Influence of delayed casting on compressive strength of concrete: an experimental study

H. M. A. Mahzuz¹ · Md. Mehedi Hasan Bhuiyan¹ · Nursat Jahan Oshin¹

Received: 5 December 2019 / Accepted: 29 January 2020 / Published online: 1 February 2020
© Springer Nature Switzerland AG 2020

Abstract

Concrete is expected to be placed right after the mixing of cement, aggregates, and water. However, an unexpected delay before placing can occur for many reasons. This affects the compressive strength of the hardened concrete. The aim of the study is to observe the effect of casting delay (up to 480 min or 8 h) on the 28-day compressive strength of concrete. Both, Ordinary Portland cement and Portland Limestone Cement were used to observe the variation in change of strength for casting delays. Additional water was added each hour to regain workability maintaining a slump 75 ± 6 mm. In addition, the effect of not using water after delaying was also observed. After going through all the procedures, the decrease in compressive strength per hour was identified. However, not using water as the delay continues, results in a rapid loss of both workability and compressive strength as well.

Keywords Cement · Delay · Remix · Compressive strength · Setting time · Slump · Water · Workability

1 Introduction

Although it is desirable to place fresh concrete as soon as the mixing operation is completed, the placing of concrete in its final position might be delayed due to many reasons. Improper methods of handling of concrete, site organization, work scheduling, adverse environmental condition and breakdown of equipment are some of the causes for the unexpectedly long delay. In the construction sites where ready-mixed concrete is used, the delay time is mainly determined by the site location from the central batching plant and by the traffic conditions on road. As the workability of fresh concrete greatly diminishes with time, too long of a delay may cause the concrete to be unfit for placing. This problem is especially serious in hot weather and when chemical admixtures are used. It is a bad practice of construction to regain the workability of fresh concrete by adding some water. This may result in a variation

of water-cement ratio, thus can reduce the strength of concrete, since the water-cement ratio is inversely related to concrete strength: the higher W/c (water to cement ratio), the lower the strength [1–3]. This ratio also controls concrete paste porosity. Therefore it is a key parameter in determining concrete nature [4–6].

Workability depends on water content, the shape of aggregate and size distribution, cementitious content and degree of hydration. Moreover, it can be increased by the addition of chemical admixtures (e.g. plasticizer or superplasticizer) without altering the water-cement ratio. The addition of water or adding chemical admixtures in concrete mixture increases concrete workability. However, excessive water leads to increase bleeding or segregation of aggregates, with the resulting concrete having reduced quality [7, 8].

Delay in casting can result in the cold joint and it can affect concrete strength as well. A study was undertaken

✉ H. M. A. Mahzuz, mahzuz_211@yahoo.com; Md. Mehedi Hasan Bhuiyan, nayeem47hasan@gmail.com; Nursat Jahan Oshin, nursatjahan67@gmail.com | ¹Department of Civil and Environmental Engineering, Shahjalal University of Science and Technology, Sylhet 3114, Bangladesh.

on a delay time-lapse of “45, 75, 120 and 180 min”, focusing on the cold joint where two batches of different delayed mixes are placed. It was found that without a retarding agent, a delayed placed second part in the sample causes an increase in strength. Compressive strength increased initially up to the initial setting time and then decreased as the time lag between mixing and casting increased. Then the IST and FST of the cement were increased by adding 0.1% of sugar as a retarding agent. As a result, the strength of concrete increased even after 180 min delay in casting [9].

Mohamadien [10] studied on a similar type of cold joint of the second layer of concrete, maintaining the delay times of 4, 9 and 16 h. It was found that the compressive strengths of concrete would decrease by increasing the time of casting of the second layer of concrete. Due to the grouting between the two layers, the reduction in the compressive strength was 3%, 4% and 7% at the time of 4, 9 and 16 h respectively. When painting the separator with grout, the reduction became 8%, 11%, and 14%.

Another study [11] was carried out on a time delay of up to 120 min. Here superplasticizer was used to improve workability. It was opined that delay of 120 min produced a 25% increase of compressive strength for plain concrete, whereas an increase of 13% to 17% was noted for superplasticizer added concrete with incremental addition after 90 min of delay. Cook [12] reported a similar finding up to a delay period of 90 min.

In a research [13] casting delay was addressed for different different periods like 15, 30, 45, 60 and 75 min. It was found that compressive strength decreased by about 17% for samples with workability improvement additive, 20% for water and cement as a concrete additive and 34% for water as concrete additive compared to control group without any additives when immediately remixed. It was concluded that the use of a workability additive improves the workability when leaving the concrete mixture for periods of 45 to 75 min but it decreased the compressive strength (10%) compared to control values at the same periods.

2 Scope and objective of the study

It is known that the compressive strength of concrete decreases if there is a delay in casting. However, it is still unknown how much strength reduces for a specific time delay. This study focused on the change in compressive strength with the elapsed time after the mixing of fresh concrete. In most of the previous researches, various admixtures were used to reduce workability loss for delay. Superplasticizer is widely used where delay before casting is inevitable [14]. But when a delay occurs accidentally or

unplanned then some water is added instantly to regain workability. Therefore, in this study, this situation is handled by adding some water after the delays and determined the change in the compressive strength of the concrete. Previous researches are based on a delay of up to 120 min (2 h) to 180 min (3 h). While what may happen if the time is prolonged, it is still unknown. Therefore, despite the above-mentioned literature review further research is felt to be carried out. Therefore, the objectives of this study formulated based on the knowledge gaps are:

1. To determine the change in strength of concrete for a specific time interval of cast delay, up to 480 min (8 h).
2. To study the difference of change in strength if, (i) water is not added, and (ii) water is added maintaining a 76 mm slump after the delay.
3. To study the change in strength of two commonly used types of cement, Ordinary Portland Cement (OPC) and Portland Limestone Cement (PLC).

3 Methodology

In this study, two types of cement were used. One was Ordinary Portland Cement (OPC) under the specification of ASTM C150 [15], where the content of Clinker, Limestone, and Gypsum are 95 – 100%, 0% and 0 – 5% respectively. The other was Portland limestone cement (PLC) under the specification of ASTM C1157 [16], where the content of Clinker, Limestone, and Gypsum are 65 – 79%, 21 – 35% and 0 – 5% respectively. The initial and final setting times of cements are determined by VICAT Apparatus according to ASTM C191 [17]. Also, in this study normal consistency of OPC and PLC were determined according to ASTM C187 [18].

As fine aggregate, Sylhet Sand (Fineness Modulus: 2.47, Bulk Density: 1326 kg/m³, Specific Gravity: 2.63 and Water Absorption: 1.00%) was used. Sieve analysis of the sand had been conducted according to ASTM C136 [19]. The bulk density, specific gravity and water absorption test of sand are conducted according to ASTM C128 [20]. As coarse aggregate (Bulk Density: 1524 kg/m³, Specific Gravity: 2.65 and Water Absorption: 0.55%), crushed stones size of 19.05 mm (3/4 inch) and 12.7 mm (1/2 inch) were mixed in 2:1 ratio and used. The bulk density, specific gravity and water absorption test of crushed stone are conducted according to ASTM C127 [21].

A volume-based mix ratio of 1:1.5:1.5 has been considered for this study. This is one of the common mix-ratios used in construction sites, for e.g. 1:1.5:3, 1:2:3, 1:2:4, etc. Similar study can be conducted using different mix ratios, but in present case 1:1.5:1.5 is selected. To achieve a 75 mm slump, the initial water-cement ratio was found

from the slump test- 0.42 for OPC and 0.43 for PLC. However, as delay continues, to maintain a 75 mm slump, it was necessary to add water. The resulting water-cement ratio was kept in record. However, adding water to the concrete definitely increases its water-to-cement ratio, which may cause decrease in the compressive strength. And in the practice, it is not allowed to randomly change the water-to-cement ratios in the construction. It is done to maintain the workability. The quantified result of the above mentioned process is shown in the next section. It to be noted that the slump test was done according to ASTM C143 [22].

In this study, a mixer machine is used for mixing all the ingredients to simulate the practical site condition. Mixing was done for at least three minutes each time after the delay and water addition. For each data, three-cylinder specimens (height: 200 mm, dia: 150 mm) were prepared. Immediate after mixture three control specimens were cast, the data found from these samples is considered the control value with respect to other data. After that the mixture was divided into two parts, i) no water was added to the mixture, and ii) water was added to the mixture. For the 2nd part, the delay times (i.e. the time of concrete casting) are 1) 60 min (1 h), 2) Initial Setting Time (IST), 3) 180 min (3 h), 4) 240 min (4 h), 5) Final Setting Time (FST), 6) 360 min (6 h), 7) 420 min (7 h) and 8) 480 min (8 h). After 24 h, de-molding was done and the samples were kept in the curing chamber and after 28 days compressive strength test was performed as per ASTM C39-96 [23] to observe the effect of casting delay.

4 Result analysis

The main purpose of the study is to assess the compressive strength of the concrete when they are placed with delay after mixing. For this, concrete was cast with various delay times with and without additional water. The compressive strength test was conducted after 28 days of continuous curing. The results are discussed and presented here with suitable charts and tables. The normal consistency, Initial setting time and final setting time of both OPC and PLC are shown in Table 1.

The part of the wet concrete mixture (of both OPC and PLC) where no water added began to lose workability as

time passed. Therefore it became tougher to temp and cast in the mould. And after 180 min the concrete mixture became significantly dry and totally lost its workability. As a consequence casting had to be stopped. Figure 1 shows the visible condition of the concrete mixture at mould. After 24 h when the mold was removed the state of the samples is shown in Table 2.

On the other hand, in the rest, the part of the wet concrete mixture (of both OPC and PLC) water was added to retain workability with time. To do that the target slump was ~ 75 mm, as already mentioned earlier. The respective W/c ratios are shown in Figs. 2 and 3.

The influence of maintaining the workability on the compressive strength of concrete is clear from Figs. 4 and 5. Here, the compression test result is presented. From the maximum, minimum and average values it can be said that a significant fall of strength happened after one hour, both for OPC and PLC. As per different codes like International Building Code (IBC) (section 1905.1. 1), ACI 318 Standard (section 5.1. 1) and BNBC 2014nh (6.1.2.6) [24] the minimum strength of structural concrete is 17 MPa. It is seen that the strength had dropped below 17 MPa after 75 min of delay, both for the samples of OPC and PLC with no water addition.

Meanwhile fully different scenario than the above is seen in the compression test result of a concrete mixture where water was added to retain workability. For the OPC samples, the average curve is showing a slightly downward approach up to 180 min (Fig. 6). After that, the compressive strength is seen to increase up to FST(290 min), from which the strength began to fall again significantly. A quite similar approach is observed in PLC samples. The average compressive strength decreased up to 180 min after that increasing approach is seen up to FST (275 min), from which the strength began to fall again. Although the average compressive strength of both the samples of OPC and PLC did not decrease below 17 MPa up to a delay of 480 min, it may go below that strength after 480 min of

Fig. 1 Concrete placed into molds after 180 min of initial mixing without water

Table 1 Initial setting time and final setting time of OPC and PLC

Cement type	Normal consistency (%)	Initial setting time (min)	Final setting time (min)
OPC	25	96	290
PLC	27	132	275

Table 2 Change of the visible condition with time of concrete cylinder specimens where water was not added

Cube specimen	Casting was delayed up to–			
	0 min	60 min	96 min	180 min
OPC
PLC

Fig. 2 W/c ratio of concrete mixture of OPC to maintain 75 mm slump **Fig. 3** W/c ratio of concrete mixture of PLC to maintain 75 mm slump

delay (as expected from the trend). Considering the initial and final value the linear hourly decreases of compressive strength in different cases are shown in Table 3.

It is true that both casting delay and addition of water can decrease the concrete strength. The present study tries

to quantify this fact. That's why test setup is done to check the concrete strength both with and without addition of water in the same casting delay. The result is clear in Figs. 4, 5, (decrease in strength caused by the no water addition) and 6 and 7 (decrease in strength caused by the

Fig. 4 Compressive strength of concrete of OPC at different casting delay, with no water, added after the initial mixture

Fig. 5 Compressive strength of concrete of PLC at different casting delay, with no water, added after the initial mixture

water addition). It is clear from the result that addition of water secures much higher strength than the non addition of water in the same casting delay.

5 Conclusion

While concrete casting is going on, no casting delay is expected. It is the best practice to place it as soon as possible. This study tried to quantify the decrease of concrete compressive strength if any unexpected delay occurred. The key outcomes are summarized below:

Fig. 6 Compressive strength of concrete of OPC at different casting delay, with water added after the initial mixture

- Delay in casting is a strong variable for the declining trend of compressive strength of concrete for both OPC and PLC concrete samples,.
- In “no-water addition” case, the workability and compressive strength of concrete samples (of both OPC and PLC) significantly began to fall after the 1st hour of mixing.
- In “water addition” case, the compressive strength of concrete samples (of both OPC and PLC) significantly began to fall after the final setting time (FST).
- To retain the constant workability of concrete (~75 mm slump) water was added. As a consequence, though the W/c ratio (Figs. 2 and 3) increased yet from the experimental result it was seen that such concrete secured comparatively much better strength than that of the case of no water addition (Figs. 4, 5, 6, 7).
- The hourly decreases of compressive strength of concrete for different cases are shown in Table 3. These values can be used as a thumb rule for casting delay in real field. For example, it can be said that with water addition the compressive strength of concrete (of OPC) falls 0.93 MPa per hour for delay of casting. As a round number it can be proposed 1 MPa to draw more concern for quick casting.
- This research was conducted maintaining a fixed mix ratio, workability, fine and coarse aggregate properties. Similar studies can be conducted on a larger scale making the above points variable.
- Among many of the limitation it can be said that, the specific reason for the fall of the compressive strength of concrete after the FST is not studied in this research. Yet, the initial step was taken in this study as well the numerical values are hoped to play an experimental

Table 3 Rate of decrease of compressive strength (f'_c) per hour

Sample of	No water was added (time period 3 h, Figs. 4 and 5)			Water was added (time period 8 h, Figs. 6 and 7)		
	Initial f'_c , MPa	f'_c at 480 min	Rate of f'_c decrease	Initial f'_c , MPa	f'_c at 480 min	Rate of f'_c decrease
OPC	26.14	1.65	8.16	26.14	18.71	0.93
PLC	33.36	3.72	9.88	33.36	20.15	1.65

Fig. 7 Compressive strength of concrete of PLC at different casting delay, with water added after the initial mixture

and documentary baseline for bigger and more generalized studies in the future.

Acknowledgements The authors of the paper are grateful to the Department of Civil and Environmental Engineering, Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh, for providing all the necessary support for the research. The authors are also grateful to the honorable reviewers and editors of this prestigious journal for giving their valuable time and effort to process the paper.

Compliance with ethical standards

Conflict of interest It is to ensure that, the authors of the article, "Influence of Delayed Casting on Compressive Strength of Concrete: an Experimental Study" have no competing or conflict of interests regarding the submission in this prestigious Journal.

References

- Bentz DP, Aitcin P-C (2008) The hidden meaning of water-cement ratio. *Concr Int* 30(5):51–54
- Nallathambi P, Karihaloo B, Heaton B (1984) Effect of specimen and crack sizes, water/cement ratio and coarse aggregate texture upon fracture toughness of concrete. *Mag Concr Res* 36(129):227–236
- Živica V (2009) Effects of the very low water/cement ratio. *Constr Build Mater* 23(12):3579–3582
- Dowell A, Cramer S (2002) Field measurement of water-cement ratio for Portland cement concrete. Phase II, Field evaluation and development
- Popovics S, Ujhelyi J (2008) Contribution to the concrete strength versus water-cement ratio relationship. *J Mater Civil Eng* 20(7):459–463
- Bashandy AA (2012) The feasibility of remixing concrete. *Eng Res J* 10:135
- Ferrari L, Kaufmann J, Winnefeld F, Plank J (2011) Multi-method approach to study influence of superplasticizers on cement suspensions. *Cem Concr Res* 41(10):1058–1066
- Baskoca A, Ozkul M, Artirma S (1998) Effect of chemical admixtures on workability and strength properties of prolonged agitated concrete. *Cem Concr Res* 28(5):737–747
- Rathi V, Kolase P (2013) Effect of cold joint on strength of concrete. *Int J Innov Res Sci Eng Technol* 2(9):4671–4679
- Mohamadien H (2013) The impact of the time when casting the second layer of concrete on its mechanical properties. *J Eng Sci* 41:919–929
- Ravindrarajah RS (1985) Casting delay on workability and strength of concrete. *Int J Cem Compos Lightweight Concr* 7(2):109–113
- Cook GC (1943) Effect of time of haul on strength and consistency of ready-mixed concrete. In: Paper presented at the ACI journal proceedings
- Bashandy A (2012) The feasibility of remixing concrete. *Eng Res J* 135:98–107
- Zhang M-H, Sisomphon K, Ng TS, Sun DJ (2010) Effect of superplasticizers on workability retention and initial setting time of cement pastes. *Constr Build Mater* 24(9):1700–1707
- ASTM C (2002b) 150, Standard specification for Portland cement. Annual book of ASTM standards, p 4
- ASTM C (2008) 1157, Standard performance specification for hydraulic cement. Annual book of ASTM standards
- ASTM C (2003b) 191, Standard test method for time of setting of hydraulic cement by Vicat Needle. Annual book of ASTM standards
- ASTM C (1998) 187, Standard test method for normal consistency of hydraulic cement, Philadelphia, PA: American Society for Testing Materials. Annual book of ASTM standards
- ASTM C (2002a) 136, Standard test method for sieve analysis of fine and coarse aggregates. Annual book of ASTM standards, vol 4, no 02
- ASTM C (2001a) 128-01, Standard test method for density, relative density (specific gravity), and absorption of fine aggregate. Annual book of ASTM standards
- ASTM C (1992) 127-88, Test method for specific gravity and adsorption of coarse aggregate. Annual book of ASTM standards
- ASTM C (2001b) 143, Standard test method for slump of hydraulic-cement concrete. Annual book of ASTM standards

23. ASTM C (1996) C 39-96, Standard test method for compressive strength of cylindrical concrete specimens. Annual book of ASTM standards, p 4
24. BNBC (2014) Chapter-6, Strength Design of Reinforced Concrete Structures, Bangladesh National Building Code, Housing and Building Research Institute (HBRI), Vol 2, pp 6–298

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.