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INVESTIGATION ON PROPERTIES OF READY MIXED CONCRETE OVER TRANSIT TIME

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Graphical abstract

Abstract

Ready-mixed concrete (RMC) is a contemporary item that facilitate to mix concrete in a specialized yard and deliver it at site while ensuring the quality as fresh concrete. The transit time of RMC, which is influenced by road congestion, is important since it may have an impact on the workability and compressive strength of RMC. Therefore, it is necessary to investigate the impact of transit time on properties of RMC. In this study, a two-phased experimental program was designed; where RMC has been used with (phase-1) and without admixture (phase-2). Concrete mix-ratio was designed to attain M20 concrete; however, the target strength was 25MPa. Fresh concrete properties, i.e., workability, was measured at designated times (i.e., 0, 45, 90, 120, 150, 180 and 210minutes) over a period of 3.5 hours after the mixing of concrete. Over this period, concrete-mixer was continuously rotated at 18-20 rpm speed and cylinders were cast at previously mentioned time intervals. The experimental results showed that transit time has a remarkable impact on workability of RMC when the admixture is not utilized, i.e., slump value reduced from 210 to 25mm over 3.5 hrs. travelling. However, the slump value can be maintained up to 115mm using 1% admixture. In contrast, there is no remarkable impact of transit time on the compressive strength as the average strength in both phases reached or relatively close to the target strength (i.e., 25MPa). The target strength compliance might be attributed to the continuous rotation of the RMC mixer during the transit time.

Keywords: RMC; transit time; setting time; workability; compressive strength.

1.0 INTRODUCTION

Ready Mixed Concrete (RMC) is concrete that is mixed in a batch plant and delivered to the construction site “ready to use” according to project specifications. Ready-mixed concrete shall be mixed and delivered to the site using of one of the following combinations of operations such as Central-Mixed Concrete, Shrink-Mixed Concrete, and Truck-Mixed Concrete (Daniel and Lobo, 2005). Ready mixed concrete (RMC) is now widely utilized in developed countries as well as in developing countries like Bangladesh. In the current mega projects of Dhaka city of Bangladesh, there might be no other good option except to use the ready mixed concrete due to the space limitation in construction sites.

Several surveys and experimental studies were conducted by researchers to understand the suitability of RMC in developing countries as well as to investigate the properties of RMC. Manjunatha et al. (2014) investigated consumer choices and observations about the quality and services of RMC as a building material in Bangalore, India. The study found that customers can pick any one between RMC and Site Mixed Concrete casting or both, depending on their budget and time restrictions in the construction industry in Bengaluru. Also, it was found that the quality and service of the concrete (RMC) provided is satisfactory. Rahman et al. (2011) conducted a study on RMC, including an experimental attempt and a survey, in the context of Bangladesh. In that experiment, four cylindrical samples from each of the five ready-mix concrete companies were collected from worksite locations, and four samples were tested for compressive strength after 28 days of curing.

According to that survey, there are enough ready-mixed concrete companies in Bangladesh to fulfill customer demand. However, sometimes ready mixed concrete suppliers face challenges to attain specified concrete strength.

Mahzuz et al. (2020) conducted an experimental study on the influence of delayed casting on the compressive strength of concrete with and without water mixing after initial mixing. The experimental results demonstrated that no addition of water as the delay continues results in a rapid loss of both workability and compressive strength. However, the addition of water to maintain a target slump reduced the effect on compressive strength. The compressive strength decreased by about 8.16 MPa, and 0.93 MPa per hour for the concrete with Ordinary Portland cement (OPC) and Portland Limestone Cement (LMC), respectively. Mohan et al. (2020) studied the slump retention of Ready-Mix Concrete and also investigated the relationship between slump and transit duration, temperature, and mix, as well as the influence of additive re-dosing in concrete. In the experiment, water demand was raised, and slump loss was accelerated when the temperature rises during transit duration. Slump loss was increased with time, where different types of admixtures were used. Chowdhury et al. (2016) conducted an experimental investigation on the effect of delay in casting on the compressive strength of concrete. The experimental results showed that the compressive strength of concrete decreased after 90 minutes of concrete mixing in both cases of the w/c ratio of 0.5 and 0.6. Trejo et al. (2014) studied the effects of extended discharge times and revolution counts for ready-mixed concrete. The experimental results indicated that the mixing time and drum revolution counts had no significant effects on the majority of concrete properties (compressive strength and workability) and durability characteristics of ready-mixed concrete. Kirca et al. (2002) investigated the effects of prolonged mixing of non-retempered concrete and also re-tempering on the consistency and compressive strength of concrete. The experimental results found that prolonged mixing reduced the workability and increases the compressive strength of the non-re-tempered concrete. Gaynor et al. (1985) studied the effect of temperature and delivery time on concrete properties. The experimental results showed that the extended delivery time might have a slight effect on the properties of concrete.

The previous experimental studies focused on various parameters, i.e., strength, workability, casting delay, etc., however, there is a lack of comprehensive investigation of the workability and compressive strength of RMC with continuous mixing or prolonged mixing of RMC. Therefore, this study focuses on the workability and compressive strength of RMC with continuous or prolonged mixing over a certain transit time considering with and without admixture.

2.0 EXPERIMENTAL PROGRAM

2.1 Test Specimens

The experimental program has two phases; where concrete casting of phase-1 and phase-2 has been carried out without and with admixture, respectively. In phase 1, several concrete cylinders (100 mm diameter and 200 mm height) have been constructed at different time intervals, as mentioned in Table 1, after the mixing of RMC. In phase-2, an admixture (Type-B) has been added in RMC to retard the initial setting time. In both phases, three cylinders have been constructed at each time interval; details are shown in Table 1.

Table 1 Details of specimens

Specimen (100 x 200 mm cylinder)		Concrete casting and slump value measurement time (*mins.*)							
		t_1= 0	t_2 = 45	t_3 = 90	t_4 = 120	t_5 = 150	t_6 = 180	t_7 = 210	Total
Phase-1	w/o admixture	3	3	3	3	3	3	3	21
Phase-2	w/ admixture	3	3	3	3	3	3	3	21
								Total =	42

2.2 Material Properties

2.2.1 Cement

All test specimens have been constructed using regular Portland Composite Cement (PCC) available in Bangladesh. The initial setting time test has been conducted as per ASTM C191-21 for cement with and without admixture. Figure 1 shows the relationship between needle penetration and time of the PCC from where the initial setting time has been determined. The initial setting time of PCC without and with admixture are 86 and 92 mins., respectively, which indicates that there is a little variation between the setting times when admixture has been used. It is to be mentioned that 1% admixture (Type B) has been utilized herein as per practice of RMC supplier.

2.2.2 Aggregate

Locally available fine and coarse aggregates have been used as shown in Figure 2 (a)-(b). Stone chips of 20 mm and 12 mm downgrade have been blended to get an appropriate coarse aggregate that satisfies the upper and lower limits of the gradation curve as per ASTM C-33. River sand, having an FM of 2.95 has been utilized in the concrete. Figure 3(a)-(b) show the gradation curves of fine and coarse aggregates, respectively where both aggregates comply with ASTM C-33 gradation curve limits.

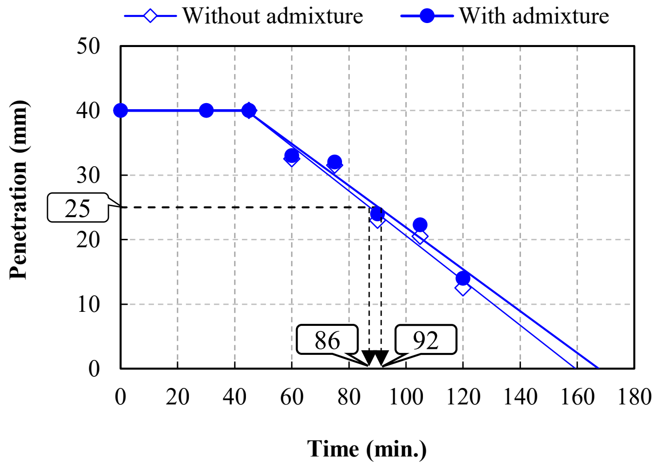
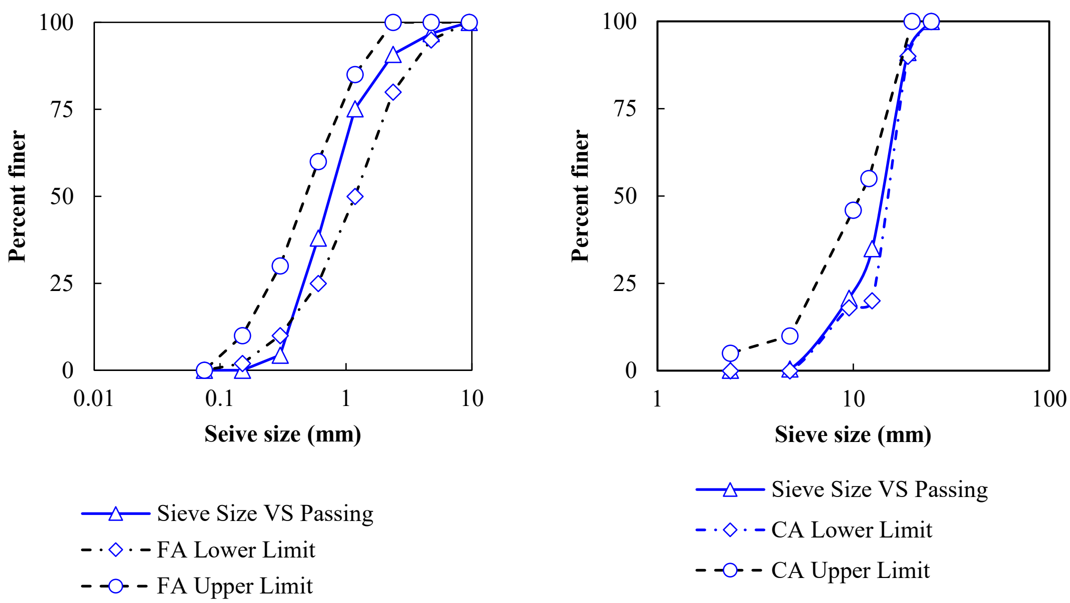


Figure 1 Initial setting time of cement

(a) (b) (c)

Figure 2 (a) Stone chips (20 mm down); (b) Stone chips (12mm down) and (c) Sylhet sand



(a) (b)

Figure 3 Gradation curve for (a) fine aggregate and (b) coarse aggregate

2.2.3 Admixture

Generally, admixtures are used in concrete to improve strength, durability, workability, high hardness, and water tightness as well as to speed up or slow down setting and hardening, and minimize the heat of hydration, segregation, and entrain air. In this study, Chryso retarding admixture (Type: B as per ASTM C494/C494M) has been used which increases strength and setting time. An optimum admixture dosage can only be established after trial, however, based on a field survey in the building and construction industry, the admixture dosage (1% of cement) has been selected.

2.3 Concrete Mix Design And Specimen Casting

As mentioned earlier, locally obtainable resources have been employed to construct concrete cylinders. In the preceding, all of the material attributes have been listed. An assumption of a target strength of 25 MPa has been made during concrete mix design; where the design strength requirement is 20 MPa. Concrete's mix ratio has been determined to be 1:1.5:3 (C: FA: CA) with a water to cement ratio of 0.48. In phase 1, concrete has been mixed with an aforementioned mix design ratio and several concrete cylinders (100 mm diameter and 200 mm height) have been constructed at different time intervals, as mentioned in Table 1, after the mixing of RMC. During the construction of specimens, an electrical concrete mixing machine as shown in Figure 4 (rotation speed 18-20 rpm) has been used. The slump test has also been conducted at designated times. After casting and demolding, the constructed cylinders have been cured in lime water for 28 days. In phase-2, an admixture (Type- B and 1% of cement) has been added in RMC to retard the initial setting time. The test specimens have been cast and cured similarly as mentioned in Phase - 1.

2.4 Tests of Concrete

2.4.1 Slump Test

In both phases, the slump test of concrete has been conducted as per ASTM C143/C143M-20 where concrete's consistency has been evaluated to understand the workability. Since, slump test of concrete was conducted over time, shear and collapse slumps were found along with true slump, in case of concrete without admixture. The collapse, shear and true slump of the concrete without admixture are shown in Figure 5(a)-(c). In the case of concrete with admixture, collapse and shear slump were observed mostly. In general, the expected slump value of concrete should be considered as per location of casting i.e., beam, column, or slab casting. The definition of states of workability as shown in Table 2 has been considered as suggested by Shahidan et al. (2015).

Figure 4 Rotation of RMC after mixing

Table 2 Degree of workability for different slump (Shahidan et al. 2015)

Degree of Workability	Slump	
	mm	inch
Very low	0-25	0-1
Low	25-50	1-2
Medium	50-100	2-4
High	100-175	4-7

(a) At *t* = 0 min (Slump = 210 mm) (b) At *t* = 120 min (Slump = 110 mm) (c) At *t* = 210 min (Slump = 30 mm)

Figure 5 Slump test of concrete without admixture

(a) (b)

Figure 6 Compressive test (a) specimen under loads and (b) specimen damage after releasing compression load

2.4.2 Compressive strength test

The compressive strength test, as per ASTM C39/C39M-21, has been conducted after 28 days of curing of the concrete cylinders after casting. All the specimens have been tested using a concrete compression test machine having a capacity of 2000kN. Figure 6(a)-(b) show two different specimens during, and after testing, respectively. For all the specimens, the maximum load and corresponding crack propagation have been noted and observed to understand the failure mechanism of each cylinder.

3.0 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Concrete Properties

Fresh and hardened concrete properties, slump values and compressive strength of concrete, respectively of all the tested cylinder specimens at designated time intervals have been measured as discussed earlier. Slump values and concrete cylinder compressive strength (28 days) are reported in Table 3. The observed slump values indicate that the workability of RMC without the admixture fallen to a very low category with transit time; whereas, the workability of RMC with admixture (1% of cement) sustained the high state of workability with transit time. The observed compressive strength results demonstrate that most of the specimens (cast at different time intervals) can attain the compressive strength near to the target strength of 25 MPa or more, with some exceptions. The concrete cylinder commonly fails in different ways, as shown in Figure 7, under compression as suggested by ASTM C39/C39M-14. Almost all of the specimens have failed like a Type-2 failure pattern where one or more vertical cracks appeared from the top, and a cone formed, not always developed properly, at bottom. However, one cylinder failed like a Type-3 failure pattern. It is to be noted that in most of the cases mortar of the concrete has failed which indicates the lower strength of mortar when compared to stone aggregate.

3.2 Effect of Transit Time on Slump Value

The measured slump values of concrete, for both phases, at different time intervals are shown in Figure 8. The slump value of the RMC without admixture (phase-1) reduced substantially over time. Initially, the workability state was more than high or high up to 125 minutes. After that, the workability state was medium up to 196 mins. This is followed by a low workability state. On the other hand, the slump value of the RMC with 1% admixture content (phase-2) did not reduce substantially over time. The workability state was more than high or high throughout transit time. The effect of the admixture is most prominent after the initial setting time as evident from the Figure 8. Therefore, the workability of RMC is substantially hampered, high to low state, by a transit time of 3.5 hours The additional revolution at mixing speed (i.e., continuous or prolong mixing) of RMC can be attributed to the substantial reduction of workability (Daniel and Lobo 2005). In addition, the reduction of workability of concrete due to casting delay is also reported by several researchers (Shaikuthali et al. 2019; Mohan et al. 2020; Loh et al. 2021; Cordoba et al. 2020; Erdoğdu et al. 2005; Martini et al., 2010). However, workability reduction can be mitigated by the utilization of 1% retarding admixture.

Table 3 Compressive strength test result after 28 days

Time, t (min)	Specimen name	Without admixture			With admixture		
		Slump value (mm)	Average Strength (MPa)	Failure Type*/**	Slump value (mm)	Average Strength (MPa)	Failure Type*/**
0	$_{1}C_{11}$	210	22.7	Type-2(M.F.)	215	27	Type-2(M.F.)
	$_{1}C_{12}$			Type-2(M.F.)			Type-2(M.F.)
	$_{1}C_{13}$			Type-2(M.F.)			Type-2(M.F.)
45	$_{1}C_{21}$	180	26.9	Type-2(M.F.)	180	25.5	Type-2(M.F.)
	$_{1}C_{22}$			Type-2(C.F.)			Type-2(M.F.)
	$_{1}C_{23}$			Type-3(M.F.)			Type-2(M.F.)
90	$_{1}C_{31}$	130	26.2	Type-2(M.F.)	150	25.5	Type-2(M.F.)
	$_{1}C_{32}$			Type-2(M.F.)			Type-2(M.F.)
	$_{1}C_{33}$			Type-3(M.F.)			Type-2(M.F.)
120	$_{1}C_{41}$	110	25.2	Type-2(M.F.)	140	20	Type-2(M.F.)
	$_{1}C_{42}$			Type-2(M.F.)			Type-2(M.F.)
	$_{1}C_{43}$			Type-2(M.F.)			Type-2(M.F.)
150	$_{1}C_{51}$	90	25.8	Type-2(C.F.)	140	24	Type-2(M.F.)
	$_{1}C_{52}$			Type-2(M.F.)			Type-2(M.F.)
	$_{1}C_{53}$			Type-2(C.F.)			Type-2(M.F.)
180	C_{61}	80	27.8	Type-2(M.F.)	125	25.5	Type-2(M.F.)
	$_{1}C_{62}$			Type-2(M.F.)			Type-2(M.F.)
	$_{1}C_{63}$			Type-2(C.F.)			Type-2(M.F.)
210	$_{1}C_{71}$	30	21.8	Type-3(M.F.)	115	30	Type-2(M.F.)
	$_{1}C_{72}$			Type-2(M.F.)			Type-2(M.F.)
	$_{1}C_{73}$			Type-2(M.F.)			Type-2(M.F.)

*Type 2: Well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end) is produced; Type 3: Columnar vertical cracking through both ends, no well-formed cones
** MF: Mortar failure; CF: Combined failure of mortar and aggregate

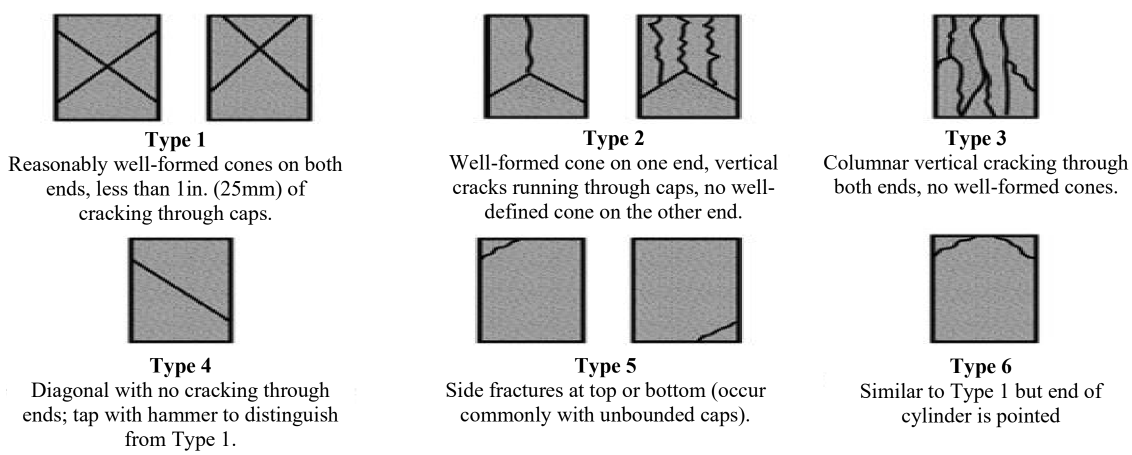


Figure 7 Failure pattern (ASTM C39/C39M-14)

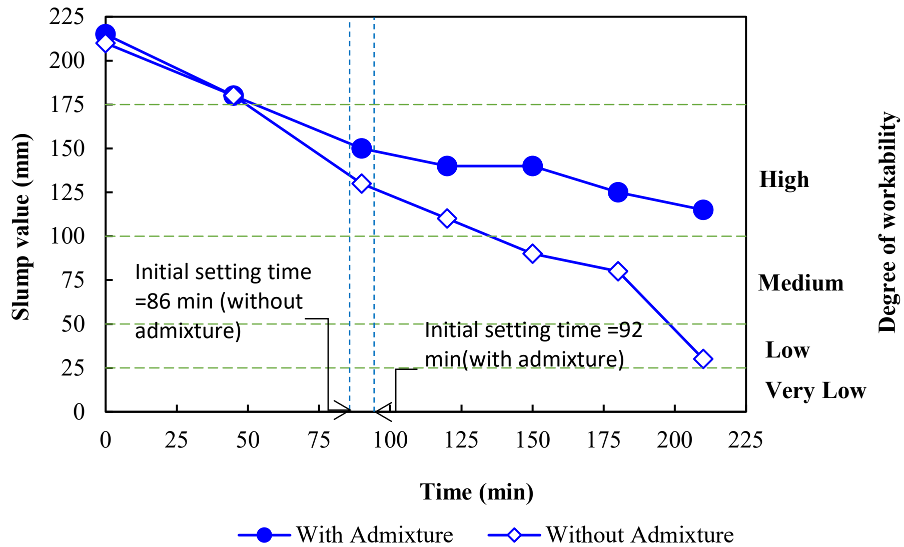


Figure 8 Slump vs. Time (with and without admixture)

3.3 Effect of Transit Time on Compressive Strength

The compressive strength of RMC, for both phases, cast at different time intervals are shown in Figure 9. The compressive strength of concrete, both without and with admixture, was close to the target compressive strength of 25 MPa, however, did not fall below the design compressive strength 20 MPa. Therefore, 3.5 hours of transit time might not have a remarkable effect on the compressive strength and this can be attributed to the mixing procedure, i.e., continuous mixing during the specimen construction. However, the compressive strength of concrete with admixture increased sharply after 150 minutes of rotation. While concrete without admixture showed a slight increment of compressive strength after 150 minutes followed by a rapid fall after 175 minutes. The strength increment can be attributed to the fact that the increased mixing time leads to the evaporation of water, i.e., a reduction of water to cement ratio, which in turn increases the concrete strength. The strength increment can also be attributed to the grinding effect of overmixing. The grinding effect is that as the hydration process progress, the hydration products were removed from the surface of cement grains, causing finer grading of cement and a greater amount of hydration which leads to strength improvement (Kirca et al., 2002). In other words, during conventional mixing some cement particles agglomerate to form a flocculation unit, which does not participate in the hydration reaction. This agglomeration state between particles can be destroyed by vibration (which was done by continuous mixing) which leads to more compressive strength by more hydration reaction (Zhao et al., 2021).

3.4 Effect of State of Workability on Compressive Strength

The relationship of compressive strength and slump values of RMC, without and with admixture, is portrayed in Figure 10 where the degree or state of workability is also mentioned. The compressive strength of RMC was very close to or more than the target compressive strength of 25 MPa when the workability state is in between medium to high, except for one specimen set (3 cylinders). The particular specimen set contained porous concrete cylinders, as shown in Figure 11, which showed early failure. It is also evident that the compressive strength deviated more from the target strength when the workability state is either low or more than the high state, however, the compressive strength did not fall below the design compressive strength of 20 MPa. Therefore, a medium to high workability state, i.e., slump value 50 -175 mm, might be suitable to achieve target compressive strength.

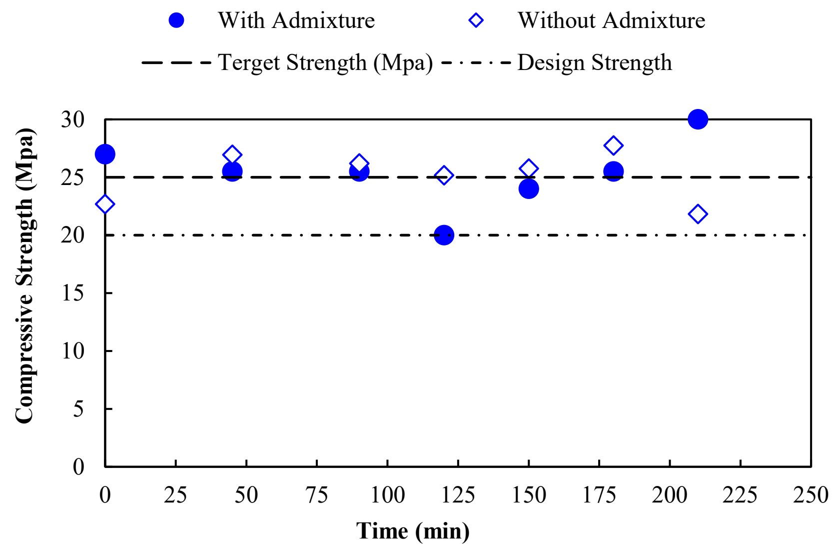


Figure 9 Compressive Strength vs. Time (with and without admixture)

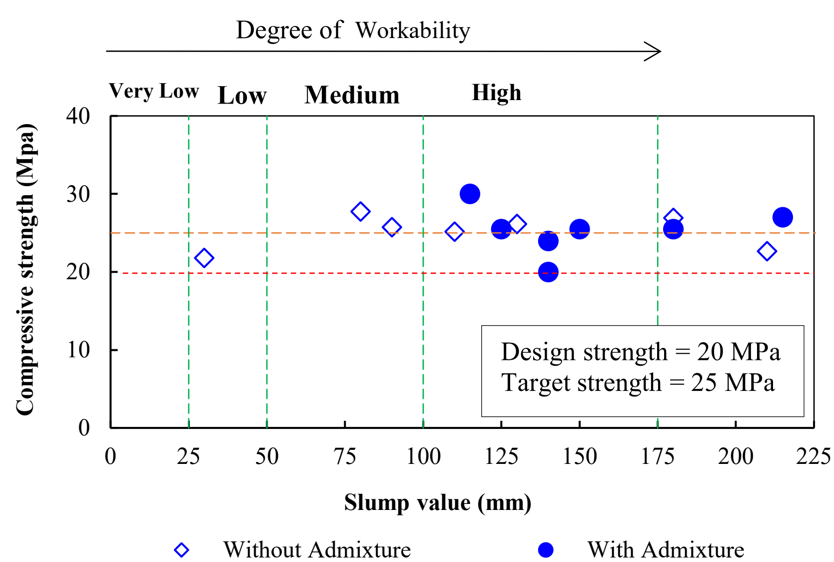


Figure 10 Compressive strength vs. slump value (with and without admixture)

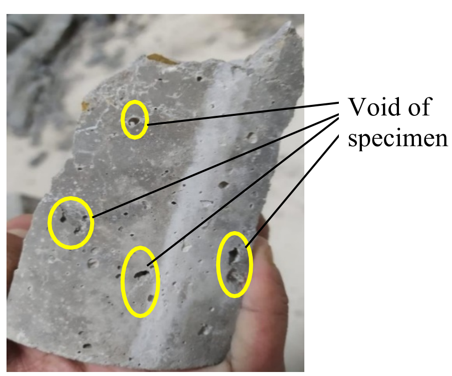


Figure 11 Void in cylinder specimen 1C42

4.0 CONCLUSIONS

This study aims to investigate the impact of transit time on concrete properties (e.g., workability, compressive strength) of RMC. An experimental program was designed considering two phases (Phase-1: without admixture and Phase-2: with 1% retarding admixture). In both phases, the properties of fresh concrete (i.e., slump value) and hard concrete (i.e., compressive strength) were measured at different time intervals. The following conclusions are made considering the limited scope of this study:

- The workability of RMC is substantially hampered, high to low state, by a transit time of 3.5 hours; which can be mitigated through the utilization of 1 % retarding admixture.
- A transit time of 3.5 hours for RMC with continuous mixing might not have a remarkable effect on the compressive strength and this can be attributed to the reduced water to cement ratio and grinding effect.
- Medium to high workability state i.e., slump value 50 -175 mm, might be more suitable to achieve the target compressive strength.

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