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Quantifying Cement Content to Regain the Compressive Strength of Delay Casted Concrete

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Abstract

Retempering of concrete is a common practice in construction industries to regain workability and compressive strength thought Concrete should be casted just after mixing with water. Casting delay significantly affects the concrete compressive strength and workability. This study aims to observe the effects of water and cement retempering on delayed casted concrete up to 4 hours by measuring concrete compressive strength after 28 days of curing. Three variables; 1) retempering with water (RW), 2) retempering with water and cement (RWC1) and 3) retempering with water and cement (RWC2) were considered. Three concrete types having different coarse aggregates (crushed stone, uncrushed-round stone, and brick chips) were used. The results indicate that the compressive strength of crushed stone, single stone and brick chips concrete was decreased after retempering with water (RW). Retempering with water and cement in different doses (RWC1 & RWC2) increased the compressive strength of the concrete. Regression model was used to quantify the needed cement (Kg/m3). Equations were also developed relating to casting delay and cement required (Kg/m3) to gain the initial concrete compressive strength.

Keywords: Concrete, casting delay, compressive strength, retempering, remixing, slump, workability.

1.0 Introduction

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 improper handling of concrete, site situation, work plan, adverse environmental conditions, breakdown of equipment, and so on [1, 2]. For the placement of ready-mixed concrete, the delay time is mainly governed by the site location from the central batching plant and by the traffic conditions. As the workability of fresh concrete reduces with time, such concrete may become unfit for placement [3, 4]. This problem is very alarming in hot weather and when chemical admixtures are used. It is a bad construction practice to regain the workability of fresh concrete by adding water since this practice reduces the strength of concrete [5-7]. Also, the increment of the cement ratio adversely affects concrete paste porosity, which is an important parameter in determining concrete quality [8, 9]. Workability depends on water content ratio, aggregate size and shape, cementitious content and degree of hydration, chemical admixtures (e.g. plasticizer or superplasticizer), etc. [10, 11]. Generally retempering is done by water, super-plasticizer, and cement slurry [12-14]. It is also true that in delayed cast concrete if retempering is not done it can significantly reduce the concrete strength and workability just after 1 hour of mixing [15-17].

There are a lot of study that focuses on the state of concrete strength by retempering with specific results. For example, it is seen that the optimal properties observed in concrete with 20% fly ash replacement, additional cement, and water. Strength peaks at 45 minutes [18, 19]. Retempering in hot-dry climates aims to increase slump for faster casting. The study assesses its impact on RMC's workability and strength across 12 sites. Increased slump correlates with reduced strength, aiding strength prediction [20]. The investigation explores retempering methods for concrete slump adjustment. ASTM C 494 Type F superplasticizer used to restore initial slump. Longer mixing durations show higher compressive strength compared to water retempering [21]. Concrete strength remains unaffected up to 50 mins of retempering, but declines after. This effect is consistent in aged structures. Overall, retempered concrete's durability is compromised after 50 mins, as observed through 28-day strength reduction [22]. Different additives were tested in concrete mixes with continuous mixing. Slump loss was least in mixes with gluconate retarder. Strength remained stable with prolonged mixing but declined with retempering, albeit less in gluconate mixes. Bond strength was also better in gluconate mixes [23, 24].

2.0 Research gaps and current research objectives:

In all the above-mentioned studies, the common predominant feature observed is the utilization of crushed stone as the volumetric material. A notable knowledge gap is seen in quantifying the retempering technique to regain the original strength of concrete when the delay in casting happened. Though few studies are seen with retempering, all of them used crushed aggregate as the coarse aggregate. This oversight is regarded as both the scope and objective of the current study. A research framework can be devised to quantify the cement content necessary to restore the compressive strength of concrete cast after delays. Three types of aggregates, namely crushed stone, uncrushed round stone, and crushed brick chips, can be employed in the study to measure the relative comparison. The objective is to investigate the optimal cement dosage needed to counteract the adverse effects of casting delays on concrete strength.

Specifically, the objectives of the current research are:

1) To evaluate the impact of casting delays on concrete compressive strength retempered with water only and retempered with both water and cement (i.e. RWC1 and RWC2).

2) To specify the additional cement content with time to regain the initial concrete compressive strength.

3.0 Research Procedure

A questionnaire survey is generally used to gather information from a number of respondents [25-27]. In the current study, it is conducted to identify the maximum length and causes of casting delay including retempering measures usually practiced by several masons, contractors, and field engineers in different construction projects. Such a step helps identify the field condition and need for studies onwards. After that lab-based setup is formulated.

The engineering properties of the cement (PCC) (initial and final setting time), fine aggregate, coarse aggregates (Sieve analysis, bulk density, specific gravity, unit weight) were measured as per ASTM standards; ASTM C191 for Cement's initial and final setting times (137 and 270 min respectively), ASTM C187-16 for normal consistency (29.5%), ASTM C136 for Sieve analysis (FM of fine aggregate 2.56), ASTM C127 and C128 for Bulk density, Sp. Gravity and water absorption (Table 1), ASTM C143 for slump test, ASTM C39 for the 28-day compressive strength test.

Table 1. Properties of fine and coarse aggregates

Parameters	Fine aggregate	Crushed stone	Uncrushed - round stone	Brick chips
Bulk Density(kg/m^3)	1586	1643	1737	1163
Specific Gravity	2.65	2.69	2.91	1.79
Water Absorption (%)	1.45	0.6	1.11	16.97
Uniformity coefficient,*Cu*	--	3.19	3.08	3.03
Coefficient of curvature,*Cc*	--	1.3	1.16	1.16

Three types of tests coarse aggregates were used in this experiment as the volumetric material; crushed stone, uncrushed-round stone, and brick chips. A common mix ratio used for the research is 1:2:3 (by weight) with a water-cement ratio of- 0.63 (on field condition). The choice of the mix ratio and water-cement ratio is arbitrary, but these values are commonly used in construction due to their practicality and effectiveness. Immediately after mixing cylindrical specimens were prepared from fresh concrete to be used for reference value for the 28-day compression test. Portions of the mixture were separated to allow 1, 1.5, 2, 2.5-, 3- and 4-hour casting delay. Water was added to maintain a 150-175 mm slump since such a slump is easy to handle by the workers. Retempering was done, i) just by water (RW), ii) both by a small amount of water and cement (RWC1), and iii) both by a higher amount of water and cement (RWC2). The flow chart of the research methodology diagram is presented in Fig. 1.

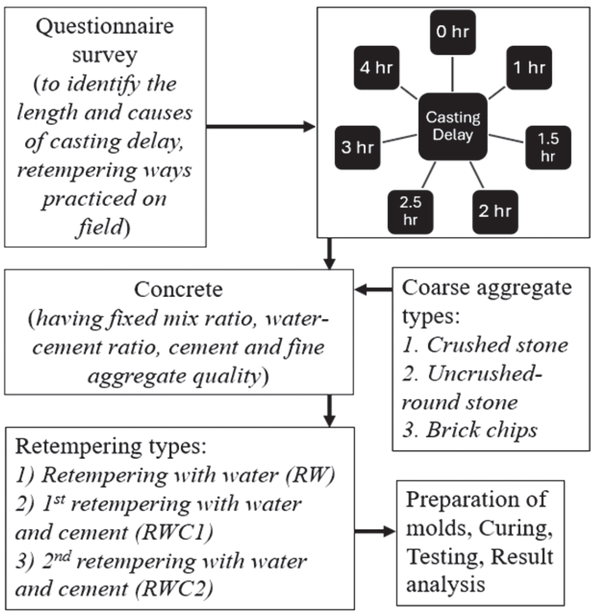

Figure 1. Flow chart of research methodology diagram. It can be noted that i) each data is the average of three different samples, ii) for RW samples water-cement ratio- 0.63 was not maintained but the slump range was 150-175 mm, iii) for RWC1 and RWC2 samples water-cement ratio- 0.63 was carefully maintained keeping the slump range as mentioned.

In total, 189 [= 7 (i.e. casting delays) ×3 (i.e. cylinder samples to average each testing value) ×3 (i.e. types of coarse aggregates) ×3 (i.e. retempering types)] concrete cylindrical specimens were made. Crushed stone, uncrushed-round stone, and brick chip concrete had 63 specimens each. Specimens have a 100 mm diameter and 200 mm height. Workability was much reduced for every delay interval. Water is added to regain workability. A portion of concrete from the bulk mixture in each interval was separated. From that, nine cylindrical specimens of each coarse aggregate type were made, where three retempering with water (RW), three retempering with water and cement (RWC1), and the last three retempering with water and more Cement (RWC2).

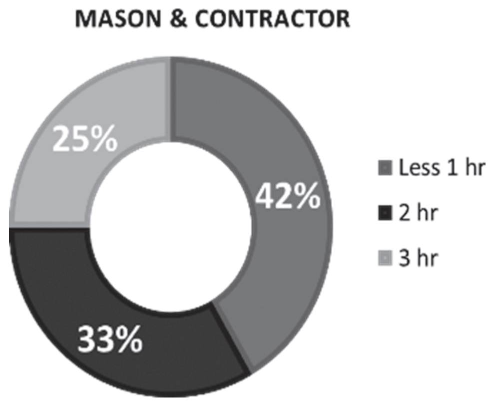

Fig. 2: Opinion of Mason & contractor for delayed casting

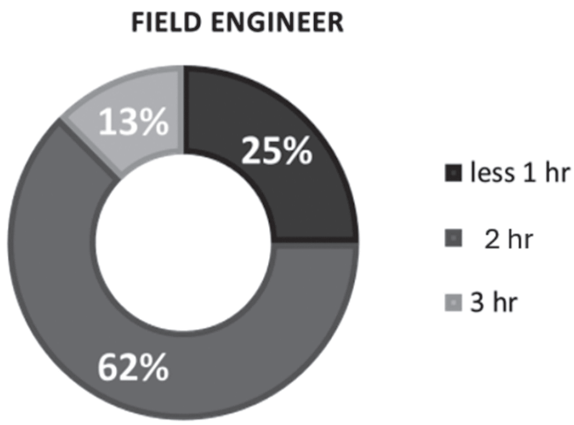

Fig. 3: Opinion of field Engineer for delayed casting

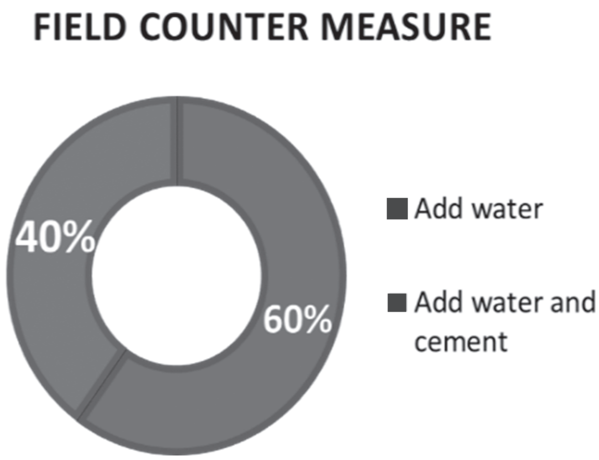

Fig. 4: Retempering measures

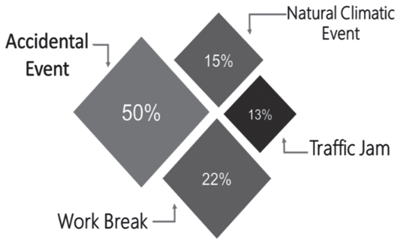

Fig. 5: Causes of casting delay.

It was found that among the mason and contractor (Fig. 1), 42% face casting delay of less than 1 hour, 33% face 2 hours, and 25% people face 3 hours. On the other hand, among the field engineers (Fig. 3), 25% face casting delay of less than 1 hour, 62% face 1.5 hours, and 13% face 3 hours.

A noticeable difference in the respective surveyed values is seen. This may be because of the presence of engineers that usually make workers more careful of the quality construction. Ultimately it led to less experience in casting delay for 'less 1 hr' and '3 hr' in the case of field engineers. This also emphasizes the presence of qualified field engineers when construction is going on.

The maximum casting delay faced in the field is 3 hours. So, adding one hour more, a 4-hours casting delay is conducted in present studies. To gain the workability and strength of concrete (Fig. 4), 60% add water, and 40 % add water and cement. Survey works also identify the significant causes of casting delay (Fig. 5). But there is no evidence of how much strength is regained by such retempering. 50% of the surveyed persons think the cause of the casting delay is an unanticipated event (breakdown of equipment), 22% believe due to a work break, 15 % think due to a natural climatic event (rainfall, storm, etc.), and 13% believe due to traffic jam.

4.2 Retempering effect on crushed stone concrete

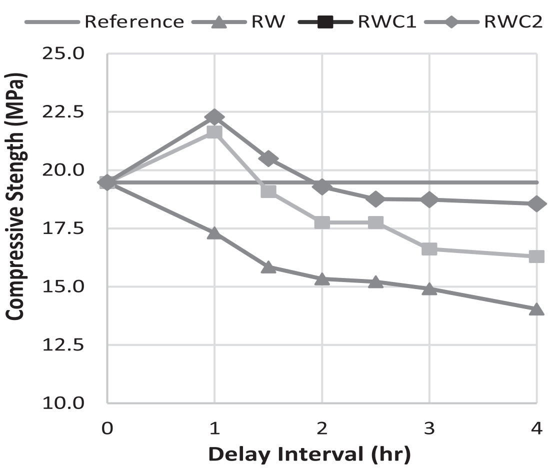

Fig. 6: Change of Compressive strength of concrete having crushed stone as coarse aggregate with time resulting from RW, RWC1, and RWC2.

Fig 6 shows that the compressive strength of concrete retempering with water (RW) decreases over time due to delay. Strength is reduced by 11.10% $\left(=\frac{19.47-17.31}{19.47}\times 100\right)$ after 1 hour and it was followed by 27.87% $\left(=\frac{19.47-14.04}{19.47}\times 100\right)$ after 4 hours delay of concrete casting. The average loss of strength per hour delay is 1.36 MPa $\left(=\frac{19.47-14.04}{4}\right)$ for a 4-hour casting delay. Retempering with water and cement in two doses (i.e. RWC1 and RWC2), strength is increased, maintaining the initial water-cement ratio and slump range (i.e. 0.63 and 150-175 mm, respectively). So, strength is increased, overcoming loss due to the delay, as shown in Fig 6.

The cement added in RWC1 and RWC2 are shown in Table 2. Also, the related compressive strength of concrete is shown in Fig 6. It is seen that, for example, for a 1-hour casting delay, by adding cement of 0, 7.01, and 14.01 kg/m3 (of the volume is of wet concrete mix) the related compressive strength is 17.31, 21.63, and 22.28 MPa respectively. The selection of the cement content is fully done on a random basis. Therefore, from the 'Least Square' method, as shown in Table 2 (for the current case, $C_n = 2.386S - 41.685$), the cement needed to gain the initial compressive strength (i.e. 19.47 MPa) is 4.77 Kg / m3 for a 1-hour casting delay. In the same manner for other intervals the cement needed to gain the initial compressive strength (i.e. 19.47 MPa) is calculated from the 'Least Square' method and the final result is placed in Fig. 7. A polynomial equation-1 $[with\ R^2 = 0.9902]$ can be proposed to relate the time of casting delay to the amount of added cement.

$$C_n = 0.2757T^4 - 2.0343T^3 + 1.2908T^2 + 20.918T - 15.827 \ldots (1)$$

Where, C_n = Cement needed (in Kg per m3 of wet volume of concrete) to achieve the initial compressive strength of concrete and, T= Casting delay from 1-4 hours.

Table 2: Cement added to the concrete having *crushed stone* as coarse aggregate

Delay (hr)	Cement added (kg/m³)			**Cement added model using the** 'Least Square' method
	RW	RWC1	RWC2	
0	0	0	0	--
1	0	7.01	14.01	$C_n = 2.386S - 41.685$
1.5	0	8.49	17.62	$C_n = 3.581S - 57.464$
2	0	8.91	19.74	$C_n = 4.869S - 75.443$
2.5	0	10.61	20.17	$C_n = 5.403S - 82.876$
3	0	11.04	21.87	$C_n = 5.691S - 84.399$
4	0	14.01	23.35	$C_n = 5.173S - 71.847$

Note: C_n is the cement needed to achieve the initial compressive strength of concrete, S

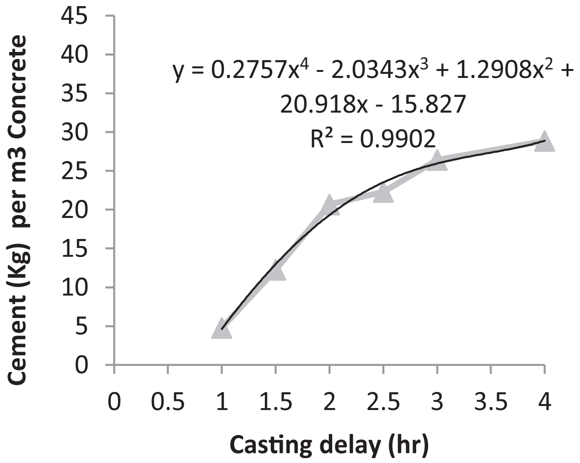

Fig 7: Cement needed to revive the initial compressive strength (19.47 MPa) of concrete having crushed stone as coarse aggregate with time.

4.3 Retempering effect on uncrushed-round stone concrete

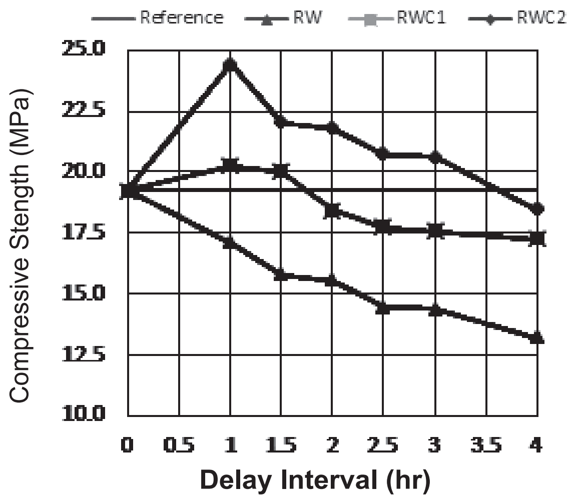

Fig 8: Change of Compressive strength of concrete having uncrushed-round stone as coarse aggregate with time resulting from RW, RWC1 and RWC2.

The compressive strength of concrete is diminished over time due to delay when retempered with water (RW), as illustrated in Fig 8. Compressive strength is reduced by 11.3% $\left(=\frac{19.26-17.08}{19.26}\times 100\right)$ after 1 hour and followed by 31.33% $\left(=\frac{19.26-13.23}{19.26}\times 100\right)$ after 4 hours delay of concrete casting. The average loss of strength per hour delay is 1.51 MPa $\left(=\frac{19.26-13.23}{4}\right)$ for a 4-hour casting delay. Retempering with water and cement in two doses (i.e. RWC1 and RWC2), strength is increased, maintaining the initial water-cement ratio and slump range (i.e. 0.63 and 150-175 mm, respectively). Thus, the strength is increased, compensating for the loss due to the delay, as shown in Fig 8.

The cement added in RWC1 and RWC2 is shown in Table 3. Also, the related compressive strength of concrete is shown in Fig 8. It is seen that, for example, for a 1-hour casting delay, by adding cement of 0, 12.09, and 17.40 kg/m³ (the volume is of wet concrete mix) the related compressive strength is 17.08, 20.26, and 24.42 MPa respectively. The selection of the cement content is entirely random. Therefore, from the 'Least Square' method, as shown in Table-3, (for the current case, $C_n = 2.315S - 37.838$), the cement needed to gain the initial compressive strength (19.26 MPa) is 6.75 Kg/m³ for a 1-hour casting delay. In the same manner for other intervals, the cement needed to gain the initial compressive strength (19.26 MPa) is calculated from 'the Least Square' method, and the final result is placed in Fig 9. A polynomial equation-2 $[with\ R^2 = 0.9919]$ can be proposed to relate the time of casting delay to the amount of added cement.

$$C_n = 0.5184T^2 + 4.8136T + 1.7983 \dots (2)$$

Where, C_n = Cement needed (in Kg per m³ of the wet volume of concrete) to achieve the initial compressive strength of concrete and, T= Casting delay from 1-4 hours.

Table 3: Cement added to the concrete having uncrushed-round stone as coarse aggregate

Delay (hr)	Cement added (kg/m^3)			Cement added model using the 'Least Square' method
	RW	RWC1	RWC2	
0	0	0	0	--
1	0	12.09	17.4	$C_n = 2.315S - 37.838$
1.5	0	13.1	18.9	$C_n = 3.044S - 48.029$
2	0	13.3	20.8	$C_n = 3.305S - 50.127$
2.5	0	14.4	22.2	$C_n = 3.536S - 50.197$
3	0	17.1	22.9	$C_n = 3.679S - 51.193$
4	0	20.1	25.5	$C_n = 4.905S - 64.808$

Note: C_n is the cement needed to achieve the initial compressive strength of concrete, S

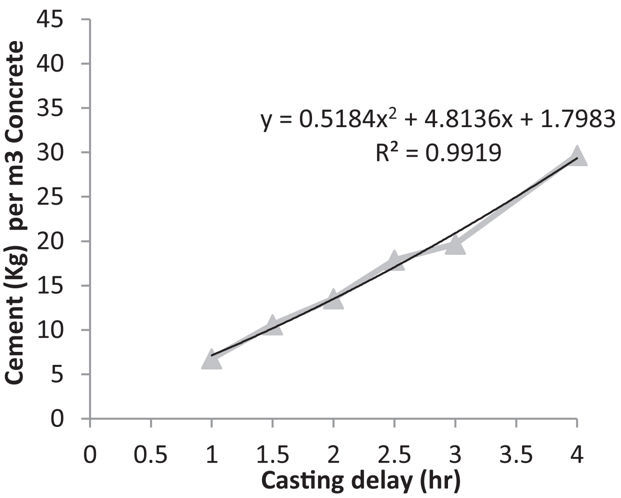

Fig 9: Cement needed to revive the initial compressive strength (19.26 MPa) of concrete having uncrushed-round stone as coarse aggregate with time.

4.4 Retempering effect on brick chips concrete

The compressive strength of concrete having brick chips as coarse aggregate is seen to be decreased due to retempering with water (RW) for casting delay, as presented by Fig 10. Strength is reduced by 3.47% $\left(= \frac{15.96-15.41}{15.96} \times 100\right)$ after 1 hour and followed by 20.32% $\left(= \frac{15.96-12.72}{15.96} \times 100\right)$ after 4 hours delay of concrete casting. The average loss of strength per hour delay is 0.81 MPa $\left(= \frac{15.96-12.72}{4}\right)$ for a 4-hour casting delay. After retempering with water and cement in two doses (i.e. RWC1 and RWC2), strength is increased, maintaining the initial water-cement ratio and slump range (i.e. 0.63 and 150-175 mm, respectively). So, strength is increased, overcoming the delay effect, as shown in Fig 10.

The cement added in RWC1 and RWC2 is shown in Table 4. Also, the related compressive strength of concrete is shown in Fig 10. It is seen that, for example, for a 1-hour casting delay, by adding cement of 0, 12.11, and 24.20 kg/m^3 (of the volume is of wet concrete mix) the related compressive strength is 15.41, 16.94, and 19.07 MPa respectively. The selection of the cement content is fully done on a random basis. Therefore, from the 'Least Square' method, as shown in Table 4 (for the current case, $C_n = 6.540S - 99.985$) the cement needed to gain the initial compressive strength (15.96 MPa) is 4.39 Kg/m^3 for a 1-hour casting delay.

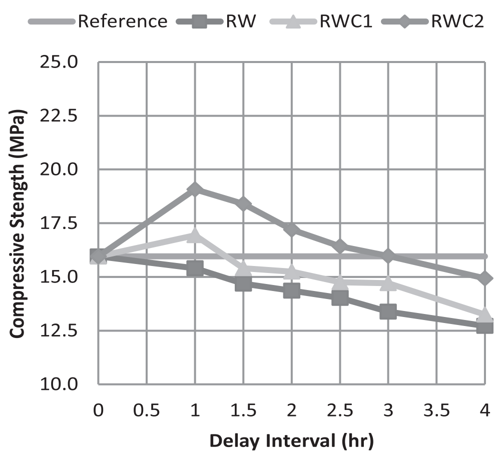

Figure 10: Change of Compressive strength of concrete having ***Brick chips*** as coarse aggregate with time resulting from RW, RWC1, and RWC2.

In the same manner for other intervals the cement needed to gain the initial compressive strength (15.96 MPa) is calculated from the 'Least Square' method and the final result is placed in Fig 11. A polynomial equation-3 $[with\ R^2 = 0.997]$ can be proposed to relate the time of casting delay to the amount of added cement.

$$C_n = 0.5825T^2 + 9.731T - 5.358 \ldots (3)$$

Where, C_n = Cement needed (in Kg per m^3 of the wet volume of concrete) to achieve the initial compressive strength of concrete and, T= Casting delay from 1-4 hours

Table 4: Cement added to the concrete having ***Brick chips*** as coarse aggregate

Delay (hr)	Cement added (kg/m^3) RW	RWC1	RWC2	Cement added model using the 'Least Square' method
0	0	0	0	--
1	0	12.11	24.2	$C_n = 6.540S - 99.985$
1.5	0	13.11	25.1	$C_n = 5.954S - 83.507$
2	0	13.16	25.69	$C_n = 8.590S - 121.031$
2.5	0	13.34	27.3	$C_n = 10.846S - 149.861$
3	0	15.5	27.81	$C_n = 10.760S - 143.596$
4	0	16.14	29.51	$C_n = 12.006S - 148.449$

Note: C_n is the cement needed to achieve the initial compressive strength of concrete, S

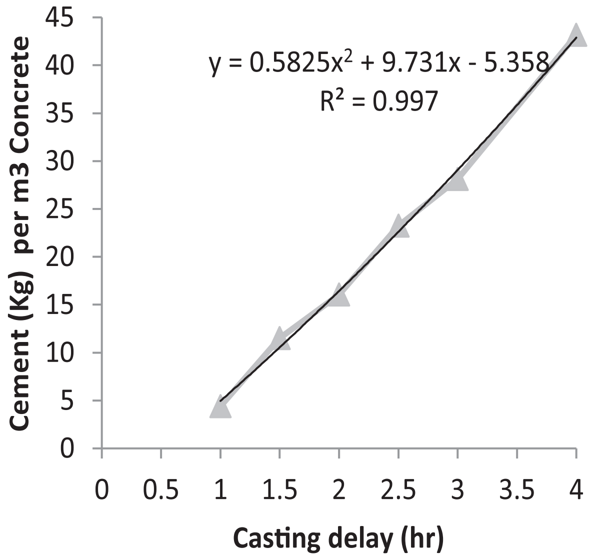

Figure 11: Cement needed to revive the initial compressive strength (15.96 MPa) of concrete having ***Brick chips*** as coarse aggregate with time.

5. Comparison of the results of retempering:

Having the same mix ratio (i.e. 1:2:3) the concretes of crushed stone, uncrushed round stone, and brick chips have different initial strengths (i.e. 19.47, 19.26, and 15.96 MPa, respectively). The cement needed to regain the initial compressive strength is the lowest for crushed stone and the lowest for brick chips. Crushed stone, generally has angular and rough surfaces, providing better interlocking and bonding with the cement paste. This enhanced interlocking contributes to higher strength development having relatively lower additional cement under casting delay. Rounded surfaces of uncrushed round stone offer less interlocking potential, requiring more cement paste to make bond and to achieve adequate strength. Lower crushing value and potential voids of brick chips can reduce the efficiency of cement paste utilization, leading to a need for more cement to achieve the initial strength. The lower cement requirement for crushed stone to regain initial compressive strength compared to uncrushed round stone and brick chips can be attributed to factors like particle shape, size distribution, mineral composition, and water absorption. These factors collectively influence the efficiency of cement paste utilization and the overall strength development of the concrete.

6. Conclusion

Casting delay is an unexpected situation in construction sites that may result in economic loss [28], quality deterioration [29], mismatch in time scheduling [30], material and time wastage [31], legal and even contractual penalties [32], and so on. To reduce especially the time and material wastage retempering is a common practice [33-35]. There is no pure guideline for scientific retempering in concrete casting delay. This study it has been tried to generate some experimental data by which at least some information can be got for more research in this field. The concluding remarks of the study are:

A. Under the retempering only by water (i.e. RW) the average loss of concrete compressive strength per hour delay is 1.36 MPa, 1.51 MPa, and 0.81 MPa where crushed stone, uncrushed round stone, and brick chips were used as coarse aggregate, respectively.

B. For retempering, both water and cement (in Kg/m^3) are estimated and presented in Section 4 for the concrete of all three types of coarse aggregates.

C. Additionally, three empirical equations (1-3) are proposed where the amount of necessary cement (in Kg/m^3) to regain the initial compressive strength is the function of a casting delay of up to 4 hours. Such relations may be useful for professionals to use on-site. The equations were developed based on experimental data. Besides, no validation work was done to justify the equations' accuracy level. This can be considered as a limitation of the study.

D. The study is conducted only for the PCC cement having a fixed mix ratio, water-cement ratio, slump range, and the properties mentioned in Table 1. Changes in those inputs can also change the test result.

E. The findings of this study may serve as a foundational reference for more studies with a comprehensive understanding of this field.

7. Acknowledgement:

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8. Conflicts of interest

The authors affirm that there are no conflicts of interest regarding the publication of this paper.

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