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Recurring as a Means of Partial Strength Recovery of Concrete Subjected to Elevated Temperatures

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***Abstract*—**Concrete is found to undergo degradation when subjected to elevated temperatures and loose substantial amount of its strength. The loss of strength in concrete is mainly attributed to decomposition of C-S-H and release of physically and chemically bound water, which begins when the exposure temperature exceeds 100°C. When such a concrete comes in contact with moisture, the cement paste is found rehydrate and considerable amount of strength lost is found to recover. This paper presents results of an experimental program carried out to investigate the effect of recuring on strength gain of OPC concrete specimens subjected to elevated temperatures from 200°C to 800°C, which were subjected to retention time of two hours and four hours at the designated temperature. Strength recoveries for concrete subjected to 7 designated elevated temperatures are compared. It is found that the efficacy of recuring as a measure of strength recovery reduces with increase in exposure temperature.

***Keywords*—**Elevated Temperature, Recuring, Strength Recovery, Compressive strength.

I. Introduction

CONCRETE is a very popular construction material and it finds its application in almost all the civil engineering disciplines. It's characteristics such as mouldability and high compressive strength has made it a versatile building material. Concrete offers good resistance to heat because of its low conductivity and incombustible nature and further, no toxic fumes are emitted from concrete surface when it is heated. Because of all these characteristics concrete can be rated as the best building material as far as resistance to elevated temperature is concerned

The concrete basically consists of two phases, the aggregate phase and the hardened cement paste phase. There is a thermal incompatibility between the aggregate phase and hardened paste phase which initializes the cracking process when the concrete is heated [1]. The cement paste begins to the dehydrate at about 110°C [2] and as the temperature rises above 300°C there will be subsequent decomposition of $Ca(OH)_2$ and the calcium silicate hydrates as the temperature progresses above 600°C [3].

The tendency of aggregates is to expand due to high temperature before disintegration. This differential thermal expansion between aggregates and cement paste leads to surface crazing which further leads to deeper cracking [4]. Aggregate stability has a major influence on performance of concrete at elevated temperature and the deterioration [5], [6]. The differential thermal expansion combined with decomposition of CSH gel leads to deterioration of ITZ, which is one of the major causes of deterioration of concrete strength [7], [8].

Whenever structural concrete is subjected to elevated temperatures its effects can be visualized in the form of surface cracking, spalling, and disintegration that render the concrete structure unserviceable. The damaged concrete surface is usually repaired by removing the weak layers of concrete (or where the cement paste has lost significant amount of binding property) and their replacement with fresh concrete. But studies conducted by [8], indicate any thermally damaged concrete has the tendency to recover the lost strength by rehydration whenever the concrete is exposed to moist environment. In their studies they found the concrete to recover almost 80% of its original strength in the span of about 12 months. Studies on similar lines were carried out by [9], wherein the thermally deteriorated concrete were subjected to air and water curing. It was found that if the thermally exposed concrete is given constant moisture supply the concrete rehydrates itself to recover the strength and durability.

The strength deterioration of concrete is attributed to the coarsening of pore structure and opening of the capillaries, due to dehydration of the gel, that were initially filled by the hydration products. When moisture is supplied to such concrete partial rehydration of cement paste will take place and the capillaries created due the elevated temperature exposure will be refilled by rehydration process [10]. This rehydration is expected to result in regain of certain amount of its lost original strength. The compressive strength of certain cement pastes does not reduce much even up to 500°C or higher [11]. This paper presents the results of the effect of 7, 14, 28 and 56 days of water recuring of thermally deteriorated OPC concrete cubes (100 mm) on their compressive strength.

II. Experimental Methodology

Ordinary Portland Cement 43 grade with brand name ACC was used for preparing the concrete specimens. The chemical composition of the cement is given in Table I. River sand conforming to zone 3 (I.S 383-1970 grading requirements) with specific gravity 2.65 was used. Coarse aggregates with specific gravity 2.77 satisfying I.S 383-1970 [12] grading requirements for graded aggregates were used. The mix proportion is given in Table II.

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TABLE I
CHEMICAL COMPOSITION OF CEMENT

Soluble Silica (%)	21.6
Alumina (%)	5
Iron Oxide (%)	3.7
Lime (%)	63.1
Magnesium (%)	0.8
Insoluble Residue (%)	1.8
Sulphur (Sulphur Trioxide) (%)	2.1
Loss On Ignition (%)	2
Chloride Content (%)	0.01

TABLE II
MIX PROPORTION

Water	Cement	Fine Aggregate	Coarse Aggregate	
0.45	1	1.198	2.23	
			10mm	20mm
			0.877	2.046

The concrete was mixed in a concrete mixer and poured into moulds of size 100mm x 100mm x 100mm. After 24 hours the concrete cubes were demoulded and cured for 28 days under water. The concrete cubes were subjected to elevated temperature in an electric oven target temperature range was 200°C to 800°C at an interval of 100°C. The temperature build up during test was as shown in Fig. 1. The temperature time gradient steepens up to 400°C around 20°C/min and flattens gradually above 400°C is at rate of 7°C/min.

After the target temperature was reached the specimens were maintained at that temperature for duration of 2 hrs in order to achieve thermal steady state. The furnace was switched off and the specimens were left in the furnace until the interior of the furnace reached room temperature. One set (3 nos.) of specimen was tested to evaluate the strength retained after exposure to elevated temperatures. The naturally cooled specimens were then immersed in water for recuring for 7, 14, 28 and 56 days. Destructive testing was done for one set on 7th, 14th and 28th day to evaluate the strength gain after recuring. The residual strength after recuring was compared against the strength of concrete at ambient temperature.

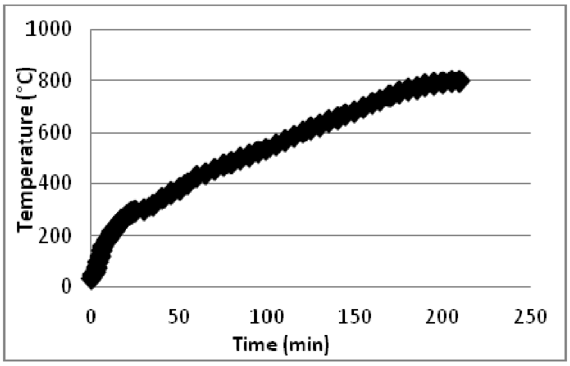

Fig. 1 Time temperature curve

III. RESULTS AND DISCUSSIONS

A. Visual Observations

Fig. 2 shows the surface of concrete exposed to 800°C along with the concrete at room temperature. Concrete subjected to elevated temperature showed colour change and surface cracking. Changes reported here are similar to those reported by previous researchers [3], [11]. The concrete color changed from normal (at ambient conditions) to pink (400°C) to grey (700°C-800°C). Color changes are found to depend on target temperature. Fig. 2 also shows severe cracking of concrete subjected to 800°C. Cracks are distributed all over the surface of the cubes, but were more pronounced at the edges. However no spalling of edges has taken place. Severe cracking after 700°C and 800°C exposure signifies the deterioration on bond between cement paste and aggregates resulting into substantial loss of strength.

Fig. 2 Concrete exposed to 800°C

B. Strength Deterioration and Recovery

Fig. 3 shows the deterioration of strength (Expressed as strength ratio, which is the ratio of retained strength after exposure to elevated temperatures to the strength at ambient conditions) due to elevated temperature exposure and its subsequent recovery with continuing recuring till 56 days. The concrete subjected to an elevated temperature of 200°C and 300°C retained about 92 and 81 % of their ambient strength respectively. After recuring for 7 days the strength of 200°C and 300°C exposed concrete is about 94 and 83% respectively. After 56 days of recuring, the 200°C and 300°C exposed concrete recovered almost 95% and 85% of its ambient strength respectively.

The concrete exposed to 400°C suffered strength deterioration of 25% of its ambient strength. After recuring for 7 and 14 days, concrete regained about 77% and 79% of its ambient strength. After 56 days of recurring, concrete had regained 83% of its ambient strength. The temperature of 500°C and above the cement paste hydration products such as calcium hydroxide and the CSH deteriorates. For the exposure temperature of 500°C and above the recovery is below 75% of its ambient strength since after exposure to 500°C and above the cement paste loses its interlayer water and bond water thereby creating large voids which are very difficult to be filled by new hydration products. Partial filling ability of new hydration products will help in partial recovery of lost strength.

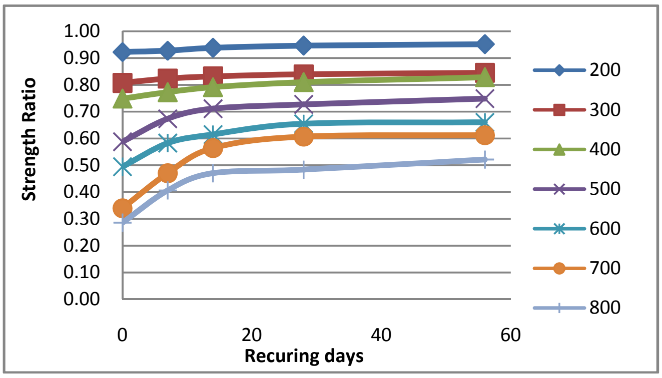

Fig. 3 Strength improvement through recuring for concrete subjected to heating for 2 hrs

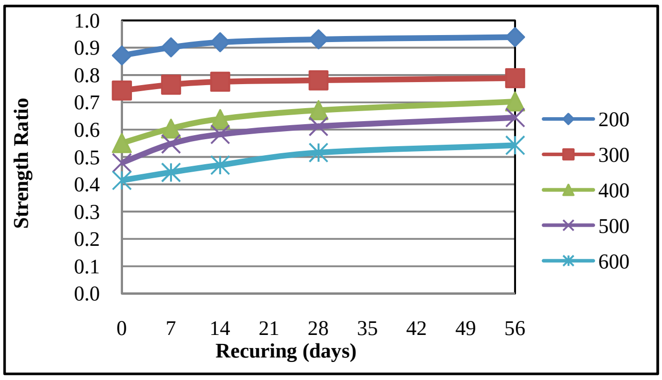

Fig. 4 Strength improvement through recuring for concrete subjected to heating for 4 hrs

Concrete exposed to 600°C experienced large deterioration of strength and the residual strength is only about 50%. After recuring the concrete regained 18% of its ambient strength in just 7 days. At the end of 56 days of recuring the residual strength recovered is 66% of its ambient strength. Similarly for 700°C and 800°C the concrete had suffered severe strength loss, on recuring recovered 61% and 52% of its ambient strength.

Fig. 4 shows the effect of recuring for the thermally deteriorated concrete exposed to heating for 4 hrs. For the concrete exposed to 400°C the gain in strength was observed but comparatively slower as compared to the concrete exposed to 2 hr heating. For the exposure temperatures of 500°C and 600°C the strength recovery was not very appreciable, while the concrete specimen exposed to 700°C and 800°C were damaged to an extent that they lost their integrity and hence could not be recured.

The concrete with exposure duration of 3hr and 4hr recovered about 21 and 34% of the lost strength respectively after recuring for 56 days.

IV. Conclusions

1. Recuring is the most economical and easiest technique to recover the strength lost as a result of elevated temperature exposure. Concrete regains its lost strength because if constant supply of moisture to the dehydrated cement paste.
2. For lower temperature substantial amount of strength is recovered after recuring, for higher temperatures (above 400°C) all the lost strength cannot be recovered because the new hydration products formed as a result of recuring, fill the voids and cracks formed as a result of elevated temperature exposure partially.
3. The rate of strength gain is faster during the initial 7 days of recuirng and later slows down.
4. Recuring capacity of the dehydrated cement paste decreases with the increase in exposure duration.
5. The technique of recuring is significant as it could reduce the expenses required for repair and rehabilitation of thermally deteriorated concrete and conserve resources.

References

[1] J P olliver, J C Maso, B Bourdette. “Interfacial Transition Zone in Concrete”. Advanced cement based materials vol.2, pp.30-38, 1995.
[2] Y. Xu, Y.L. Wong, C.S. Poon, M. Anson. “Influence of PFA on cracking of concrete and cement paste after exposure to high temperatures”, Cement and Concrete Research vol 33, pp. 2009–2016, 2003.
[3] Khoury G A, Majrona C E, Pasavento F Shrefler B A. “Modeling of heated concrete”. Magazine of Concrete Research, 54 vol 77 pp.101, 2002.
[4] Arioz O. “Effects of elevated temperatures on properties of concrete” Fire Safety Journal vol 42, pp. 516-522, 2007.
[5] B. Georgali, P. E. Tsakiridis. Microstructure of fire-damaged concrete. A case study Cement & Concrete Composites 27, 2005 255–259.
[6] D Campbell Allen,P M Desai. Influence of aggregate on behavior of concrete at elevated temperatures, Nuclear Engineering and Design, 6, August 1967, Pages 65-77.
[7] S C Chakrabarti, K N Sharma and Abha Mittal, ‘Residual strength in concrete after exposure to elevated temperature, The Indian Concrete Journal, Dec 1994 713-717.
[8] Chi-Sun Poon, Salman Azhar, Mike Anson, Yuk-Lung Wong, “Strength and durability recovery of fire-damaged concrete after post-fire-curing”,Cement and Concrete Research, Volume 31, Issue 9, September 2001, Pages 1307-1318.
[9] C. Alonso, L. Fernandez. “Dehydration and rehydration processes of cement paste exposed to high temperature environments”, Journal of Materials Science vol 39 pp.3015 – 3024, 2004.
[10] Gabriel A. Khoury and Patrick J. E. Sullivan, ‘Research at Imperial College on the Effect of Elevated Temperatures on Concrete’, Fire Safety Journal, vol-13, pp.69 – 72, 1988.
[11] Yuzer, Nabi , Fevziye Akoz, Leyla Dokuzer O zturk, “Compressive strength–color change relation in mortars at high temperature”, Cement and Concrete Research vol- 34 pp.1803–1807, 2004.
[12] IS: 383-1970 "Specifications for coarse and fine aggregates from natural sources for concrete", Bureau of Indian Standards, New Delhi.