Effect of Steam Curing on the Properties of High Early Strength Silica Fume Concrete

Ramesh Nayaka¹, Diwakar G S²*, Virupaxappa Gudur³

¹Centre for Innovative Construction Technology (CICT), Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia
²Department of Civil Engineering, Manipal Institute of Technology, Manipal University, Manipal, 576104, Karnataka, India
³Department of Civil Engineering, Navodaya Institute of Technology, Raichur, 584103, Karnataka, India
Email: diwa0630@gmail.com

Abstract. Recently, tremendous changes in project delivery methods in construction industry and still way looking towards acceleration of construction works. In this connection FastTrack construction method is current trend in construction industry. In this method, it is challenging task to delivery project at shortest time without compromising on quality and curing. Generally, conventional method of concrete curing need 28 days to be hardened and then can remove formwork however this method delays the project completion and does not holds good in precast construction. In this context, there is need for accelerating curing to attain early strength then can remove formwork early and to reduce the cycle time and increase the formwork repetitions. Henceforth, in this study attempts to attain 50 mm slump and achieve high early strength of 50 MPa at 7 days by adopting steam curing method for silica fume concrete. The concrete mixes were designed according to ACI – 211.4R – 08 and water to cement ratio was set 0.27. Three trail mixes were prepared in different cases one without silica fume, another with silica fume and finally, silica fume with addition of admixture to achieve targeted workability and strength. The results obtained in this study shows that compressive strength achieved 45.16 MPa after 72 hours curing and 51 MPa at 7 days of curing. Moreover, it was important to notice that an increase in the early strength gain due to effect of steam curing and steam curing method affects the ultimate strength of silica fume concrete. Besides, the delay period before steam curing is very essential for the early strength gain.

1. Introduction

Portland cement concrete is familiar to everyone. Concrete is used as a construction material in everything from dams to skyscrapers, as well as concrete pavement. Concrete is made up of three basic components: water, aggregate (rock, sand, or gravel) and Portland cement. The water hydrates the cement to form a gel that holds all the aggregate together. Curing plays an important role on strength development and durability of concrete. Curing takes place immediately after concrete placing and finishing, and involves maintenance of desired moisture and temperature conditions, both at depth and near the surface, for extended periods of time. Properly cured concrete has an adequate amount of moisture for continued hydration and development of strength, volume stability, resistance to freezing and thawing, and abrasion and scaling resistance [1].
Recently, tremendous changes are happening in project delivery methods in construction industry and fast-track construction method is the current trend in construction industry. In this method, it is a challenging task to deliver a project at shortest time without compromising on quality and curing. Generally, conventional method of concrete curing need 28 days to be hardened and then formwork can be removed, however this method delays the project completion and does not hold good in precast construction. In this context, there is need for accelerating curing to attain early strength so that formwork can be removed early and to reduce the cycle time and increase the formwork repetitions. Steam curing is a method for accelerated curing whereby concrete is cured in hot steam to obtain the required strength early. Concrete that has been subjected to steam curing is called steam-cured concrete. The primary reason for using steam in the curing of concrete is to produce a high early strength. This high early strength is very desirable to the manufacturers of precast and pre-stressed concrete units which often require expensive forms or stress beds. They want to remove the forms and move the units to storage yards as soon as possible the minimum time between casting and moving the units is usually governed by the strength of the concrete. Steam curing accelerates the gain in strength at early ages but the uncontrolled use of steam may seriously affect the growth in strength at later ages.

The objective of the study the effect of steam curing on high strength Portland cement concrete and desired to achieve strength of 60 MPa compressive strength at 7 days and a slump of 50 mm. The design high strength cube specimens to be subjected to controlled steam curing and attained strength to be reported after periods of 4, 8, 12 and 72 hours. The concrete mixes were designed according to ACI – 211.4R – 08 and water to cement ratio was set 0.27.

2. Materials and Methods

2.1. Materials
Cement used for the mix was Coromandel King OPC grade 53 cement compiles with ASTM C150-14. The physical properties and setting time of cement is given in Table 1: In this study two different grades of aggregate were used for the mixture of concrete. Aggregate passing through 16 mm and retained on 12.5 mm along with aggregate passing through 40 mm and retained on 20 mm sieve. The physical properties of fine and coarse aggregates presented in Table 2:

| Table 1. Properties of Cement                      |   |
|---------------------------------------------------|---|
| Specific Gravity                                  | 3.51 |
| Fineness                                          | 165 kg/m² |
| Initial Setting Time                               | 70 min |
| Final Setting Time                                 | 335 min |

| Table 2. Properties of Aggregates                  |   |
|---------------------------------------------------|---|
| Properties                                        | Fine Aggregate | Coarse Aggregate |
| Specific Gravity                                  | 2.59 | 2.83 |
| Fineness Modulus                                  | 3.75 | 3.17 |

The mix design was performed based on design procedure specified in ACI 211.4R - 08 [2] as a guide for selecting proportions for high-strength concrete using ordinary Portland cement and other cementitious materials. ASTM C-143 – 14 [3] has been referred to for performing slump cone test. The base mix design chosen for optimization was a high strength concrete grade of M80 designed using the guidelines provided in ACI211.4R-08[2]. The target strength was 50 MPa at 7 days. The design used
was observed to give a higher strength by steam curing effect. Keeping all the other parameters constant, the cement content was modified and 10% by weigh of silica fume replaced with cement in order to obtain the target 7-day strength. The details of mix design adopted is provided in Table 3. The steps followed in this investigation is shown in figure 1.

Table 3. Details of mix design and the content of each material for different mixes

| Trial No. | Cement (kg/m³) | Fly Ash (kg/m³) | Silica Fume (kg/m³) | Sand (kg/m³) | Coarse Aggregate (kg/m³) | Water (kg/m³) | w/c ratio | Super plasticizer (%) |
|-----------|----------------|----------------|---------------------|--------------|------------------------|---------------|----------|----------------------|
| 1         | 472.50         | 157.50         | -                   | 492.10       | 730.20                 | 486.80        | 165.31   | 0.27                 |
| 2         | 567.00         | -              | 63.00               | 492.10       | 730.20                 | 486.80        | 165.31   | 0.27                 | 0.8          |
| 3         | 630.00         | -              | -                   | 492.10       | 730.20                 | 486.80        | 165.31   | 0.27                 |             |
| 4         | 567.00         | -              | 63.00               | 492.10       | 730.20                 | 486.800       | 165.31   | 0.27                 | 0.8          |

Figure 1. Methodology followed for the study

3. Materials and Methods

3.1. Fresh State

3.1.1. Slump Test. Slump test was conducted based on the method specified by ASTM C-143 [3] the slump cone test set up as shown in figure 2. The slump cone was filled in three layers with each layer tamped 25 times using a tamping rod. The surface was levelled by rolling the tamping rod over the top surface of the cone. The cone was removed vertically and the drop-in height of the concrete was measured.
3.2. Curing condition
In order to study the effects of steam curing cycles on the hardened properties of high strength concrete mixture, total time of steam curing was considered, curing chamber is shown in figure 3 and temperature effect with respect to duration is shown in figure 4. In addition, the mist curing also tested for the comparison.

![Figure 2. Slump cone test setup](image)

![Figure 3. Steam curing chamber](image)

![Figure 4. Process of steam curing](image)
3.3. Hardened state
The compressive strength was performed at three days and seven days on a computerized compression testing machine of a capacity of 3000 KN tested according to BS EN 12390-3:2009[4]. Cubes sizes of 150mm were used for the test. The testing set up is shown in figure 5.

![Testing setup for compressive strength of concrete specimens](image)

**Figure 5.** Testing setup for compressive strength of concrete specimens

4. Results and Discussion
The weight and three and seven day’s strength of the cubes tested for trail mixes are as shown in Table 3 & Table 4. The curing effect on concrete at 4, 8, 12 and 72 hours is shown in Table 5. It was observed that the mixes with 25% of fly ash obtained 28.15 MPa and 36.60 MPa at 3 and 7 days respectively and attained results were not met the desired strength therefore in second trial 10% of silica fume added to concrete instead of fly ash. It was observed that there was enhancement in the strength of 4 MPa and 8 MPa, hence same mix was adopted (trial mix 4) and compared with control mix (trial mix 3) for achieving desired strength. However, the strength obtained 44.31 MPa and 52.44 MPa at 3 and 7 days respectively for without additive mix whereas 39.23 MPa and 51.03 MPa obtained for 10% silica fume concrete.

| Sl. No. | Trial Mix 1 (With 25% fly ash) | Trial Mix 2 (With 10% Silica fumes) |
|---------|-------------------------------|-----------------------------------|
|         | Weight in kg | Comp. Strength (MPa) | Sl. No. | Duration | Weight in kg | Strength (MPa) |
| 1       | 2.383 | 28.21 | 1 | 3 days | 2.475 | 32.86 |
| 2       | 2.4  | 29.19 | 2 | 3 days | 2.367 | 28.46 |
| 3       | 2.444 | 27.06 | 3 | 3 days | 2.451 | 35.68 |
| 4       | Average | 28.15 | | Average | 32.33 | |
| 5       | 2.465 | 37.35 | 4 | 3 days | 2.422 | 44.72 |
| 6       | 2.498 | 35.85 | 5 | 3 days | 2.428 | 49.3 |
| 6       | Average | 36.6 | | Average | 39.43 | |

**Table 3.** Compressive strength of fly ash and silica fumes concrete mixtures
Table 4. Compressive strength of control and silica fumes mixtures

| Sl. No. | Duration | Weight (kg) | Comp. Strength (MPa) | Sl. No. | Duration | Weight (kg) | Comp. Strength (MPa) |
|---------|----------|-------------|----------------------|---------|----------|-------------|----------------------|
| 1       | 3 days   | 2.584       | 46.81                | 1       | 3 days   | 2.491       | 41.71                |
| 2       | 3 days   | 2.529       | 43.59                | 2       | 3 days   | 2.491       | 40.85                |
| 3       |          | 2.485       | 42.54                | 3       |          | 2.521       | 35.13                |
|         | Average  | 44.31       |                       |         | Average  | 39.23       |                      |
| 4       | 7 days   | 2.513       | 50.02                | 4       |          | 2.490       | 51.47                |
| 5       | 7 days   | 2.536       | 54.93                | 5       | 7 days   | 2.491       | 51.6                 |
| 6       |          | 2.604       | 52.38                | 6       |          | 2.510       | 50.01                |
|         | Average  | 52.44       |                       |         | Average  | 51.03       |                      |

On the effect of mist curing condition, the strength obtained were 32.44 MPa, 32.60 MPa, 35.19 MPa and 45.16 MPa at 4 hrs, 8 hrs, 12 hrs and 72 hrs respectively is shown in Table 5. Observations show that effect of mist curing doesn’t have significant influence on strength enhancement [4].

Table 5. Compressive strength of mist curing concrete specimens

| Sl. No. | Duration of Mist Curing | Weight in kg | Strength Mpa |
|---------|-------------------------|--------------|--------------|
| 1       | 4 hours                 | 2.702        | 32.59        |
| 2       | 4 hours                 | 2.605        | 30.62        |
| 3       | 4 hours                 | 2.607        | 34.11        |
|         | Average                 | 2.564        | 29.30        |
| 4       | 8 hours                 | 2.593        | 34.01        |
| 5       | 8 hours                 | 2.605        | 34.50        |
|         | Average                 | 2.63         | 38.16        |
| 4       | 12 hours                | 2.548        | 33.1         |
| 5       | 12 hours                | 2.52         | 34.31        |
|         | Average                 |              | 35.19        |
| 4       | 72 hours                | 2.602        | 45.54        |
| 5       | 72 hours                | 2.514        | 49.52        |
| 6       | 72 hours                | 2.663        | 40.43        |
|         | Average                 |              | 45.16        |

On the effect of mist curing condition, the strength obtained were 32.44 MPa, 32.60 MPa, 35.19 MPa and 45.16 MPa at 4 hrs, 8 hrs, 12 hrs and 72 hrs respectively is shown in Table 5. Observations show that effect of mist curing doesn’t have significant influence on strength enhancement [4].

The compressive strength test was conducted on 150 mm cube specimens immediately after steam curing and at the ages of 3 and 7 days. The results are presented in figure 6. It was observed that the steam curing condition the strength after 4 hrs of curing obtained 32 MPa and there was not much changes at 8 hrs and lower or no change in compressive strength due to delay time and increase in pre-curing period. Furthermore, 12 and 72 hrs the strengths obtained were 35 MPa and 45 MPa respectively this result indicates that increase in temperature and total cycle time of steam curing led to higher compressive strength due to the accelerated hydration reactions and rapid formation of.
calcium – silica – hydrate (CSH) gel which is most important bind phase in hardened state of concrete. Mist and steam curing had achieved similar results [5].

\[\text{Figure 6. Compressive strength vs duration with the effect of steam curing}\]

The percentage gain in the strength due to effect of steam curing with respect to duration is as shown in Figure 7. It can be seen from the figure that due to effect of steam curing achieved early strengths. After 3 & 7 days of water cured specimen under went for steam curing and achieved 83% of strength after 4 hrs of steam curing whereas after 7 days curing obtained only 64%. At the end of 72 hrs 3 days cured specimen achieved 115% of total strength but 7 days cured specimen obtained only 88%. The obtained results clearly shows that the effect steam curing have highly influenced after 3 days curing than the 7 days curing. The tested specimens were failed in general failure is shown in figure 8.

\[\text{Figure 7. Percentage gain in compressive strength vs duration}\]
Figure 8. Failure pattern of specimen

5. Conclusions

In this study, investigated influence of steam curing on early age high strength concrete and through investigation results can be concluded as follows:

- There was enhancement in the early compressive strength due to effect of steam curing, however delay period before steam curing is very essential for the early strength gain.
- The steam curing influencing the ultimate high strength of concrete.

6. References

[1] Malyuta, D. A., Khalafalla, M., & Wu, W. (2013). Review of Different Construction and Building Materials used before 21st Century in Africa Compared to the Present Situation after 21st Century.

[2] ACI211.4R – 08, Guide for Selecting Proportions for High Strength Concrete Using Portland Cement and Other Cementitious Materials, American Concrete Institute, Farmington Hills, USA, 2008.

[3] ASTM C143 / C143M-15a, Standard Test Method for Slump of Hydraulic-Cement Concrete, ASTM International, West Conshohocken, PA, 2014.

[4] BS EN 12390–3; Testing Hardened Concrete – Compressive Strength of Test Specimens (2009), London, UK

[5] Yazıcı, H. (2007). The effect of curing conditions on compressive strength of ultra high strength concrete with high volume mineral admixtures. Building and environment, 42(5), 2083-2089.

[6] Yazıcı, H. (2008). The effect of silica fume and high-volume Class C fly ash on mechanical properties, chloride penetration and freeze–thaw resistance of self-compacting concrete. Construction and Building Materials, 22(4), 456-462.

Acknowledgments

The financial support from Manipal University to conduct this research work is acknowledged.