International Journal of Current Advanced Research
ISSN: O: 2319-6475, ISSN: P: 2319-6505, Impact Factor: 6.614
Available Online at www.journalijcar.org
Volume 7; Issue 6(H); June 2018; Page No. 13568-13571
DOI: http://dx.doi.org/10.24327/ijcar.2018.13571.2431

Research Article

EFFECT OF TEMPERATURE ON FRACTURE TOUGHNESS OF PLAIN CEMENT CONCRETE

P. Arulselvam*

Department of Civil and Structural Engineering, Prist University Puducherry-605007

A R T I C L E   I N F O

Article History:

Received 11th March, 2018
Received in revised form 27th April, 2018 Accepted 5th May, 2018
Published online 28th June, 2018

Key words:

Strength, Stiffness, Toughness and Brittleness

A B S T R A C T

Concrete is widely used as a primary structural material. In structures like cooling towers in thermal power stations and pressure vessels in nuclear power plants, concrete is subjected to high temperatures. Fire in buildings, structures and tunnels etc., also contributes to high temperature in concrete members. The exposure of concrete to elevated temperatures affects its properties, mostly decreases the compressive, tensile and flexural strengths of concrete. Appropriate information about the mechanical properties of concrete such as strength, stiffness, toughness and brittleness is inevitably required to design these structures. Besides this, determining the flexural toughness is very useful in assessment of behaviour of the structures under various loading and environmental conditions and assessing post fire safety of concrete structures.

CHAPTER 1

INTRODUCTION

General

Concrete is widely used as a primary structural material. In structures like cooling towers in thermal power stations and pressure vessels in nuclear power plants, concrete is subjected to high temperatures. Fire in buildings, structures and tunnels etc., also contributes to high temperature in concrete members. The exposure of concrete to elevated temperatures affects its properties, mostly decreases the compressive, tensile and flexural strengths of concrete. Appropriate information about the mechanical properties of concrete such as strength, stiffness, toughness and brittleness is inevitably required to design these structures.

Need For Study

Concrete is an inflammable construction material and widely used as a primary structural material. Under normal conditions, most concrete structures are subjected to a range of temperature no more severe than that imposed by ambient environmental conditions, concrete itself is incombustible and it has excellent fire resisting properties when compared with other materials. Due to its low coefficient of thermal conductivity, it preserves effectively the steel reinforcement which is highly sensitive to high temperatures.

Corresponding author:* **P. Arulselvam
Department of Civil and Structural Engineering, Prist University Puducherry-605007

However, there are important cases where these structures may be exposed to much higher temperatures such a jet aircraft engine blasts, building fires, chemical and metallurgical industrial applications in which the concrete is in close proximity to furnaces, and some nuclear power-related postulated accident conditions. Its exposure to elevated temperatures causes deterioration in properties (i.e) compressive strength, flexural strength, modulus of elasticity, bond etc. and leads to failure due to crack formation and spalling of concrete.

Objectives of the Study

The main objectives of the study are

1. To investigate the effects on concrete of exposure to high temperatures of 300 ˚C, 600 ˚C and 900˚C.
2. To gain knowledge of behavior of concrete under elevated temperatures.

To establish a relationship between exposure of concrete of concrete to high temperatures/ fire and the fracture properties by studying the behavior of concrete under high temperatures.

High Temperature Effects on Concrete

Spalling of Concrete

When concrete is exposed to high temperatures, deterioration on its properties such as compressive strength, flexural strength, modulus of elasticity, bond to reinforcement takes place. When concrete is exposed rapidly to very high temperatures with high pressure the hardened cement paste keeps the water from escaping, thus causing in vapor pressure to be developed internally, resulting in explosive spalling.

Cracking of Concrete

When concrete is exposed to elevated temperatures, it causes large volume change due to thermal dilations, thermal shrinkage and creep associated with the loss of water, leads to development of large internal stresses resulting in micro cracks and fractures.

When concrete is heated under fire, the increase in temperature in the deeper layers of material is progressive, but because the process is slow temperature gradients are produced between the surface and core of the material causing formation of cracks.

Fracture Toughness of Concrete

Fracture toughness is the resistance of the material to failure from fracture starting from pre- existing crack.

Importance of Fracture Toughness

Concrete is used in many complex structures such as tall buildings, bridges, dams, retaining walls, submerged structures, liquid and gas containment structures, chimneys, pavement in runways and nuclear structures. Concrete consists of inherent flaws/ micro cracks which are the effective source of crack dissemination and fracture under external loads. In concrete structures failure takes place due to the stress concentration caused by the cracks. The formation of cracks to a significant amount reduces the load carrying capacity and leads to collapse of the entire structure. A complete study of the structural behavior of concrete with inherent flaws under static and dynamic loading is essentially required in designing complex structures. This involves determination of fracture toughness of concrete.

CHAPTER 2

LITERATURE REVIEW

General

Felicetti et al. (1996) conducted experimental study to measure the fracture energy on two high performance concretes having water to binder ratio 0.43 & 0.30. Both direct tension test on notched cylinders and three point bending of beams were carried out after heating to temperature of 105°C, 250°C, 400°C and 500°C. They found that the residual fracture energy is independent of temperature level.

De Souza & A.L. Moreno Jr. (2010) performed an experimental investigation on behavior of ordinary concrete when submitted to high temperatures of 300°C, 600°C and 900°C for two hours followed by slow cooling, to assess the variation of compressive strength, tensile strength and deformation modulus. They also investigated the effects due to rapid cooling of concrete. From the results of experiments they have drawn the conclusions of: It was observed that at temperatures close to 900ºC, mechanical properties of concrete, either to tension or compression, can reach values close to zero. The values of longitudinal deformation modulus with heating, which significantly interferes with the vertical displacement of a structural element, were observed to be close to zero for temperatures lower than 900ºC. It was also observed that rehydration after heating can contribute for recovering a significant portion of a concrete initial mechanical strength, either to compression, tension of deformation modulus.

CHAPTER 3

Proposed Study

This project is about measuring the residual fracture toughness of ordinary concrete exposed to elevated temperatures, which consists of the following activities.

- Materials
- Mix Proportion
- Slump cone test
- Preparation of test specimens
- Experimental Procedure– Three point bend test & Four point test
- Calculation of fracture toughness

Materials

The test specimens shall be prepared with ordinary cement concrete consisting of cement, sand and stone aggregates. The mix ratio shall be determined for M25 as per Indian Standard code 10262-2009. Materials used with their properties are listed below.

Cement

Ordinary Portland cement of 43 grade conforming to IS 8112 was used for the experimental programme.

Physical Properties

Specific gravity = 3.15.
Initial setting time = 45mins
Final setting time = 260mins
Fineness modulus = 1.00

Fine Aggregate

Locally available river sand was used as fine aggregate Laboratory tests were conducted on fine aggregate to determine the different physical properties as per IS 2386(Part –III)-1963 (Reaffirmed on 1997). The results depicted that the river sand conformed to zone II as per IS 383-1970(Reaffirmed on 1997)

Physical Properties

Surface texture = smooth
Fineness modulus = 2.65
Bulk density= 1786 kg/cum
Specific gravity= 2.65
Sieve analysis = Zone II

Coarse Aggregate

Coarse aggregate consisting of crushed stone aggregates of 20mm nominal size was used for making the specimens.

Physical Properties

Particle shape= Angular
Impact value = 15.3
Bulk density= 1650 kg/cum
Specific gravity= 2.74
Sieve analysis= As per IS for 20 mm

Mix Proprtion

Concrete mix design for M25 grade concrete was prepared as per the provisions in IS: 10262-2009. The water cement ratio was taken as 0.45 by weight of cement. The mix proportion adopted is shown in table 1. The complete mix design is given in appendix A.

Table 1 Mix Design of Concrete

Mix Proportions	Cement	Fine Aggregate	Coarse Aggregate	Water
Per m³	413.33kg	669.47 kg	1178.62kg	186.0kg
Mix Ratio	1.000	1.62	2.85	0.450
Per Bag of Cement	50.00kg	80.98kg	142.58kg	22.50kg

Slump Cone Test

This is the very simple method commonly used to determine the workability of fresh concrete. This test was carried out as per the procedure laid down in IS: 1199-1959. The freshly concrete prepared as per the design mix ratio was filled in a clean slump cone mould the inner surface of which was already applied with light coat of oil, in four layers of equal height. Each layer was tamped 25 times by rounded end of tamping rod. After top layer was rodded the concrete was struck off level with a trowel. The mould was removed immediately by raising it slowly in the vertical direction. The difference in level between the height of the mould and that of top of highest point of subsided concrete is measured. This difference in height in millimetre is the slump of concrete. The slump value recorded was 65 mm in slump cone test which indicates medium degree of workability.

Preparation of Test Specimens

In order to determine the compressive strength of concrete, twelve numbers of concrete cubes of size 150x150x150mm were cast (Refer fig. 3.2) from the same mix of concrete used for preparing test specimens for fracture toughness. These cubes Were also cured in water for 28 days.

Experimental Procedure

Heating of Specimens

Three heating temperatures i.e 300˚C, 600˚C and 900˚C were adopted. The electric furnace shown in fig. 3.3 was employed for testing of beam specimens and cubes. This furnace was provided with heating elements at the two opposite sides, rear side, and refractory lining on all six faces. The internal dimensions of the furnace are 500x500x500mm. The furnace has a maximum heating capacity of 1200˚C and a Programmable controller attached to the power supply.

The specimens were heated to the elevated temperature of 300˚C, 600˚C and 900˚C inside the furnace and heated for one hour holding time. The rate of heating adopted was 120˚C in an hour. Then the furnace was shut down and the specimens were allowed to cool slowly in the furnace to room temperature. The specimens were taken out of the furnace and tested in a flexural testing machine to determine the fracture toughness.

Compression Test

Crushing strength test was carried out on concrete cube specimens 150x150x150mm size, cast from same concrete mix that was used for preparation of test specimens for fracture toughness test after 28 days curing. Three cubes were tested for room temperature, nine cubes were tested after subjected to high temperatures of 300˚C, 600˚C and 900˚C i.e three cubes per each temperature range. The test was carried out using a calibrated digital 100 ton hydraulic machine.

CHAPTER 4

RESULTS AND DISCUSSIONS

Compression Test

The test results are shown in Table 2. The crushing strength values are the average of three values arrived from experimental failure loads.

Table 2 Crushing strength of concrete

Sl.No.	Size in millimeter	Temperature	Crushing strength
1	150x 150x150	Room Temp.	35.40 N/Sq.mm
2	150x 150x150	300˚C	65.38 N/Sq.mm
3	150x 150x150	600˚C	40.53 N/Sq.mm
4	150x 150x150	900˚C	28.98 N/Sq.mm

From the results, it is seen that the compressive strength is 35.40N/sq.mm (base value) which is approximately equal to the target strength of 31.60N/sq.mm considered in the design. The crushing strength increases to 65.38 N/sq.mm at 300˚C (i.e) raises by 85%, 40.53 N/sq.mm at 600˚C, increases by 15% from base value, and drops down to 28.98N/sq.mm at 900˚C (i.e) decreases by 18%.

Visual Examination

Colour change

The colour change induced in concrete, when exposed to high temperatures is permanent. The colour change in concrete depends on the type of aggregates used. The colour sequence observed is approximately as follows.

Gray colour was observed at 300˚C, yellowish gray at 600˚C and pale pink colour was observed 900˚C. At 600˚C and 900˚C the colour of the stone aggregates were observed to have changed into yellowish brown.

CRACK EXTENSION PROFILE

The crack extension profile of the test specimens for various heated temperatures are shown in fig.4.6. It was observed that the extending crack plane does not deviate from the existing crack plane in the specimen.

Post Failure Surface

The post failure surfaces of the beam specimens are shown in fig.4.7. It was observed that mainly bond failure between cement mortar and stone aggregate took place and hence uneven rough surfaces are visible along the direction of crack resulting in increase in fracture toughness of concrete.Also it was observed that the colour of stone aggregates also changed to yellowish brown colour on the specimens heated to temperatures of 600˚C and 900˚C.

CHAPTER 5

CONCLUSION

In this paper, the fracture toughness of ordinary concrete was evaluated by conducting three point and four point bending tests on notched beams in slow cool down states after exposing to high temperatures of 300˚C, 600˚C and 900˚C. The compressive strength tests were also performed on cube specimens for the same temperatures. From the experimental investigation the following conclusions can be drawn.

- Elevated temperatures have significant influence on the fracture toughness of concrete.
- The crushing strength also sustained an increase-decrease tendency with increasing temperatures. Its values increases at 300˚C and 600˚C by 85% & 15% respectively, whereas it decreases at 900˚C by 18%.
- The crack extension follows the pre-existing crack plane and did not deviate from the existing crack plane.
- Mortar failure was observed in the test specimens when post failure surfaces were examined.

References

1. Alam M R, Azad M A K and Kadir M A (2010), 'Fracture toughness of plain concrete specimens made with industry burnt brick aggregates', *Journal of Civil Engineering (IEB)*, Vol.38 (1) (2010) 81-94, pp.81-94.
2. Baker G (1996), 'The Effect of exposure to elevated temperatures on the fracture energy of plain concrete', *RILEM Materials and structures*, 1996, Vol.29, no 190, pp. 383-388.
3. Bicanic N and Nielson C V (2003), 'Residual fracture energy of high performance and normal concrete subject to high temperatures', *RILEM Materials and Structures,* Vol.36, no.262, pp. 515-521.
4. Binsheng Zhang, Martin Collen and Tony Kilpatrick (2014), 'Fracture toughness of high performance concrete subjected to elevated temperatures. Part I -The effects of heating temperature and testing condition (hot & cold)', The Advances concrete construction", Vol. 2, no. 2, pp. 145-162.
5. De Souza A A A and Moreno Jr. A L (2010), 'The effect of high temperatures on concrete compression strength, tensile strength and deformation modulus', *IBRACON Structures and Materials Journal*, Vol.3, no.4, pp. 432-448.
6. Felicetti, R., Gambarova, P.G., Rosati, G.P, Corsi, F and Giannuzzi G. (1996), 'Residual mechanical properties of high strength concretes subject to high-temperature cycles', 4th Inter. Synopsis on Utilisation of High Strength/High Performance Concrete, pp. 579-588. Paris.
7. Hisham Abdel-Fattah and Sameer A.Hamoush (1997), 'Variation of the fracture toughness of concrete with temperature', *Construction and Building Materials*, Vol. 11, no.2, pp. 105-108.
8. Jiangtao Yi, Kequan Yu and Zhoudao Lu (2012) 'Residual fracture toughness of concrete subject to elevated temperatures', *Materials and Structures*, Vol.45, no.8, pp. 743-746.

How to cite this article:

P. Arulselvam (2018) 'Effect of Temperature on Fracture Toughness of Plain Cement Concrete', *International Journal of Current Advanced Research,* 07(6), pp. 13568-13571. DOI: http://dx.doi.org/10.24327/ijcar.2018.13571.2431

****