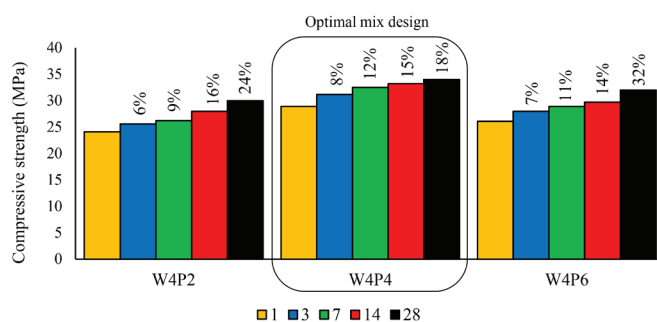


Fig. 4 Compressive strength of the mix designs at the age of 28 days for the different curing periods (SP type: PCE and W/C ratio = 0.4)

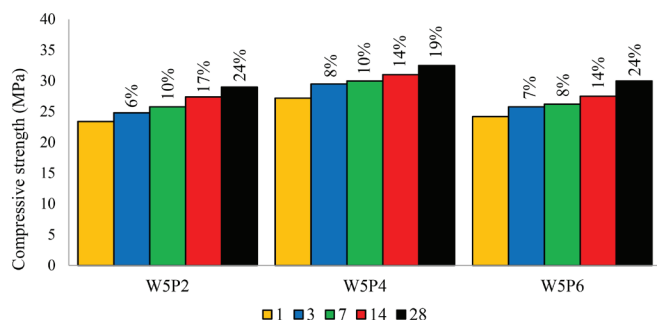


Fig. 5 Compressive strength of the mix designs at the age of 28 days for the different curing periods (SP type: PCE and W/C ratio = 0.5)

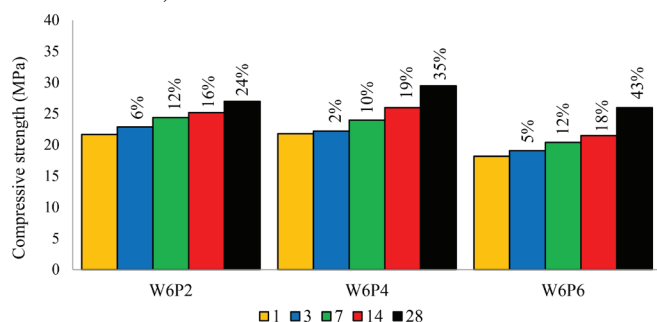


Fig. 6 Compressive strength of the mix designs at the age of 28 days for the different curing periods (SP type: PCE and W/C ratio = 0.6)

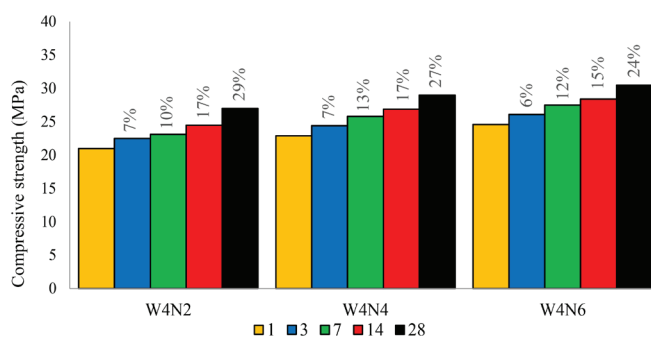


Fig. 7 Compressive strength of the mix designs at the age of 28 days for the different curing periods (SP type: PNS and W/C ratio = 0.4)

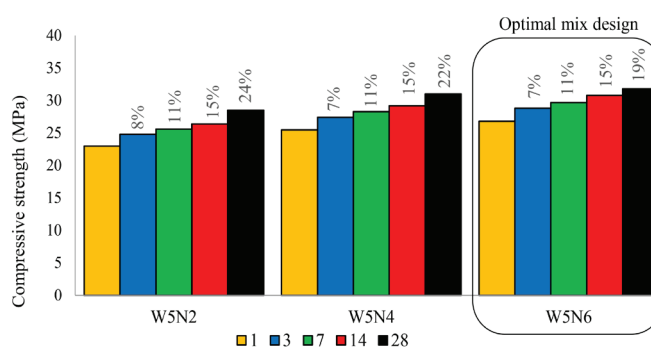


Fig. 8 Compressive strength of the mix designs at the age of 28 days for the different curing periods (SP type: PNS and W/C ratio = 0.5)

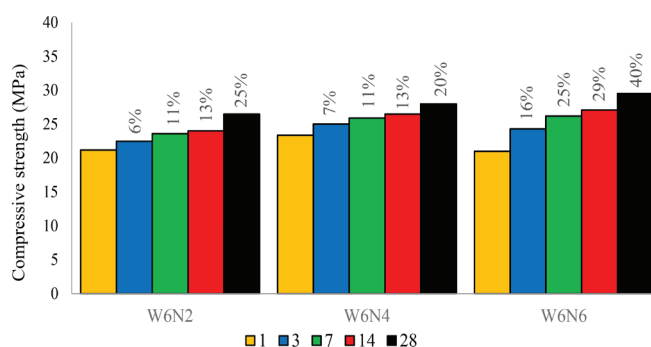


Fig. 9 Compressive strength of the mix designs at the age of 28 days for the different curing periods (SP type: PNS and W/C ratio = 0.6)

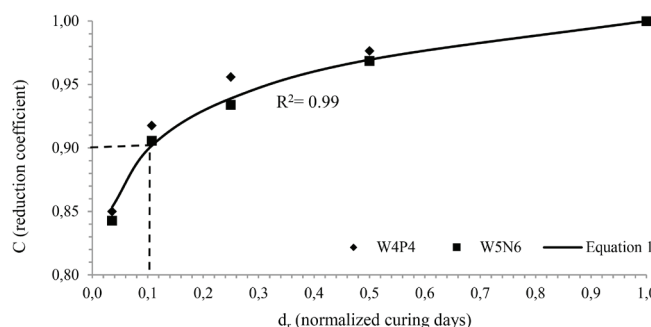


Fig. 10 The reduction coefficient (C) of the strength of the 28-day concrete in terms of the normalized curing days (d_r)

3.2 Evaluation of the concrete's strength at different ages

Regarding the test results (they are not reported herein), the ratios of the concrete's compressive strength at the specified age relative to the full setting of the 28-day concrete's strength are estimated and shown in Figs. 11 and 12. The strength was gained at different ages by considering the complete curing for two different types of SP (PCE and PNS).

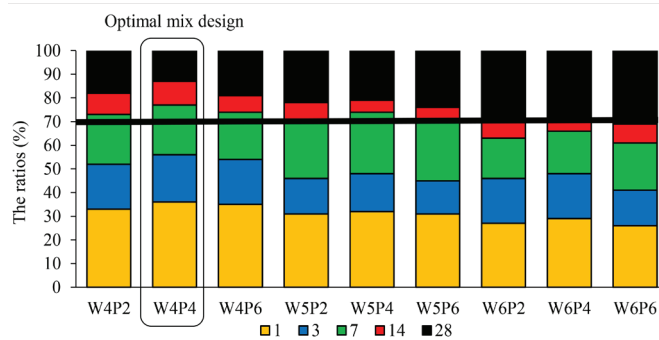


Fig. 11 The ratios of the concrete's compressive strength at the specified age relative to the full setting of the 28-day concrete (SP type: PCE)

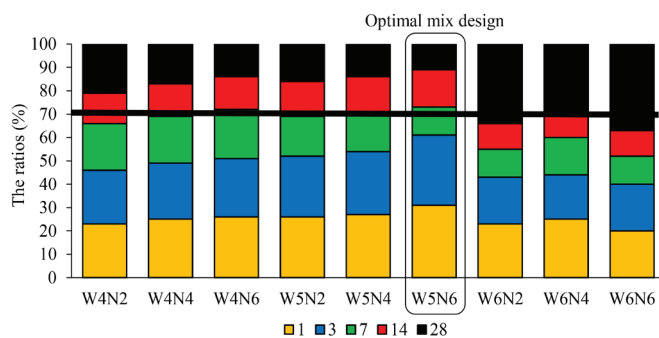


Fig. 12 The ratios of the concrete's compressive strength at the specified age relative to the full setting of the 28-day concrete (SP type: PNS)

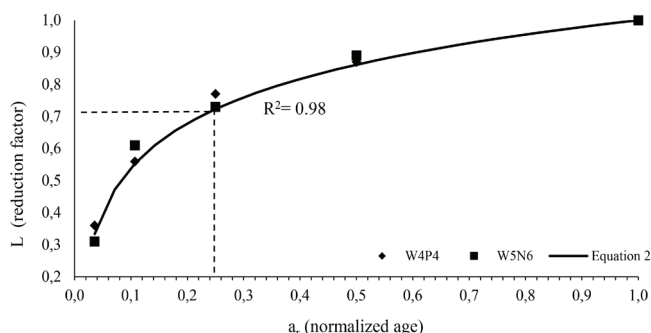


Fig. 13 The reduction factor for the concrete's strength at the specified age relative to the 28-day strength in terms of the normalized age

Based on recent field investigations in Iran, 70% of the design load consists of the dead load and anticipated construction loads. Therefore, 70% of the concrete's characteristic strength in the current research was considered as the main criterion for removing the formworks and shoring system. In this way, the structure is stable in the case of the loads applied. The 70%

ratio line is plotted in these figures as well.

As shown in Figs. 11 and 12, it was observed that in the case of the W4P4 and W5N6 samples (optimal mix designs), the concrete at the age of 7 days shows adequate compressive strength and provides the possibility for removing the formworks and shoring system. Therefore, we have concluded that 7 days curing time shall be considered as the proper time interval to interrupt concrete works between the different parts of a structure.

In order to quantify the test results and estimate the compressive strength at different ages, the following equation is proposed for the two optimal mix designs (W4P4 and W5N6). This equation was obtained by curve fitting, the data for which are presented in Figs. 11 and 12 (see Fig. 13).

$$L = 0.2 \ln a_r + 1 \quad (2)$$

where

L is the reduction factor for the concrete's strength at the specified age relative to the 28-days strength, and a_r is the normalized age (the age of the concrete at the time of the breaking test divided by 28 days for the complete setting).

Again, the diagram displays good agreement between Eq. (2) and the experimental results (correlation coefficient: R^2 is 0.98). Moreover, according to Fig. 13, the concrete reaches 70% of the full 28-day setting in $a_r=0.25$, which is equivalent to 0.25×28 days ≈ 7 days. It confirms that 7 days is appropriate as the time interval.

3.3 Statistical analysis

The aim of this section is to investigate the impact rate of parameters such as the SP type and its dosage, curing time, and W/C ratio on the 28-day concrete's compressive strength and the evaluation of strength at different ages in terms of the probabilistic approach. Since the data are in the form of paired observations, a two-sample t-test was used for the statistical analysis.

In this method, the two-sample problem is essentially reduced to a one-sample problem by using the computed differences $d_1, d_2, \dots, d_n$. Thus, the hypothesis is reduced to

$$H_0: \mu_1 - \mu_2 = d_0 \quad (3)$$

where μ_1 and μ_2 represent the population means.

H_0 is rejected at the significance level of α when the computed t-statistic

$$t = \frac{\bar{d} - d_0}{s_d / \sqrt{n}} \quad (4)$$

exceeds $t_{\alpha/2, n-1}$ or is less than $-t_{\alpha/2, n-1}$ (Critical regions). A level of significance of $\alpha = 0.05$ was chosen for this research. Variable n , is the sample size to perform the test.

In Eqs. (3) and (4), $\bar{d}$ and S_d are random variables representing the sample mean and standard deviation of the differences of the observations (Walpole et al. 2016). The experimental data form the observations in this research. Variable d_0 , shows the value of the improvement or decline in the aforementioned parameters. In this way, the statistical analysis is separately conducted in the two following sub-sections:

3.3.1 The impact rate of the SP type and its dosage, curing time and W/C ratio on the compressive strength of the 28-day concrete

In this sub-section, the impact rate of the SP type and its dosage, curing time and W/C ratio on the compressive strength of the 28-day concrete are examined respectively. It should be noted that all the data illustrated in this phase of the statistical analysis were extracted from Table 3.

3.3.1.1 The impact rate of the SP type on the compressive strength of the 28-day concrete

In Table 4, the mean values ($\bar{d}$) and standard deviations (S_d) were estimated for an increase in the compressive strength of the 28-day concrete at different ages of the curing time for the samples containing the PCE type with reference to the PNS type. The improvements in the compressive strength (d_0) are reported as well by equalizing Eq. (4) with $t_{\alpha/2, n-1}=2.306$ (for the sample size of $n=9$).

Figure 14 displays the rate of increase in the compressive strength for the samples containing the PCE type relative to the PNS type. The rate is defined as variable d_0 divided by the average value of the 28-day concrete's compressive strength for the samples containing the PNS type. All the data are reported for the different ages of the curing time. According to Figure 14, the SP type can be effective on the concrete's compressive strength up to 10%.

3.3.1.2 The impact rate of the SP dosage on the compressive strength of the 28-day concrete

In Table 5, the mean values ($\bar{d}$) and standard deviations (S_d) of the increase in the compressive strength of the 28-day concrete are reported for samples with different SP dosages regarding the sample containing 0.2% SP. The improvement values (d_0) in the compressive strength are reported as well by equalizing Eq. (4) with ($t_{\alpha/2, n-1}=2.045$ for the sample size of $n=30$).

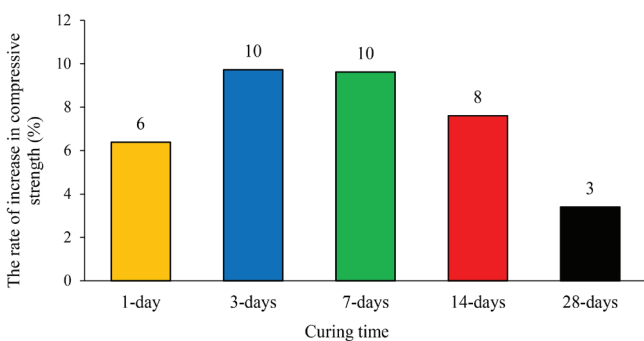


Fig. 14 The rate of increase in the compressive strength for the samples containing the PCE type relative to the PNS type

Tab. 4 Mean values ($\bar{d}$) and standard deviations (S_d) for the increase in the 28-day concrete's compressive strength along with their improvements (d_0) at different ages of the curing time for samples containing the PCE type with reference to the PNS type (MPa)

Curing Time														
1-day			3-days			7-days			14-days			28-days		
$\bar{d}$	S_d	d_0	$\bar{d}$	S_d	d_0	$\bar{d}$	S_d	d_0	$\bar{d}$	S_d	d_0	$\bar{d}$	S_d	d_0

Tab. 5 Mean values ($\bar{d}$) and standard deviations (S_d) for the increase in the compressive strength of the 28-day concrete along with their improvements (d_0) for the samples with different SP dosages regarding the samples containing 0.2% SP (MPa)

0.4% SP			0.6% SP		
$\bar{d}$	S_d	d_0	$\bar{d}$	S_d	d_0
2.77	1.64	2.2	1.57	2.56	0.6

To estimate the rate of increase in the 28-day compressive strength for the samples containing different dosages relative to the samples with 0.2% SP, it was required to divide the variable d_0 by the average value of the 28-day concrete's compressive strength for the samples with 0.2% SP. These rates are estimated at 8% and 2% for the samples with 0.4% and 0.6% SPs, respectively (indicating an effect on the concrete's compressive strength of up to 8%).

3.3.1.3 The impact rate of the curing time on the compressive strength of the 28-day concrete

In Table 6, the mean values ($\bar{d}$) and standard deviations (S_d) are reported for the increase in the compressive strength of the 28-day concrete for the samples with different days curing relative to the samples with one-day curing. The improvements in the compressive strength (d_0) are reported as well by equalizing Eq. (4) with ($t_{\alpha/2, n-1}=2.11$ for the sample size of $n=18$).

Figure 15 indicates the rate of increase in the 28-day concrete's compressive strength for the samples with different days of curing compared to one-day curing. The rate is defined as variable d_0 divided by the average value of the compressive strength of the 28-day concrete for the samples with one-day curing. According to Figure 15, the complete curing of the concrete can improve the concrete's strength by up to 23%.

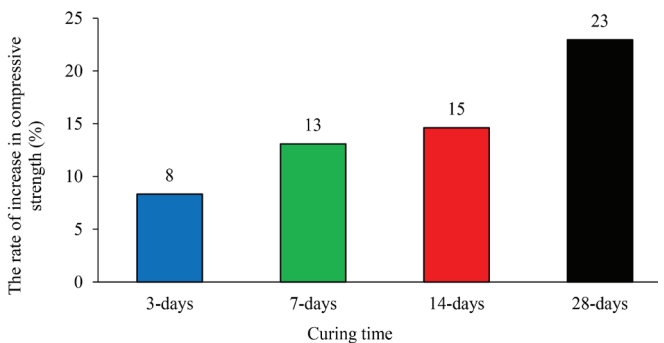


Fig. 15 The rate of increase in the compressive strength of the 28-day concrete for the samples with different curing times regarding the samples with one-day curing

Tab. 6 Mean values ($\bar{d}$) and standard deviations (S_d) for the increase in the compressive strength of the 28-day concrete along with their improvements (d_0) for the samples with different curing days regarding the samples with one-day curing (MPa)

Curing Time											
3-days			7-days			14-days			28-days		
$\bar{d}$	S_d	d_0	$\bar{d}$	S_d	d_0	$\bar{d}$	S_d	d_0	$\bar{d}$	S_d	d_0
1.66	0.62	2.0	2.73	0.73	3.1	3.79	0.69	3.5	5.93	1.04	5.4

3.3.1.4 The impact rate of the W/C ratio on the compressive strength of the 28-day concrete

In Table 7, the mean values ($\bar{d}$) and standard deviations (S_d) are reported for the decrease in the compressive strength of the 28-day concrete for samples with different W/C ratios compared to the samples with a 0.4 W/C ratio. The decrease in values (d_0) in the compressive strength are estimated by equalizing Eq. (4) with ($t_{\alpha/2, n-1} = 2.045$ for the sample size of $n = 30$).

Tab. 7 Mean values ($\bar{d}$) and standard deviations (S_d) for the decrease in the compressive strength of the 28-day concrete along with their decrease (d_0) for the samples with different W/C ratios regarding the samples with 0.4 W/C ratio (MPa)

0.5 W/C ratio			0.6 W/C ratio		
$\bar{d}$	S_d	d_0	$\bar{d}$	S_d	d_0
0.31	2.04	0.45	-3.27	3.37	2.00

To estimate the rate of decrease in the 28-day compressive strength for the samples with different W/C ratios compared to the samples with a 0.4 W/C ratio. It is necessary to divide the variable d_0 by the average value of the compressive strength of the 28-day concrete for the samples with 0.4 W/C ratio. These rates are estimated at 2% and 7% for the samples with 0.5 and 0.6 W/C ratios, respectively (indicating the effect on the concrete's compressive strength of up to 7%).

3.3.2 The evaluation of the concrete's compressive strength at different ages

All the data used in the statistical analysis of this subsection were obtained from Figures 11 and 12. In Table 8, the mean values ($\bar{d}$) and standard deviations (S_d) of the decrease in the concrete's compressive strength at different ages are compared to the 28-day concrete's compressive strength. The decrease in values (d_0) in the compressive strength are estimated by equalizing Eq. (4) with ($t_{\alpha/2, n-1} = 2.11$ for the sample size of $n = 18$). The rate of the gain in strength (R) is defined as the difference between the average value of the full setting of the 28-day concrete's strength and d_0 divided by the average value

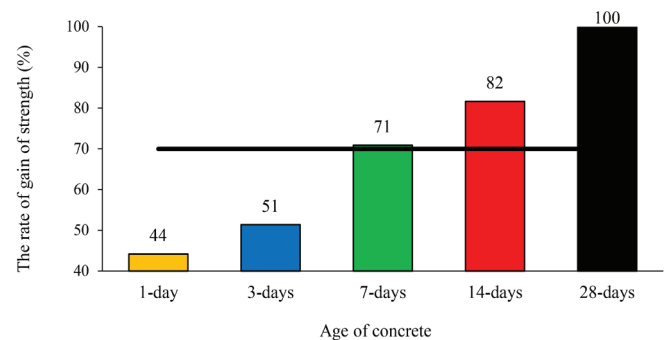
of the full setting of the 28-day concrete's strength (%).

In Figure 16, the rates of the gain in strength (R) are plotted to enable a better visualization. This figure also shows a 70% ratio line in which the molds and shoring systems can be removed. It corresponds to the concrete's age in 7 days with complete curing during this period. In confirmation of what was stated in the section "The evaluation of concrete strength at different ages" above, a 7-day time interval for stopping the pouring of concrete with the complete curing process during this period is proposed.

4 CONCLUSIONS

This paper proposes a practical and state-of-the-art solution for the time management of construction. It should be emphasized that all the results were valid for the ambient conditions in this project. Considering the experimental results and statistical analysis, the following conclusions may be drawn:

1. In a mix design containing SP of the carboxylate type with a cement percentage of 0.4 and a W/C ratio of 0.4, the maximum compressive strength can be obtained. Therefore, it is defined as the optimal mix design for this type of SP.

**Fig. 16** The rate of the gain in the compressive strength at different ages regarding the full setting of the 28-day concrete's strength**Tab. 8:** Mean values ($\bar{d}$) and standard deviations (S_d) of the decrease in the concrete's compressive strength along with their rates (R) at different ages regarding the 28-day concrete's compressive strength (%)

Curing Time														
1-day			3-days			7-days			14-days			28-days		
$\bar{d}$	S_d	R	$\bar{d}$	S_d	R	$\bar{d}$	S_d	R	$\bar{d}$	S_d	R	$\bar{d}$	S_d	R
58.50	5.34	44	51.33	5.50	51	32.50	6.88	71	22.22	7.80	82	0.00	0.00	100

2. In a mix design containing SP of the naphthalene type with a cement percentage of 0.5 and a W/C ratio of 0.6, the maximum compressive strength can be obtained. Therefore, it is selected as the optimal mix design for this type of SP.
3. The results indicate that 3 days of curing is appropriate for the time management of the project and for achieving the required strength at 28 days. Moreover, it is concluded that 7 days' curing time can be considered as the proper time interval to interrupt concrete works between different parts of a structure. For this purpose, two formulas were suggested.
4. The statistical analysis shows that the change in SP type, its dosage, and W/C ratio have an impact rate on the compressive strength of up to 10%, whereas the change in the curing time is effective up to 23%.

5. Considering the statistical analysis derived based on the experimental data, 7 days has been determined as the time interval for concrete works between different parts of a structure. This interval time has been specified for the two optimal mix designs. Consistent curing is essential during this time period, as it ensures that the structure will be stable and support all the loads imposed.

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