A Research Experimentation on Compressive Strength of Steel Fiber Reinforced Concrete Columns Exposed to Temperature up to 700oC by NDT Methods

M K S S Krishna Chaitanya, K. Srinivasa Rao

Abstract: The aim of this study is to evaluate the performance of reinforced cement concrete (RC) columns and steel fiber reinforced concrete (SFRC) columns subjected to temperatures 100, 200, 300, 400, 500, 600 and 700^{o}C by Non-Destructive Test (NDT) methods. In order to achieve this, both RC and SFRC columns are cast and cured for 28 days. Later these columns are heated in an electrical furnace up to a temperature of 700^{0}C for different durations of 1 hour and 2 hours. In this study, Rebound hammer and Ultrasonic Pulse Velocity (UPV) tests have been conducted to study the effect of high temperature on the behaviour of columns. Based on the results of this study, it is concluded compressive strength obtained through Rebound hammer test of SFRC columns are more than those of RC columns up to 500^{0}C. Results of UPV tests show a decrease in pulse velocity value for columns heated beyond 400^{0}C.
Keywords: Reinforced concrete, steel fibers, High temperature, Compressive strength, and Non-destructive testing.

I. INTRODUCTION

Apart to natural disasters such as earthquakes, hurricanes, tsunamis, etc., the same danger poses disasters caused by people like fire and fire explosions are equally dangerous. Data from the National Crime Records Bureau show that, in 2010-2014, 1,11,361 people lost their lives as a result of Indian fires in general. In the context of these data, the prevention of structural fires or the reduction of the intensity of the fire one must take care. On the other hand, the structural resistance of a building during and after a fire disaster is an area that needs attention. High temperatures will occur during a fire, leading to a structural column to distress. This distress will reduce the overall resistance of the column. Many materials have been developed to make the building more durable and resistant to high temperatures in order to avoid structural damage. One of the best options available is the use of fibers in structural elements. Shaikh et al[11] studied the compressive strength and failure behaviour of fibre reinforced concrete at high temperatures and the results show that the compressive strength of concrete reinforced with steel fibres at higher temperatures was higher than plain concrete.

Revised Manuscript Received on June 07, 2019.
M K S S Krishna Chaitanya: Assistant Professor, Department of Civil Engineering, Anil Neerukonda Institute of Technology and Sciences, Visakhapatnam, India

Prof. K. Srinivasa Rao: Professor, Department of Civil Engineering, Andhra University College of Engineering, Andhra University, Visakhapatnam, India.

Kodur et al[7] studied the effect of strength and fiber reinforcement on fire resistance of high strength concrete columns. The addition of steel fibers improves the ductility and fire endurances of high strength concrete columns. However, strength of fiber reinforced concrete (FRC) may be estimated by destructive or non-destructive methods. Non-destructive testing is one of the most powerful and reliable tools. The content of non-destructive tests to assess the status of RC structures has increased dramatically recently due to an increase in the number of structures indicating signs of distress. Non-destructive tests are fast, easy to use and cheap. Purkiss[10] studied the residual compressive strength, flexural strength, dynamic modulus and ultrasonic pulse velocity of reinforced steel fiber at high temperatures. It was found below 600^{0}C, fibre reinforced concrete performs better than plain concrete. Novak et al[9] conducted a study on the behaviour of fibre reinforced concrete exposed to high temperatures. It was concluded that steel fiber in concrete mix for the improvement of mechanical properties and resistance to heating effects. The above studies are available for plain cement concrete. In fact, the fire disaster affects the structural elements of the building, such as columns, beams, etc. This article discusses the performance of high temperature reinforced concrete columns using rebound hammer and ultrasonic pulse velocity tests. Here, Changes in compressive strength were studied with a temperature of 100 to 700^{0}C for 1 hour and 2 hours exposure durations.

II. MATERIAL AND METHODS

Material properties: Ordinary Portland cement of grade 53 is used for sample preparation. Sand with specific gravity 2.65 is used as fine aggregate. Crushed aggregates with a specific gravity 2.8 are used as coarse aggregate[2]. Potable water is used for mixing and curing of samples. Superplasticizer of conplast SP 430 was used with a 500 ml dose per 50 kg of cement. In the present study crimped flat steel fibers having unit weight of 7.86 gm/cm^{3} and an ultimate tensile strength of 771 MPa, a length 50 mm and a width of 0.75 mm are used. The shape of these steel fibers is shown in Figure 1.

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Mix proportions: Concrete mix is designed according to Indian standards to achieve compressive strength of 30 MPa in 28 days and a slump of 50 mm [3, 4]. Each cubic meter of concrete mix consists of 391.1 kgs of cement, 656.31 kgs of fine aggregate, 1217.51 kgs of coarse aggregate, 176 kg/m3 of water and 7.82 kg/m3 of SP 430.

Mixing, casting and curing procedures: All ingredients are mixed in a 0.4 m^3 concrete mixer. The mixer is filled with proportional amount of coarse aggregate, fine aggregate, cement, water and fiber (in the case of fiber mixtures) and mixed for 5 minutes. Mixed concrete is placed in the column moulds. After 24 hours the samples are demoulded and cured for 28 days. All columns are then stored in the laboratory under atmospheric conditions before exposure to high temperatures.

Test samples: The test samples are reinforced concrete columns of 1200 mm length and 150 mm x 150 mm cross section. These dimensions are determined based on model analysis as shown in Figure 2. High yield strength deformed bars (grade 415) are used for longitudinal reinforcement and Grade 250 for shear reinforcement. Among the thirty cast columns, one is examined at room temperature for each mixture and is considered as reference columns.

Heating procedure: An electric furnace designed for this purpose is used and the furnace heat is in accordance with ISO 834[1]. The maximum working temperature of the furnace is 1050^0C. Samples are heated to 100, 200, 300, 400, 500, 600 and 700^0C for 1 hour and 2 hours exposure durations. After heating, the samples are allowed to cool to room temperature before being tested.

Testing of specimens

Schmidt Rebound hammer test: Schmidt rebound hammer test was carried out according to IS13311 (Part 2): 1992[5] to find the compressive strength of the concrete. The sample was divided into equal grid blocks and 10 points were marked on each side at equal intervals for conducting the rebound hammer test. The test results were reported in the ratio of the compressive strength of the RC columns at room temperature with fire affected concrete without and with steel fibers are shown in Figure 3 and Figure 4.

Ultrasonic pulse velocity test: Ultrasonic pulse velocity test was also carried out according to IS13311 (part1):1992[6] for the evaluation of concrete quality. The sample was divided into grid points and 5 points were marked on two sides at equal intervals for conducting the ultrasonic pulse velocity test. The results of ultrasonic pulse velocity test for concrete affected by fire and unaffected concrete are shown in Figures 5 and 6.

III. RESULTS AND DISCUSSION

Compressive strength: The percentage variation of the compressive strength of the RC columns and SFRC columns with temperatures are shown in Figure 3 and Figure 4 according to the heating durations of 1 hour and 2 hours respectively. Compared with the percentage change in compressive strength of RC columns at room temperature, SFRC columns showed better results of up to 500^0C for 1 hour duration and for 2 hours duration the SFRC columns showed better results up to 400^0C. Concrete quality grading: The variation of pulse velocity (m/sec) for RC columns and SFRC columns with temperatures are shown in Figures 5 and Figure 6 according to their heating durations 1 hour and 2 hours respectively. It is observed, quality grading is excellent or good for RC columns and SFRC columns for 1 hour exposed duration up to 500^0C and for 2 hours exposed duration it is up to 400^0C.This is due to increase in porosity / permeability between 400^0C to 500^0C. As the temperature increased beyond 500^0C quality grading is medium or doubtful due to development of voids and crakes [8].

IV. CONCLUSIONS

1. The addition of steel fibres showed a significant increase of about 17.2% in compressive strength given by rebound hammer test at room temperature.
2. In case of rebound hammer test, compare with percentage variation of compressive strength of RC columns at room temperature, SFRC columns retained in compressive strength up to 500^0C and 400^0C for 1hour and 2 hours exposed duration.
3. In case of UPV test, quality grading is excellent or good for both RC and SFRC columns for 1 hour exposed duration up to 500^0C.
4. In case of UPV test, quality grading is excellent or good for both RC and SFRC columns for 2 hour exposed duration up to 400^0C.
5. Beyond 500^0C, quality grading is medium or doubtful for both RC and SFRC columns for 1 hour exposed duration given by UPV test.
6. Beyond 400^0C, quality grading is medium or doubtful for both RC and SFRC columns for 2 hours exposed duration given by UPV test.

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Table 1
Pulse velocity (m/s) of RC and SFRC columns and quality grading

Temp (^{0}C)	RC		SFRC		Quality grading according to IS13311 (part1): 1992
	1h	2h	1h	2h	
27	4761.91	4761.91	4816.8	4816.8	
100	4997.7	4882.6	5137.6	4894.2	
200	4809.8	4632.3	4835.6	4860.3	
300	4436.9	4284.7	4615.4	4302.5	
400	4222.3	4089	4219.3	3844	Excellent and good
500	3522	3317.7	3467.7	3233.9	
600	3127.5	2824.8	2974.6	2537.1	
700	2016.6	2757.1	2045.2	2680.7	Medium and doubtful

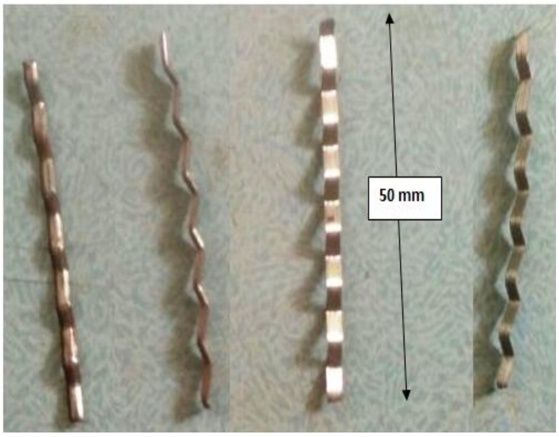

Figure 1 Crimped flat steel fibres

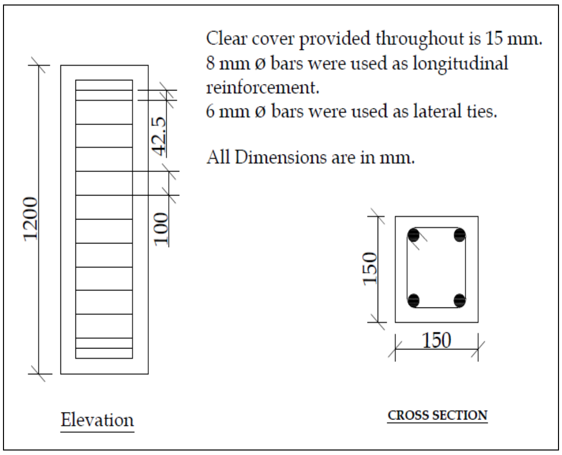

Figure 2 Details of test specimen

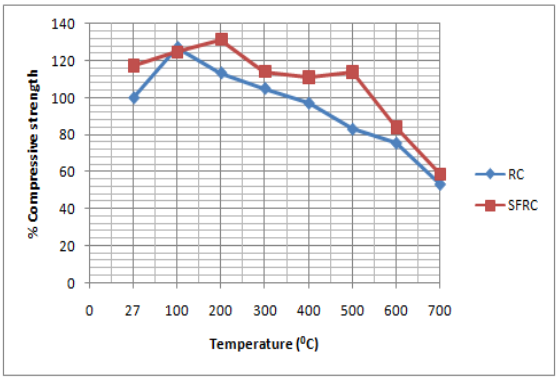

Figure 3 Variation of compressive strength with temperature for 1hour exposed duration

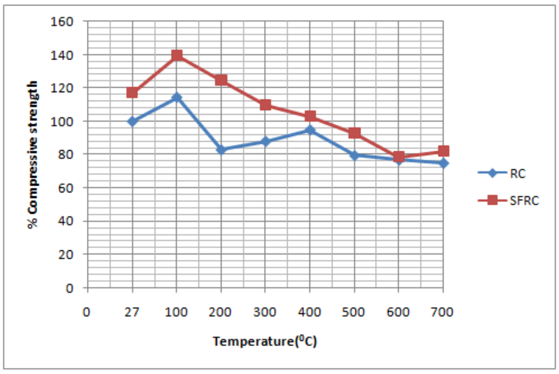

Figure 4 Variation of compressive strength with temperature for 2hours exposed duration

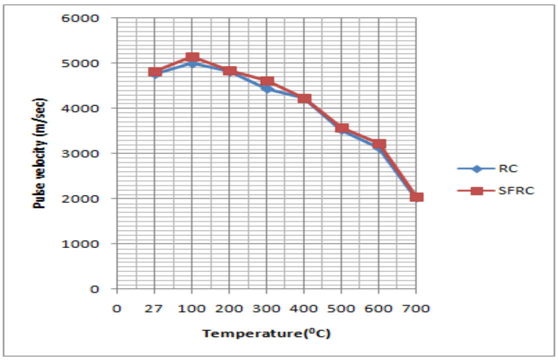

Figure 5 Variation of Ultrasonic pulse velocity with temperature for 1 hour exposed duration

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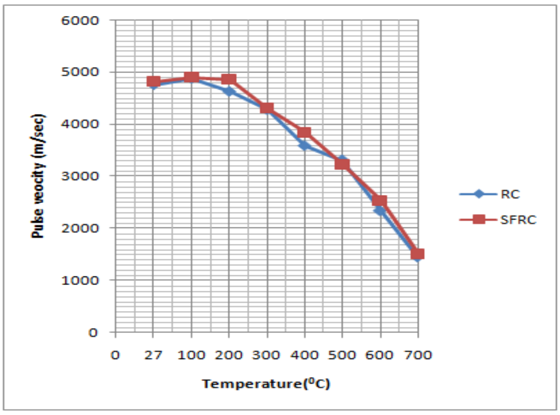

Figure 6 Variation of Ultrasonic pulse velocity with temperature for 2 hours exposed duration

AUTHORS PROFILE

M K S S Krishna Chaitanya received M.E.(SE&NDM) degree in civil engineering from Andhra University, Visakhapatnam (2009). Now he is pursuing his Ph.D from Andhra University. He is currently working as Assistant Professor in the Department of Civil Engineering, Anil Neerukonda Institute of Technology and Sceinces, Visakhapatnam. He is a member in Institution of Engineers India (IEI).

Name: **Prof. K. Srinivasa Rao**
Qualifications: B.E. (Civil Engineering), M.E. (Structural Engineering), PhD (Structures)

Dr.K.Srinivasa Rao is currently working as Professor in the Department of Civil Engineering, Andhra University College of Engineering (A), Andhra University, Visakhapatnam. He has about 26 years of teaching experience. He produced 11 PhDs and 73 MEs. His research interests include behaviour of concrete and RCC elements at elevated temperatures, ultra-high strength concrete, geo-polymer concrete, alkali activated slag concrete, Non-Destructive Evaluation of structures, Repair and Rehabilitation of Structures and Earthquake Engineering. He has published about 90 Technical Papers in National & International Journals and Conferences. He is Life Member of Indian Society for Technical Education and Indian society for Construction Materials and Structures and Fellow of The Institutions of Engineers (India) and Indian Association of Structural Engineers. He is a Reviewer for Journals Construction Materials Journal published by the Institution of Civil Engineers, UK [http://www.ice.org.uk], ASTM International Journal-Advances in Civil Engineering Materials, Journal of Frontiers in Construction Engineering (FCE), The World Academic Publishing Co.,Ltd, Journal of The Institution of Engineers (India): Series A, Scientific Research and Essays, www.academicjournals.org/SRE and International Journal of Forensic Engineering (IJFE).