Nigerian Journal of Technology (NIJOTECH)
Vol. 43, No. 3, September, 2024, pp.411 - 420
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.v43i3.2

ASSESSMENT OF FIRE DAMAGE IN CONCRETE STRUCTURES: A COMPREHENSIVE STUDY USING COLORIZATION AND NON-DESTRUCTIVE TESTING

AUTHORS:
M. Kumar[1,*], and A. B. Gupta[2]

AFFILIATIONS:
[1,2]Department of Structural Engineering, M. B. M. University Jodhpur, Raj, 342011, India.

***CORRESPONDING AUTHOR:**
Email: mahendrakumar405@gmail.com

ARTICLE HISTORY:
Received: 30 April, 2024.
Revised: 12 August, 2024.
Accepted: 25 August, 2024.
Published: 20 September, 2024.

KEYWORDS:
Phenolphthalein chemical, Colorimetry, NDT methods, Rebound number (RN), Temperatures, Concrete.

ARTICLE INCLUDES:
Peer review

DATA AVAILABILITY:
On request from author(s)

EDITORS:
Chidozie Charles Nnaji

FUNDING:
None

Abstract

The research paper investigates the impact of fire on concrete structures, focusing on evaluating the temperatures reached during the fire using the colorimetry test method. It examines color changes as indicators of temperature, assesses the extent of damage to building components, and determines the depth of carbon penetration within the structure. The study employs various assessment techniques, including rebound hammer test, colorimetry test to evaluate structural integrity post-fire. Key findings include the correlation between color changes and temperature, the effectiveness of rebound hammer tests in assessing structural integrity, and the importance of considering aggregate type in color analysis. The study was conducted using prescribed non-destructive testing (NDT) techniques. For the investigation of the fire-damaged building, the Rebound number (RN) values were used to correlate the in-situ compressive strength of concrete using the standard curves developed in the laboratory for this purpose. Moreover, the approximate temperature to which any structural element had reached was determined approximately by colorimetry test. Further the residual compressive strength of concrete of these elements was also derived applying the reduction factors in Eurocode 2 for concrete exposed to varied temperatures. The maximum percentage difference between these two sets of values was 15.46% except for one case. The residual strength values of concrete of the structural elements paved a way for satisfactory evaluation of the need of retrofitting of these elements, Overall, the research offers practical insights for assessing the residual compressive strength of concrete of structural elements of fire-damaged concrete structures by two different techniques thus aiding in decision-making for rehabilitation or reconstruction efforts of such structures.

1.0 INTRODUCTION

A handicrafts factory in Basni industrial area, Jodhpur city in Rajasthan state of India caught fire in March, 2022. The fire erupted probably due to short circuiting on ground floor. The space on the ground floor was filled with lot of handicraft items made of wood along with inflammable material like glues, paints, varnishes etc. these materials aided in quick spread of fire to a large area of the ground floor. The fire brigade reached the place within 15 minutes of fire eruption but it took around 30 minutes for the fire to stop completely because of the excessive material filled inside. After few months of the incident of fire, the building was required to be retrofitted. The need arose to evaluate the strength of the structural elements of the building so that the requirements for retrofitting them could be worked out. For this purpose, a senior professor from MBM University, Jodhpur was

HOW TO CITE:
Kumar, M., and Gupta, A. B. "Assessment of Fire Damage in Concrete Structures: A Comprehensive Study using Colorization and Non-Destructive Testing", *Nigerian Journal of Technology*, 2024; 43(3), pp. 411 – 420; *https://doi.org/10.4314/njt.v43i3.2*

contacted and a team of researchers carried out the work. The present study is a part of the structural assessment work carried out at the building.

The effect of fire on strength of concrete beams has been evaluated for a long time now [1]. Researchers have also worked on understanding the effect of fire on compressive strength of concrete with cement produced with pulverized steel mill scale. They found that the concrete strength is not compromised much up to temperature of 500ºC [2].

The primary objective of this study is to ascertain the damage caused by fire to the structural strength of various elements of the building. The first part of the study comprised of determining the temperature reached by the various structural elements of the building throughout the duration of the RCC's burning, utilizing the colorimetry test method. Color was utilized as a defining factor to gauge the temperature attained within the building, alongside assessing the number of building components affected during the fire also determining alongside if the structure has been affected by carbonation. The color change helps in evaluation of fire temperatures within structural members within a specified range. Various building components, including beams and columns, were found to have reached elevated temperatures during the structural fire. Furthermore, the discharge of carbon oxide into the atmosphere during the fire markedly undermines the structural integrity, resulting in detrimental impacts on both the environment and human well-being through the emission of harmful gases and depletion of oxygen levels. During a fire, CO_2 levels around the concrete increase significantly.

The elevated temperature and CO_2 concentration can accelerate the carbonation process, where CO_2 reacts with calcium hydroxide ($Ca(OH)_2$) in the concrete to form calcium carbonate ($CaCO_3$). This process lowers the pH of the concrete, reducing its alkalinity. Concrete's high alkalinity (pH > 12.5) is crucial for protecting the steel reinforcement from corrosion. As the pH drops due to carbonation, the protective oxide layer on the steel surface can break down, making the steel more susceptible to corrosion. Corrosion of steel reinforcement leads to the formation of rust, which occupies a greater volume than the original steel. This expansion creates internal stresses in the concrete, leading to cracking, spalling, and ultimately reducing the load-bearing capacity of the structure [3]. In addition to the meticulous colorimetry test method, the research also employed a Non-Destructive Testing (NDT) technique, notably the Rebound Hammer test, to discern the RN values which could be correlated to the residual compressive strength (f_{ck}) of the fire-damaged structure. This comprehensive approach facilitated a nuanced evaluation, enabling a thorough assessment of the building's integrity with sufficient precision and efficiency [5], [6]. The methods have been utilized in past for damage assessment of structures [8].

Two primary methodologies, namely the pertinent colorimetry approach and the nondestructive test of Rebound Hammer (RH) method, were employed to assess the fire resistance of buildings and determine residual strength in accordance with established guidelines. Scholarly discussions delve into the chemical and physical transformations occurring in concrete when subjected to heat. The assessment of fire resistance in buildings and the residual strength of concrete is conducted using carbonation and temperature variation methods. Concrete exhibits distinct alterations under heat exposure: water evaporation occurs at around 100°C, followed by silicate hydrate breakdown beyond 300°C, and portlandite dehydration above 500°C [8]. Beyond 600°C, aggregate expansion, dissolution, or metamorphosis takes place, leading to a decrease in strength, fissuring, spalling, and alterations in color [9]. Color transformations progress from grey to pink or red (300-600°C), whitish-grey (600-900°C), to buff (900-1000°C) due to interactions with iron compounds [10]. Techniques such as phenolphthalein spraying and powder analysis distinguish between carbonation and thermal effects. Using both RGB (Red, Green, Blue) and HSI (Hue, Saturation, Intensity) systems allows for a comprehensive analysis of colour changes in concrete due to temperature fluctuations, improving the accuracy and speed of thermal history assessment [10].

NDT methods are critical for evaluating structural integrity without causing damage and are widely utilized in various industries, including concrete structures, for their cost-effective inspection capabilities compared to traditional methods like coring. The NDT techniques used for the fire-damaged building included visual screening, rebound hammer tests, and Colorimetry tests to assess the damage.

Assessing the mechanical behavior of concrete under fire conditions is crucial for predicting structural performance. While color changes in concrete can indicate potential temperature ranges of mechanical deterioration, the immediate correlation between color and mechanical behavior is not straight forward.

Research suggests that systems like RGB and HSI can quantify color changes, offering insights into concrete's response to fire-induced thermal stress. Various assessment techniques exist for evaluating concrete structures' post-fire residual strength, ranging from traditional laboratory methods with optical microscopes to rapid assessment through digital imaging using cameras or scanners. The choice of assessment methodology depends on precision needs, time constraints, and resource availability [11], [12].

The research work done in the field identifies certain areas where further work is required. They are as follows:

1. Integration of Multiple NDT Techniques: Research is needed to explore the combined application of NDT methods like ultrasonic pulse velocity, rebound hammer, and half-cell potential tests for a more comprehensive assessment of concrete structures.
2. Effectiveness of NDT in Different Environmental Conditions: There is a gap in understanding how various environmental conditions, such as temperature and humidity, affect the reliability of NDT methods. Research should focus on these impacts to improve guidelines for diverse settings.
3. Quantitative Correlation between NDT Results and Structural Integrity: Establishing a quantitative link between NDT results and the actual structural integrity and remaining service life of concrete components is necessary to enhance the predictive capabilities of NDT.
4. Standardization and Calibration of NDT Equipment: Developing uniform standards for NDT equipment calibration and testing procedures is crucial, especially in regions where NDT is not yet a routine practice.
5. Long-term Performance Monitoring: Research is needed on the long-term performance of structures after repairs or strengthening interventions are suggested by NDT findings. Longitudinal studies can provide insights into maintenance planning and lifecycle management.

2.0 METHODOLOGY

The building was built of RCC framework of beams and columns with slabs and infilled brick walls. The grade of concrete used was M25 at the time of construction. The building was constructed around 15-20 years back.

The research methodology adopted in this paper involves a colour test designed to establish correlations between specific color indicators and the corresponding temperatures achieved during the firing process. This test is complemented by a conditional evaluation of the building's structural integrity. The evaluation process involves categorizing the building based on various parameters observed during a rapid-visual inspection, such as cracks, carbonation depth, soot deposition, its location and intensity, exposure of reinforcement, if any, corrosion of steel, reduction in diameters of rebars, chipping or spalling of concrete, etc. The classification of buildings according to the conditional assessment encompasses the identification and examination of beams and columns [13]. These structural elements are assessed for the extent of damage incurred during the fire, ranging from mild to severe. Temperature assessments are conducted by applying phenolphthalein spray to the building components at the time of inspection [14]. The field work for the research included the testing of 27 beams, 27 columns and 18 slabs of the building structure. Amongst these elements, five different elements of each type of structural element like beam, column, slab were selected on the basis of extent of damage visually observed. The NDT test results of these elements have been suitably tabulated in the further sections.

2.1 Colorimetry Method using Phenolphthalein

In this method, the temperature (T) at which specific colors appear in the table is used to determine the depth of carbon penetration in the concrete structure after applying phenolphthalein spray [15], [16].

The color of the concrete typically changes from grey to pink or red at temperatures ranging from 300 to 600^{o}C [16], [17]. In the old structures, the discoloration could be due to carbonation. So, carbonation zone was needed to be identified in a freshly broken surface. The phenolphthalein method for testing carbonation zone in fire-exposed concrete included firstly exposing a fresh surface of the fire-damaged concrete by chipping off the soot layer deposited over it. This ensured that the test was conducted on an uncarbonated surface. Then a 1% phenolphthalein solution was applied evenly to the freshly exposed concrete surface using a spray bottle. The colour change was observed. Areas where the concrete remained alkaline (pH > 9.0) turned pink, indicating no carbonation. Areas where carbonation had occurred (pH < 9.0) remained colourless.

The discoloration of concrete i.e. it turning into pink or red visibly, if continued farther than the carbonation zone, one could imply that it was due to fire exposure. [17],[18] To notice the discolouration carefully, microscopic technique was used [19]. At most areas tested, after spraying the phenolphthalein, there was immediate change in colour, showing that there was no effect of carbonation. Only on the surface at two locations on the beam which was near the external gate of the building, colourless zones were obtained. They showed the effect of carbonation so such locations were discarded.

Further, for the areas, where there was no effect of carbonation, the colour of concrete was intensely noted using a 30x mobile camera and approximate temperature to which it would have reached under fire, was noted, as mentioned in Table 1.

Table 1: Colour and temperature for specific elements

Element	Figure	Description	Observation	Remarks
Beam 1		The point is situated 18 feet from the right end of the column.	Pink/reddish color	Expected temperature range of 300-400°C achieved.
Beam 2		At a distance of 18 feet from the right end of the beam, the point is located.	Light pink/reddish	Expected temperature 300-400°C achieved.
Beam 3		Positioned 18 feet from the right end of the beams is the point's location.	Light pink due to soot buildup	Expected temperature 300-500°C.
Beam 4		The point is precisely located 18 feet from the right end of the beams.	Medium pink with cracks due to fire	Expected temperature of beams 400-500°C.
Beam 5		Positioned at the midpoint, the point is 7 feet from one end of the central beam.	Medium pink with soot deposition and severe cosmetic degradation	Expected temperature 400–500°C.
Column 1		Situated 3 feet from the top to the bottom side of the central column, the point is present.	Light pink due to soot deposition	Expected temperature 300-400°C.
Column 2		The point is located at the base of the second column, positioned three feet above the bottom.	Medium pink with crumbling plaster	Expected temperature ranged from 300 to 500°C.
Column 3		Positioned on the column, the point is 9 feet from the base extending upwards.	Light pink or reddish with severe soot buildup and crumbling plaster	Expected temperature between 300 and 400 °C.
Column 4		The point is situated on the column, spanning 3 feet from top to bottom.	Pink or reddish with significant visual damage	Expected temperature 400 to 500°C.
Column 5		The concrete is spalling downward, with the point measured 4 feet from top to bottom.	Highly pink or reddish with concrete spalling	Expected temperature 600°C.
Slab 1		Positioned on slab 1, the point is 3 feet by 3 feet away from the ends of the right side of beam 2 and the adjacent wall.	Medium pink/reddish due to concrete spalling	Expected temperature 500–600°C.
Slab 2		Situated between CL4 and CL5, the point is 2 3x3 feet from the left side of beam 2 and the adjoining wall.	Medium pink/reddish due to concrete spalling	Expected temperature 500–600°C.
Slab 3		The point is set 4x4 feet from beam 4 at the center and beam BR5 on the right side of the structure.	Strongly pink or reddish with significant imperfections	Expected temperature 500-600°C.
Slab 4		Set on a 3x3 grid, the point is located from a wall between CR2-CR3 and BR2.	Light to medium pink/reddish with concrete spalling	Expected temperature 400°C.
Slab 5		The point is located from column CR6, with a distance of 4x4 from the structure's right side, between CR6-CR7 and BR6.	Strong pink/reddish with visible reinforcement	Expected temperature 500–600°C.

2.2 NDT TEST METHOD

To evaluate the structural integrity of the concrete elements within the fire-damaged building, hardness measurements were conducted using a Rebound Hammer (RH) at designated intervals across various components, including slabs and column beams [20],[21]. Given the severity of the damages incurred, multiple data were undertaken to assess the concrete strength integral to the building's construction [22]. The limitations of this test would form the limitations of the results quoted. Compressive strength of concrete has been evaluated from rebound number values, using correlation equations available with the equipment and verified by laboratory tests. The RH test was performed in accordance with IS: 516 (Part 5, Sec 4) – 2020. However, as per the codal provisions, the probable accuracy of the prediction of compressive strength of concrete can vary upto ±25% [23]. The outer skin of the concrete had hardened excessively due to fire exposure. So, the surface was giving erroneous results. Hence, the surface was chiseled by 8-10 mm and then the readings were taken.

2.2.1 Rebound hammer values of beams

The rebound hammer readings were taken on three visible sides of the beams, left, right and bottom. Figure 1 shows the author taking RN readings on a structural element. The plan of network showing locations of beams, columns and slabs is shown in Figure 2. The rebound hammer readings taken at various positions along different beams and columns in the structure are summarized in Table 2 and in Table 3 respectively. It includes beams labeled B1 to B5, with measurements at left (L), right (R), and central (B) positions, spaced 7 feet apart. The "Average (RN)" column shows the mean value of RN for each beam, offering insight into concrete surface hardness at different points.

Figure 1: Photograph of performing RH test

Further, the compressive strength of concrete (f_{ck}) has been correlated from the data of RN using the curves derived and verified in the laboratory of MBM University for the different directions of probing. The direction of probing is horizontal direction for location B i.e. bottom while it is vertically upwards for L (Left side of beam) and R (Right side of beam).

Table 2: Rebound number (RN) Values at various locations on Beams

Element	Location	1	2	3	4	5	6	Average (RN)	f_{ck} (MPa)	Average f_{ck}
Beam 1 (B1)	B (7')	31	28	24	27	30	27	27.8	19.2	19.97
	L (7')	25	32	28	28	31	28	28.7	19.2	
	R (7')	33	30	31	32	26	30	30.3	21.5	
Beam 2 (B2)	B (7')	29	24	30	33	31	30	29.5	21.5	
	L (7')	30	31	29	24	27	26	27.8	18.2	
	R (7')	26	25	29	23	32	35	28.3	18.8	19.50
Beam 3	B (7')	26	35	29	32	34	24	30.0	22.2	20.10
	L (7')	32	29	28	22	25	27	27.2	17.3	
	R (7')	26	27	38	26	31	31	29.8	20.8	
Beam 4 (B4)	B (7')	27	29	25	25	27	33	27.7	19.0	17.00
	L (7')	24	25	23	26	29	27	25.7	15.5	
	R (7')	22	32	24	29	29	23	26.5	16.5	
Beam 5 (B5)	B (7')	26	25	29	27	26	24	26.2	17.1	16.40
	L (7')	29	24	26	22	23	26	25.0	14.8	
	R (7')	25	33	25	28	24	28	27.2	17.3	

Table 3: Rebound number (RN) at various locations on columns

Column	Distance from bottom	Points	1	2	3	4	5	6	Average RN	f_{ck} (MPa)	Average f_{ck}
C1	2'6"	A	21	18	25	20	14	33	21.8	11.3	18.11
	5'6"	B	22	17	24	33	34	31	26.8	16.9	
	9'6"	C	32	31	33	32	28	31	31.2	22.6	
	11'6"	D	34	28	37	36	38	27	33.3	25.8	
	2'6"	A'	25	29	23	19	30	34	26.7	16.7	
	5'6"	B'	32	33	28	32	26	36	31.2	22.6	
	9'6"	C'	32	28	25	27	23	29	27.3	17.5	
	11'6"	D'	22	26	21	21	22	20	22.0	11.5	
C2	2'6"	A	25	21	19	22	18	22	21.2	10.7	15.64
	5'6"	B	23	21	15	18	22	27	21.0	10.5	
	9'6"	C	22	23	28	21	28	33	25.8	15.7	
	11'6"	D	22	17	24	33	34	31	26.8	16.9	
	2'6"	A'	23	24	18	20	19	22	21.0	10.5	
	5'6"	B'	31	31	25	37	30	36	31.7	23.3	
	9'6"	C'	28	30	33	36	33	28	31.3	22.9	

	11'6"	D'	25	23	29	28	23	21	24.8	14.6	
C3	2'6"	A	35	34	31	37	36	37	35.0	28.3	22.91
	5'6"	B	27	32	20	26	38	35	29.7	20.6	
	9'6"	C	28	27	24	42	24	26	28.5	19.0	
	11'6"	D	32	38	29	29	26	31	30.8	22.2	
	2'6"	A'	39	22	34	33	33	39	33.3	25.8	
	5'6"	B'	31	26	24	33	38	35	31.2	22.6	
	9'6"	C'	32	34	28	32	28	36	31.7	23.3	
	11'6"	D'	23	26	33	32	33	35	30.3	21.5	
C4	2'6"	A	24	32	26	32	31	22	27.8	18.2	18.60
	5'6"	B	30	32	28	21	25	32	28.0	18.4	
	9'6"	C	25	29	33	37	34	40	33.0	25.3	
	11'6"	D	26	22	24	26	22	24	24.0	13.6	
	2'6"	A'	26	27	32	27	25	28	27.5	17.8	
	5'6"	B'	23	22	30	31	26	24	26.0	15.9	
	9'6"	C'	25	32	28	33	33	30	30.2	21.2	
	11'6"	D'	33	32	25	22	30	27	28.2	18.6	
C5	2'6"	A	20	18	26	29	15	30	23.0	12.6	14.93
	5'6"	B	30	30	27	26	30	31	29.0	19.7	
	9'6"	C	23	25	24	26	25	22	24.2	13.8	
	11'6"	D	27	24	22	21	20	22	22.7	12.2	
	2'6"	A'	18	17	20	25	22	21	20.5	10.0	
	5'6"	B'	26	22	24	32	20	24	24.7	14.4	
	9'6"	C'	32	31	25	27	28	36	29.8	20.8	
	11'6"	D'	24	32	27	33	22	18	26.0	15.9	

Table 4: RN values at various locations of slabs

Slab	Distance	Points	1	2	3	4	5	6	Average RN	f_{ck} (MPa)	Average f_{ck}
SB1	3'	A	22	23	22	26	32	31	26.0	16.9	13.79
	4'	B	23	26	24	23	20	22	23.0	13.3	
	9'	C	25	20	22	21	20	18	21.0	11.2	
	10'	D	28	25	20	20	25	22	23.3	13.7	
SB2	3'	A	21	23	24	23	22	25	23.0	13.3	11.46
	4'	B	20	17	18	21	23	21	20.0	10.2	
	9'	C	23	22	21	19	18	17	20.0	10.2	
	10'	D	23	21	21	20	23	23	21.8	12.1	
SB3	3'	A	22	23	24	25	24	24	23.7	14.1	15.01
	4'	B	23	26	23	24	27	23	24.3	14.9	
	9'	C	27	24	26	25	31	27	26.7	17.7	
	10'	D	24	25	21	23	23	22	23.0	13.3	
SB4	3'	A	24	22	26	24	26	27	24.8	15.5	17.81
	4'	B	35	30	30	29	26	24	29.0	20.8	
	9'	C	17	24	28	30	24	24	24.5	15.1	
	10'	D	31	23	27	32	30	27	28.3	19.9	
SB5	3'	A	23	31	28	22	28	27	26.5	17.5	12.32
	4'	B	22	24	18	17	21	22	20.7	10.9	
	12'	C	23	25	16	17	22	19	20.3	10.5	
	13'	D	23	21	20	18	21	18	20.2	10.4	

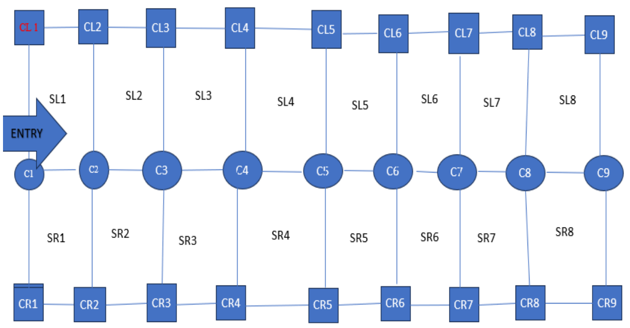

Figure 2: Plan of beam column and slab network

2.2.2 RN value of column

The RN values on various distances from the bottom to top of the columns selected for the study, within the building (C1 to C5), as shown in Table 3. It outlines the distances from the bottom, measured points, and rebound values for each column. For instance, in Column C1, located 2'6" from the bottom, rebound values range from 21 to 33, with an average of 21.80. Similar measurements are provided for columns C2 to C5. Figure 3 shows the positions along the length of a column, of points A, B, C and D for RN readings for a column. The points A', B', C' and D' are the points located diametrically opposite to A, B, C and D respectively along the column length. These average RN values offer insights into the concrete column's hardness and integrity at varying heights, aiding in structural strength evaluation [24].

The plan view shown in Figure 2 gives the locations of the left columns (CL), center column (C), right columns (CR), left slab (SL), and right slab (SR), with column numbers indicated. The columns were tested on the sides hence the direction of probing was horizontal. The relevant correlation equation was used to determine the f_{ck} of concrete of columns.

Figure 3: Locations along column length of points where RN readings were taken

2.2.3 RN Value of Slab

The RN (Rebound Number) values of slab elements chosen are mentioned in Table 4. The slabs were tested from the underside hence the direction of probing was vertically upwards. Hence the relevant correlation equation was used to determine the f_{ck} of concrete of slabs.

3.0 RESULTS AND DISCUSSION

The data presented in Table 2, Table 3 and Table 4 have been consolidated and presented comprehensively in Table 5.

3.1 Residual Strength Non-Destructive Test Results

The average values of residual f_{ck} of concrete obtained by RH test for the selected five beams, five columns and five slabs are compiled in Table 5 below for comparison.

Table 5: Average values of residual f_{ck} of concrete obtained by RH test

Beams	Average f_{ck} for beams (MPa)	Columns	Average f_{ck} for columns (MPa)	Slabs	Average f_{ck} for slabs (MPa)
B1	19.97	C1	18.11	SB1	13.79
B2	19.50	C2	15.64	SB2	11.46
B3	20.10	C3	22.91	SB3	15.01
B4	17.00	C4	18.60	SB4	17.81
B5	16.40	C5	14.93	SB5	12.32

Table 5 shows that the residual strength obtained is maximum for beams, then for columns and least for slabs. For beams, the strength ranges from 16.40 MPa to 20.10 MPa for beams, 14.93 MPa to 22.91 MPa for columns and 11.46 MPa to 17.81 MPa for slabs. This shows that the slabs have undergone maximum degradation due to fire exposure.

3.2 Results of Colorimetry Test for Temperature Evaluation

The approximate temperatures to which the selected structural elements were subjected during fire were evaluated and mentioned in Table 1. Eurocode 2 [25] provides a curve showing the reduction in compressive strength of concrete with the rise in temperature to which it has been subjected. Table 6 shows the reduction factors for f_{ck} derived from Eurocode 2. These reduction factors are multiplied with the initial compressive strength of concrete (25MPa in this case for M25 grade of concrete) for assessing the residual compressive strength of the fire-damaged elements of concrete structure.

Table 6: Reduction factors for f_{ck} for concrete subjected to various temperatures

Temperature	Strength reduction factor
20	1.00
100	1.00
200	0.95
300	0.85
400	0.75
500	0.60
600	0.45
700	0.30
800	0.15
900	0.08
1000	0.04
1100	0.01
1200	0.00

Table 6 shows the correlation between various temperatures and the residual strength factors of concrete according to Eurocode 2. At high temperatures above 300°C (572°F), concrete loses significant compressive strength due to the decomposition of compounds like calcium hydroxide. At temperatures above 400°C, steel's yield and tensile strength decrease due to thermal stress. Thermal expansion can cause cracking and spalling, while moisture loss leads to drying shrinkage and reduced strength [26]. The residual compressive strength of concrete determined by applying the reduction factors and those correlated from RN values are tabulated in Table 7. The percentage difference between the values obtained by the two different methods is also shown in the table.

Table 7: Residual compressive strength of structural elements determined by Colorimetry test and Rebound Hammer test

Structural Element number	Structural Element	Temperature (degree centigrade)	Reduction Factors as per Eurocode 2	Residual Compressive strength of M25 concrete	Average compressive strength correlated from RH test	Percentage difference between values of compressive strength

1	Beam 1	(350 ^{0}C)	0.80	20.00	19.97	0.15
2	Beam 2	(350 ^{0}C)	0.80	20.00	19.50	2.50
3	Beam 3	(400 ^{0}C)	0.75	18.75	20.10	-7.20
4	Beam 4	(450 ^{0}C)	0.675	16.88	17.00	-0.71
5	Beam 5	(450 ^{0}C)	0.675	16.88	16.40	2.84
6	Col.1	(350 ^{0}C)	0.80	20.00	18.11	9.45
7	Col.2	(450 ^{0}C)	0.675	16.88	15.64	7.35
8	Col.3	(350 ^{0}C)	0.80	20.00	22.91	-14.55
9	Col.4	(450 ^{0}C)	0.675	16.88	18.60	-10.19
10	Col.5	(600 ^{0}C)	0.45	11.25	14.90	-32.44
11	Slab 1	(550 ^{0}C)	0.52	13.00	13.79	-6.08
12	Slab 2	(550 ^{0}C)	0.52	13.00	11.46	11.85
13	Slab 3	(550 ^{0}C)	0.52	13.00	15.01	-15.46
14	Slab 4	(400 ^{0}C)	0.75	18.75	17.81	5.01
15	Slab 5	(550 ^{0}C)	0.52	13.00	12.32	5.23

Positive values in the Table 7 indicate that f_{ck} values obtained from residual factors as per Eurocode 2 from temperatures obtained by Colorimetry test are higher while negative values indicate that f_{ck} values obtained from RN data is higher. The residual compressive strength of concrete of the structural elements of the buildings has been evaluated by two methods; one by applying reduction factors derived by approximate temperatures obtained by colorimetry, to the original compressive strength of concrete. The second by correlation from rebound number values obtained by Rebound hammer test on the structural elements. The values have been tabulated in Table 7. The percentage difference between the values obtained by both methods have also been mentioned in the table.

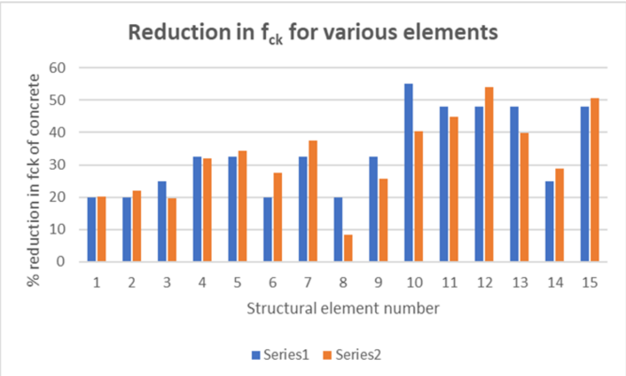

Figure 4: Percentage reduction of f_{ck} for various structural elements

The values obtained by the two methods are in fair correlation. Except for one case, the percentage difference between the values of residual compressive strength of concrete obtained by the two methods does not exceed 15.5%. This is even well within the accuracy limits of the non-destructive tests performed (±25%). The Table 7 also shows that the strength of concrete has been reduced to a large extent. The original grade of concrete was M25 which means the characteristic compressive strength of cocnrete was atleast 25 MPa initially after construction. After fire exposure, the strength values for the selected structural elemetns ranges from 11.25 MPa to 20.00 MPa obtained by reduction factors as per Eurocode 2 and ranges from 11.46 MPa to 22.91 MPa as derived from RN values. The percentage reduction in the values of fck derived by the two methods is illustrated in Figure 4.

The bar graph shown in Figure 4 shows the percentage reduction in the values of f_{ck} of concrete for the various structural elements when compared with the initial f_{ck} i.e. 25 MPa for M25 grade of concrete. The X axis shows the data for 15 structural elements, viz 5 beams, 5 columns and 5 slabs respectively as mentioned in Table 7. The graph shows that the values of percentage reduction in f_{ck} is quite similar when obtained by the two methods. The reduction in f_{ck} ranges from 20 % to 55% when obtained by colorimetry and reduction factor while the reduction varies from 8.36% to 54.16% when obtained from RH test. The structure underwent a rapid assessment to gauge fire damage, with phenolphthalein carbonation tests revealing conditions from mild to severe. Analysis showed a predominant pinkish-red hue, indicating temperatures between 300 and 600°C during the fire.

4.0 CONCLUSIONS

In summary, this study has provided valuable insights into evaluating fire-damaged concrete structures and their implications for future use. The residual strength of concrete could be effectively determined by both methods viz. colorimetry with reduction factions and by RH test. The percentage difference between the values of residual f_{ck} obtained by both methods is upto 16%. The average residual strength was found to be ranging from 16 MPa to 20 MPa for beams, 11 MPa to 23 MPa for columns and 11 MPa to 19 MPa for slabs. These elements can be suitably retrofitted using the standard techniques. The study revealed a close correspondence between the compressive strength results obtained from both the test methods, and efficacy of these techniques in assessing structural integrity. However, the colorimetry method of identifying pink/reddish colour adopted in the present study works only within the temperature range of 300 to 600ºC which forms a limitation of this method. RH method also needed chipping off of the external layer of concrete formed because of fire exposure to omit the erroneous high RN values that could be obtained. The study underscores the importance of employing comprehensive and impartial methodologies to assess such structures, enabling well-informed decisions regarding their rehabilitation or reconstruction. The results presented in this study enhance our understanding of assessing fire damage in concrete structures and offer practical insights for guiding future research and engineering endeavors in this area.

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