Effect of Different Curing Techniques on Compressive Strength of High Strength Self Compacting Concrete

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ABSTRACT: In this paper variation in compressive strength of high strength, self compacted concrete by curing with 3 different techniques is discussed. First of all several trials were carried out for appropriate mix design to create self compacting and high strength concrete. Three batches of concrete cylinders consisting of 24 cylinders in each batch were cast as per ASTM standard. Slump Test and Flow Test were carried out on each batch in order to ascertain concrete flow for self compacting concrete. Mix. ratio, water cement ratio and admixture dose were kept constant as calculated by Mix. Design. First batch, declared as control, was cured in a temperature controlled curing tank in the laboratory. The second batch was cured under prevailing site conditions. The 3rd batch was cured by the application of a curing compound. From each batch, 6 cylinders were tested for compressive strength at 3-day's age, 6 at 7 day's age and 12 for 28 day's age of concrete and average values were taken. Results were analyzed and graphs were drawn. It was noted that 28-days compressive strength of cylinders cured under site conditions was 89 % of the compressive strength of cylinders cured in water tank in the laboratory (i.e., 11 % less). Similarly compressive strength of cylinders cured by applying curing compound was 93 % of the compressive strength of cylinders cured in the laboratory (i.e., 7% less). So it was concluded that in areas with shortage of water, curing compounds can be effectively used with improved strength and sustainability of water.

1 INTRODUCTION

A devastating earthquake, measuring 7.6 on the Richter scale, hit the northern part of Pakistan on the morning of 8th October, 2005. With the death toll of about 90 thousands and injuries in the same range, it is a catastrophe on a scale never before seen in this region. The earthquake also resulted in destruction of all types of buildings and other infrastructure. An extensive investigation in the form of core testing and other non destructive testing on affected RCC structures revealed causes of failure as:

(a) Non-seismic design of structure
(b) Poor concrete strength
(c) Segregation due to poor compaction
(d) Poor curing due to shortage of water

So, in order to get sustainability of building materials during such disasters, self-compacting, high strength concrete along with revision of prevailing building codes in accordance with formation of new seismic zones looks inevitable. Since more than 20 years, high strength concretes with compressive strength ranging from 50 N/mm^2 to 130 N/mm^2 have been used worldwide in tall buildings and bridges with long spans or buildings in aggressive environment. Building elements made of high strength concrete are usually densely reinforced. The small distance between reinforcing bars may lead to defects in concrete. If high strength concrete is self-compacting, the production of densely reinforced building elements from high strength concrete with high homogeneity would be an easy work (Ma, et al. 2003).

The so-called self-compacting concrete is considered a concrete that can be placed and compacted under its own weight with little or no vibration effort, ensuring better filling of the formwork even when access is difficult. The development of concrete that has not to be vibrated is a building industry challenge, since the related energy saving improves its sustainability; the reduction in noise and health hazards improves the working environment, and freeing from workmanship skill improves the quality of the final product (Corinvaldest, et al. 2004).

Historically, curing requirements have been based on strength considerations. For Example, in the 1940s, The ASTM standard specification for the curing of Portland cement concrete contains the following requirement (ASTM 1945):

"*The concrete shall be so cured that the compressive or flexural strengths of specimens of the concrete 28 days old, are not less than 90 % of the strength of 28-day-old specimens of the same concrete cured in moist air at a constant temperature of 21 ^{0}C (70 ^{0}F)".*

Obviously for a given concrete, the curing conditions play a major role in the strength development of the concrete as it matures over time. The specified design strength of concrete, $fc^/$, is the basis for the design and construction of reinforced concrete structures. Concrete being placed in the field is sampled and tested under standardized procedures to ensure that it meets the required strength criteria. However, this testing only assures that the concrete delivered to the site has the required strength potential (Kenneth et al. 1999). Curing requirements are established to provide the necessary moisture and temperature conditions in the field for adequate strength development after concrete placement. Currently, U. S. curing requirements are based on research and experience with concrete having compressive strengths less than about 40 MPa. (Carnio, et al. 1991). Studies on the low water-cement ratio concretes now in use are needed to determine, if these curing requirements are appropriate for these new concretes. The latest version of the report of ACI Committee 308 on curing of concrete (ACI 308 1992) simply states that curing is necessary for the development of both strength and durability.

Different regions in our world face shortage of water during dry season, thus affecting proper curing. In this paper, research regarding curing of high strength, self-compacting concrete with the help of certain chemicals is discussed and benefits thus obtained are compared with traditional field curing. At the end, sustainability of building materials in case of destructive earthquakes and shortage of water in normal situations is discussed.

2 MATERIALS

2.1 *Cement*

A commercial portland-limestone cement (ASTM Type I) was used. Fineness of cement was 327.5 m^2/kg and its specific gravity was 3050 kg/m^3. The chemical composition of cement as analyzed by XRF-cement spectrometer/cement analyzer is reported as under:

SiO_2	20.29 %
Al_2O_3	5.26 %
Fe_2O_3	3.00 %
CaO	62.4 %
MgO	2.62 %
Na_2O	0.27 %
SO_3	2.51 %
K_2O	0.98 %
TiO_2	0.33 %
Mn_2O_3	0.04 %

2.2 *Aggregate*

The coarse aggregates used were natural gravels from Margalla hills of Pakistan with a maximum size of ¾", and fine aggregate (6 mm maximum size) was natural sand from Lawrancepur Pakistan, the grading of both conforming to ASTM C 33-93.

2.3 *Admixture*

A water-reducing admixture was added in each concrete mixture in order to achieve high strength and adequate workability level for concrete to be self-compacting. In this research, Glenium-51 was used for this purpose. It was applied @ 750 ml/bag of cement.

2.4 *Curing Compound*

Antisole-e-white pigment from Sika complying with ASTM C309 Type II Class A was applied on the surface of cylinders @ 5 m^2/liter.

3 CONCRETE MIX. DESIGN

Various test batches of concrete mixes were first prepared for the production of high strength self compacting concrete. Finally the following ratios were selected to achieve the 6000psi 28 day's strength:

Mix. Ratio	= 1 : 1 : 2
Water Cement Ratio	= 0.27
Admixture	= Glenium-51 @ 750 ml/bag of cement.

4 EXPERIMENTAL PROGRAM

4.1 *Casting Schedule*

Batch	No. of Cylinders	Curing Method
1	24	In Water Tank
2	24	Under Site Conditions
3	24	With Curing Compound
Total	72	

Cylinders (300 mm high, 150 mm diameter) were cast in the laboratory. Cylinders were cured under different curing conditions and then tested for compressive strength.

4.2 *Curing Methods*

(a) Water Tank
24 cylinders were stored at a temperature of 20^{o}C and relative humidity 90% for 24 hours. At the end of this period, the cubes were cured in a temperature controlled water bath up to their testing (Kenneth et al. 1999). The compressive strength of these cylinders was taken as ‘controlled’ in this research.
(b) Site Conditions
24 cylinders were cured under prevailing site conditions. They were cast and placed on a construction site. These were cured by sprinkling water along with curing of some in-situ full-scale concrete members (Kenneth et al. 1999).
.(c) Curing Compound
24 cylinders were cured by coating “Antisole-e-white pigment” from Sika complying with ASTM C 309, Type II, Class A, @ 5 m^2/liter on the surface of cylinders (Kenneth et al. 1999).
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4.3 *Slump Test*

Slump test was carried out for each batch just after mixing according to BS 1881: Part 102:1983 or ASTM C 143-90a. The mould used was a frustum of a cone, 12 in (300 mm) with the smaller opening at the top and filled with concrete in three layers. Each layer was tamped 25 times with a standard 16 mm. diameter steel rod. The cone was slowly lifted and attempt was made to measure the decrease in the height of the slumped concrete. However, incase of all three batches, the cone collapsed due to high fluidity and slump could not be measured. It was confirmation of the concrete to be self-compacting.

4.4 *Flow Test*

This test was originally developed in Germany in 1933. Now, it is included in British Standard as BS 1881: Part 105: 1984. This test is typical for concrete of high workability and in recent years has become more widely used for flowing/self-compacting. The three concrete batches prepared in our work were also subjected to flow test. The average flow values obtained for all three batches were more than 550 mm, thus indicating a flowing concrete.

4.5 *Compressive Strength Test*

For compressive strength of concrete, 72 cylinders (300 mm high with 150 mm diameter) were cast in accordance with ASTM C 192-90a or BS 1881: Part 110:1983. The cylinders were tested in a 3000 KN Compression Testing Machine. Moulds were filled in 3 layers; each layer compacted by using a vibrating table. From each batch, 6 cylinders were tested at 3-days, 6 at 7-days and remaining 12 at 28-days age.
In the compression test, the cylinders were placed with the plain faces in contact with the platens of the testing machine. The load was applied at a constant rate of stress to 0.2 to 0.4 MPa/second (3 to 60 psi/second). When cylinders failed, load was noted and stress calculated in MPa.

5 RESULTS & DISCUSSIONS

Figures 1, 2, & 3 show comparison of compressive strength of three batches of concrete cured by different curing techniques at 3, 7, & 28 days respectively.

5.1 *3-day’s Compressive Strength*

As far as 3-days compressive strength is concerned, curing under site conditions is 75.83% of lab curing (about 24.17 % less) while curing by curing compound is 83.98 % of lab curing (16.02 % less).

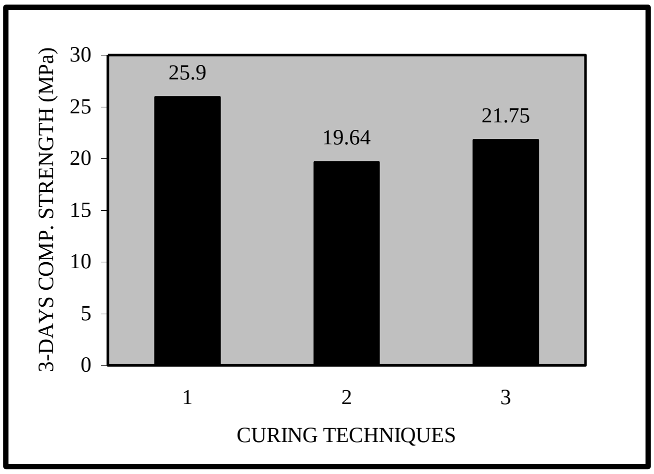

Figure 1: 3-days compressive strength of 3 batches

5.2 *7-day's Compressive Strength*

In case of 7-days compressive strength, curing under site conditions is 87.66 % of lab curing (about 12.34 % less) while curing by curing compound is 93.18 % of lab curing (6.82 % less).

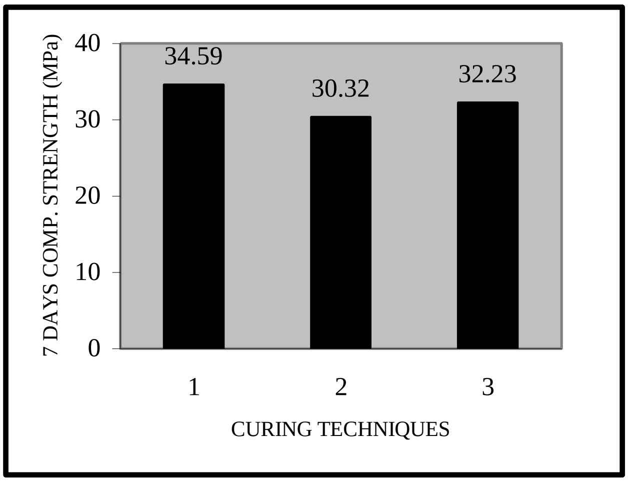

Figure 2: 7-days compressive strength of 3 batches

5.3 *28-day's Compressive Strength*

In case of 28-days compressive strength, curing under site conditions is 89.0 % of lab curing (about 11.0 % less) while curing by curing compound is 93.0 % of lab curing (7.0 % less). Compressive strength of specimens cured by the surface application of chemical compound is decidedly greater than 90 % of that of cured ideally in water tank.

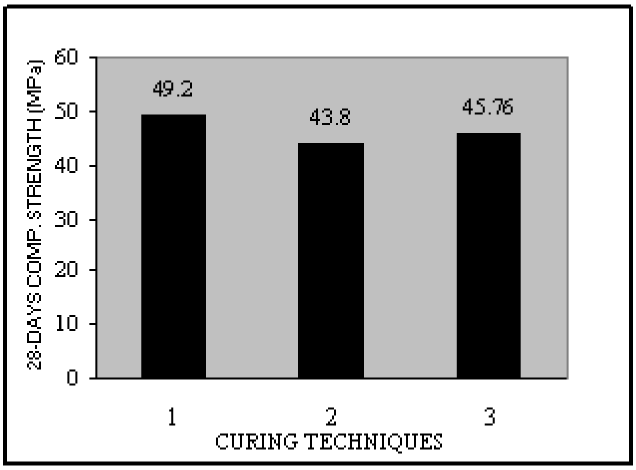

Figure 3: 28-days compressive strength of 3 batches

Results show that use of curing compound gives more strength as compared to curing in normal site conditions. Reason for this is that curing compound efficiently retards the loss of moisture while during site curing in the form of water sprinkling; moisture evaporates rapidly due to direct contact with air and day's high temperature.
It is also observed that in case of 3-day's compressive strength, difference between compressive strength of laboratory curing and other methods is more as compared to 7-day's and 28 day's compressive strength. Argument for this behavior is that during early age, rate of loss of moisture is faster in curing techniques other than full immersion in case of water tank. So hydration of cement slows down in these cases. But as the age of concrete increases, hydration process continues and compressive strength of field curing approaches close to that of water tank curing.

5.4 *Cost Analysis*

The cost comparison between curing under site conditions and that with the help of chemical compounds actually depends upon the availability of water. If water is available in plenty, obviously curing with chemical compounds is more costly. However, if there is shortage of water, curing with the help of chemical compounds can be adopted with confidence. Also it is associated with additional advantage of increase in compressive strength along with sustainability of water.

6 CONCLUSIONS

(a) During natural disasters resulting in tremendous destruction, sustainability of building materials in concrete structures can be ascertained in the following ways:

- By using improved and seismic oriented design methods.
- By using high strength concrete.
- By using self-compacting concrete in designs of congested reinforcement and thus reducing segregation & hone-combing.

(b) In areas with shortage of water, sustainability of water can be achieved by using suitable chemical compounds for curing of concrete.

(c) Additional compressive strength can also be achieved by using chemical compounds for curing.

(d) In early ages, difference between compressive strength of laboratory curing and other methods is more as compared to 28 day's compressive strength.

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