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THE IMPACT OF TEMPERATURE ON CONCRETE STRENGTH: UNDERSTANDING THE EFFECTS

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ABSTRACT

In this study, we investigated the impact of temperature levels and duration on the mechanical behavior of concrete, focusing on fire safety measures for structural members. We produced concrete mixes of M-35 and M-45 grade and prepared 48 cubes (100x100x100 mm) and 48 cylinders (150mm diameter and 300mm height). These specimens were cured for 28 days and subsequently dried at room temperature. After one day in the laboratory, they were exposed to temperatures of 300, 500, and 800°C for durations of 1 and 3 hours. We then determined various mechanical properties, including compressive strength, split tensile strength, loss in mass, rebound number, and ultrasonic pulse velocity. Our findings indicate that exposure to high temperatures resulted in a reduction in both compressive and split tensile strength of the specimens. Additionally, we observed an increase in crack width with rising temperature. These outcomes highlight the negative effects of elevated temperatures on the mechanical properties of concrete. To summarize, our study emphasizes the significance of incorporating appropriate fire safety measures in structural design. By understanding the influence of temperature on concrete strength and behavior, we can better develop strategies to enhance the fire resistance of structural elements.

1. INTRODUCTION

In the current context, as engineers responsible for the safety of structures, it is imperative to address the threats posed by various natural disasters (such as earthquakes, floods) and man-made incidents (such as blasts), which often involve fire hazards. Fire poses a significant challenge to the performance of building elements like columns, slabs, and walls, necessitating a thorough understanding of the changes in concrete properties resulting from exposure to extreme temperatures. To accurately assess the behavior of high-rise reinforced concrete members, it is crucial to study the effects of extreme temperature exposure on concrete properties. Given that high-strength concrete often incorporates different binder materials alongside cement, it has become increasingly important to investigate how the type of binder material influences concrete properties under elevated temperature conditions.

By conducting research in this area, we can gain insights into the performance of concrete structures during unexpected fire incidents. Understanding the behavior of concrete under extreme temperatures, considering factors such as binder type and concrete composition will enable us to develop strategies to enhance the fire resistance of high-rise buildings and ensure the safety of occupants in such scenarios.

2. OBJECTIVE

The primary aim of this project is to investigate the mechanical properties of high-strength concrete when subjected to high temperatures, specifically in the event of a fire. The project involves several key steps, including:

1. Material Procurement: Gathering the necessary materials required for the laboratory experiment.
2. Design Mix Preparation: Formulating the appropriate design mix for the high-strength concrete to be used in the study.
3. Specimen Preparation: Creating concrete specimens in the form of cubes and cylinders.
4. Thermal Exposure: Placing the cured specimens in an electric furnace and subjecting them to various temperatures and durations as per the experimental plan.
5. Destructive and Non-Destructive Testing: Conducting both destructive and non-destructive tests on the concrete specimens that have been thermally exposed.
6. Evaluation of Mechanical Behavior: Analyzing and observing the changes in the mechanical behavior of the concrete specimens resulting from the thermal exposure.

3. LITERATURE REVIEW

The increasing use of high-strength concrete has resulted in thinner columns and greater achievable building heights. Thermal conductivity plays a very important role for determining the heat transfer within concrete elements

Bentz, D.P., & Stutzman P.E.(2010), Modeling the Effect of Temperature on Early-Age Concrete Strength Development. Cement and Concrete Research,40(1), 138-145. This Study focuses on the early-age strength development of concrete under different temperature conditions. It employs modeling techniques to investigate the relationship between Temerature and concrete strength during the initial stages of hydration. Bamforth, P.B., & Banfill, P. F. (2006). Effects of Temperature on Strength Development of Mortar and Concrete. Magazine of Concrete Research, 58(1), 21-31. Examining the effects of temperature on the strength development of both mortar and concrete, this research investigates the impact of elevated temperatures on the hydration process and the resulting strength properties. It provides insights into the time-temperature relationship and its influence on concrete strength. Kaushik, H. B., & Kumar, R. (2012). Effect of Elevated Temperature on Mechanical Properties of Concrete. International Journal of Engineering Research and Applications, 2(6), 250-254. This study explores the mechanical properties of concrete when subjected to elevated temperatures. It examines the effects of temperature on compressive strength, tensile strength, and other key mechanical parameters, providing valuable information for assessing the performance of concrete under high-temperature conditions. Shariq, M., & Soroushian, P. (2014). Strength and Durability of Concrete at Elevated Temperatures: A Review. Journal of Materials in Civil Engineering, 26(8), 04014059. Focusing on the strength and durability of concrete when exposed to elevated temperatures, this review article summarizes existing research and discusses the mechanisms behind strength degradation. It covers various factors affecting concrete performance, including thermal spalling, micro structural changes, and the role of different concrete constituents. Gao, X., Zhu, H., & Xie, N. (2018). Mechanical Properties of Concrete at High Temperature: A Review. Construction and Building Materials, 173, 96-109. This comprehensive review article provides an overview of the mechanical properties of concrete at high temperatures. It discusses the effects of temperature on compressive strength, tensile strength, modulus of elasticity, and other mechanical parameters. It also examines the impact of high temperature on the microstructure and durability of concrete. Wong, H. S., & Buenfeld, N. R. (2007). Influence of Elevated Temperature Curing on the Strength and Microstructure of Ordinary Portland cement Pastes. Cement and Concrete Research, 37(4), 557-564. Focusing on the influence of elevated temperature curing on concrete strength and microstructure, this study investigates the effects of different curing conditions on the final strength and micro structural properties of ordinary Portland cement pastes. It provides insights into the curing practices that can optimize concrete strength under elevated temperature conditions. Huang, Z., Hu, X., & Fan, X. (2019). Review on the Effects of Temperature on the Mechanical Properties of Concrete. Construction and Building Materials, 221, 659-672. This review article offers a comprehensive overview of the effects of temperature on the mechanical properties of concrete. It discusses the impact of temperature on compressive strength, tensile strength, elasticity, and other mechanical parameters. It also explores the underlying mechanisms and provides recommendations for mitigating the adverse effects of temperature on concrete performance.

4. MATERIALS AND METHODS

The investigation involved the use of normal concrete and high-strength concrete, and the materials used were selected in accordance with the recommendations of the Bureau of Indian Standards (BIS). For the cement component, Shree Ultra 43 grade cement (OPC) from a single batch was obtained in the laboratory. The physical properties of the cement were determined through laboratory testing procedures.

Table No. 4.1. Physical characteristics of cement

Sr. No.	Properties	Referred Code	Value	Codal requirement
1	Fineness (cm^2/g)	IS:4031(P-2)-1999	2940	222 min
2	Specific Gravity		3.16	-
3	Soundness	IS:4301(P-3)-1988	1.75	30
4	Normal Consistency		28.9	30
5	Initial setting time (min)	IS:4031 (P-5)-1988	56	-
6	Final Setting time (min)		224	600 max

Table No.4.2 Chemical Properties of Cement

Sr No.	Chemicals	Chemical Compositions (%)
1	Loss of ignition	2.05
2	SiO_2	20.75
3	Al_2O_3	3.90
4	Fe_2O_3	5.50

5	CaO	61.95
6	MgO	1.5
7	SO_3	4.15
8	Free lime	1.40

MIX DESIGN

Table No.4.3 Final mix proportion for concrete

Water	Cement	Fine Aggregate	Coarse Aggregate
191.58	425.3 kg	556.06 kg	1248.3 kg
0.45	1	1.31	2.99

Concrete mixes were prepared for two different grades, M-35 and M-45, with water-cement ratios of 0.45 and 0.35, respectively.

Water	Cement	F.A	C.A
0.45	412	425	1502

Water	Cement	F.A	C.A
0.35	1	1.03	3.64

5. RESULT AND DISCUSSION

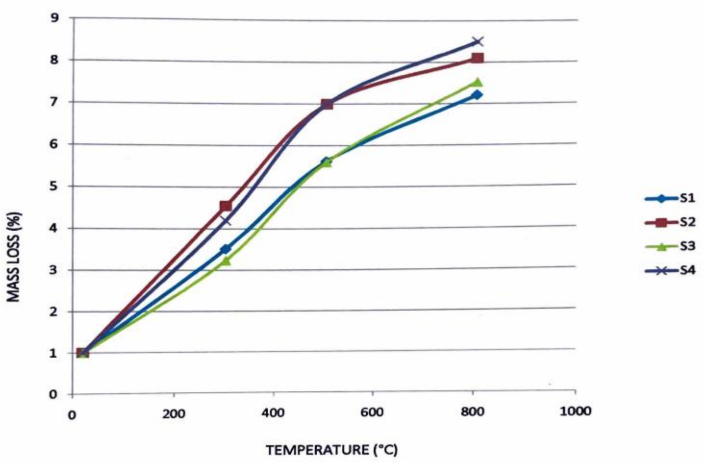
Based on the experimental investigation and test results, the following are the findings and observations;

Table -5.1 Loss in mass for concrete specimens (in % of mass)

		CUBE SPECIMEN AT TEMPERATURE			
GRADE	TIME	20°C	300°C	500°C	800°C
M-35	1 3	0 0	3.5 4.55	5.62 7	7.21 8
M-45	1 3	0 0	3.23 4.2	5.601 7	7.531 8.5

Table 5. 2: Notations used in graphs(For all successive graphs)

S.NO	DESIGNATION	DISCRIPTION
1	S1	M-35, 1hr
2	S2	M-35, 3hr
3	S3	M-45, 1hr
4	S4	M-45, 3hr



Graph 5. 1 : Mass Loss v/s Temperature

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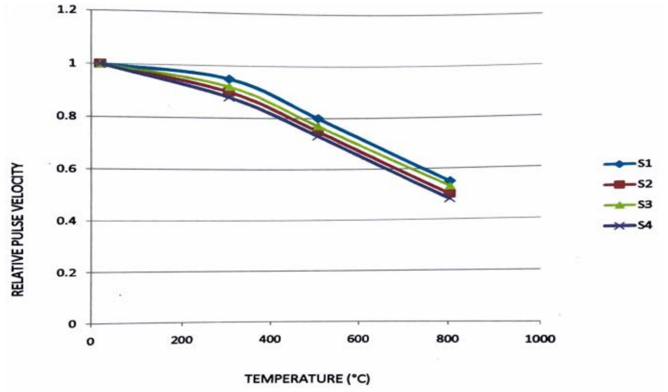
ULTRASONIC PULSE VELOCITY TEST

Table 5.3 Ultrasonic Pulse velocity for concrete specimen (in km/sec.)

		CUBE SPECIMEN AT TEMPERATURE			
GRADE	TIME	20°C	300°C	500°C	900°C
M-35	1	3.320	3.154	2.656	1.826
	3	3.309	2.988	2.49	1.66
M-45	1	4.12	3.790	3.172	2.187
	3	4.09	3.599	2.993	1.967

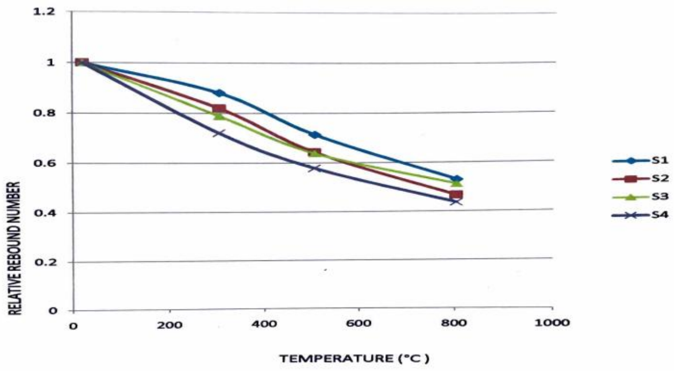


Graph 5.2 Relative Pulse velocity/ Temperature

REBOUND NUMBER

Table 5.4 Rebound no. for concrete specimen

		CUBE SPECIMEN AT TEMPERATURE			
GRADE	TIME	20°C	300°C	500°C	800°C
M-35	1	31.23	27.52	22.31	16.8
	3	31.221	25.61	20.13	14.58
M-45	1	33.431	48.86	21.38	17.13
	3	33.44	45.45	19.37	14.61



Graph 5.3: Relative Rebound Number v/s Temperature

Compressive strength

Table 5.5: Strength of Concrete specimens (in N/mm²)Compressive

		CUBE AT TEMPERATURE			
GRADE	TIME	20°C	300°C	500°C	800°C
M-35	1	43.56	41.38	22.65	10.89
	3	43.57	34.85	21.78	5.66
M-45	1	56.82	48.86	28.41	8.52
	3	56.82	45.45	22.73	5.68

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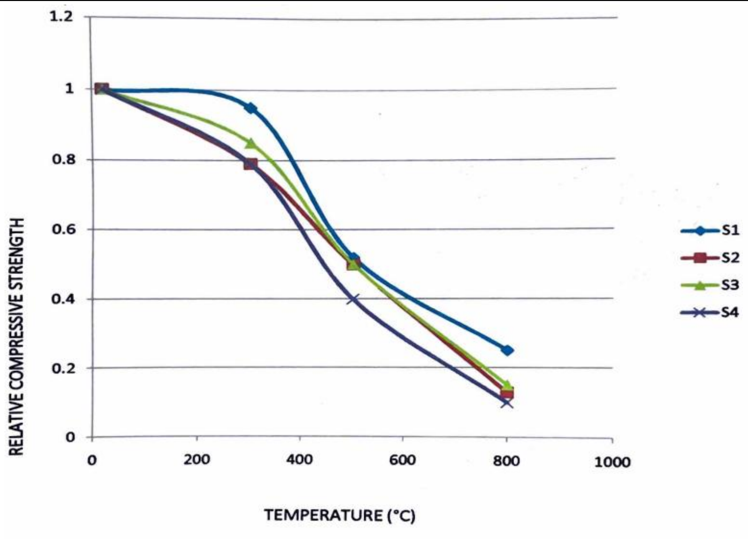
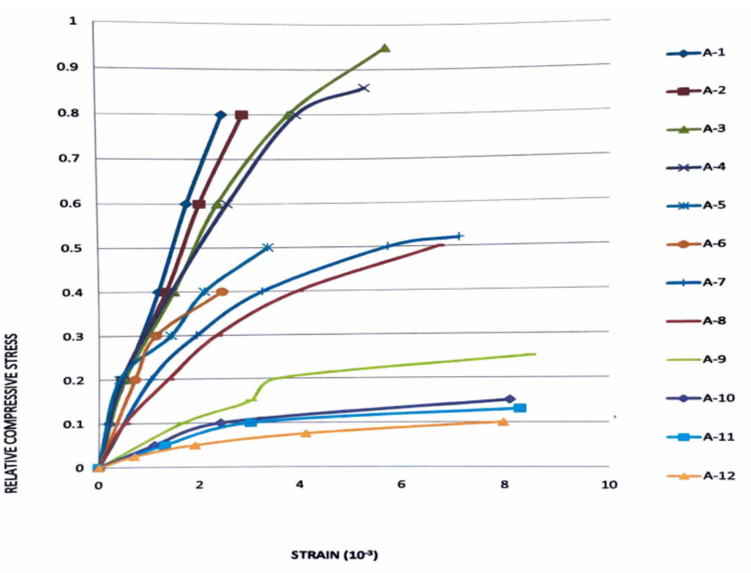


Graph 5.4: Relative compressive strength v/s Temperature

Table 5.6: Description of notations for Graph 4.5

S.NO	DESIGNATION	DISCRIPTION
1	A1	M-35, 3hr, 300°C
2	A2	M-45, 3hr, 300°C
3	A3	M-35, 1hr, 300°C
4	A4	M-45, 1hr, 300°C
5	A5	M-35, 3hr, 500°C
6	A6	M-45, 3hr, 500°C
7	A7	M-35, 1hr, 500°C
8	A8	M-45, 1hr, 500°C
9	A9	M-35, 1hr, 800°C
10	A10	M-45, 1hr, 800°C
11	A11	M-35, 3hr, 800°C
12	A12	M-45, 3hr, 800°C

Graph 5.5 shows variation of relative stress (the ratio of stress at certain elevated temperature to that of at room temperature) for M-35 and M-45 grades.

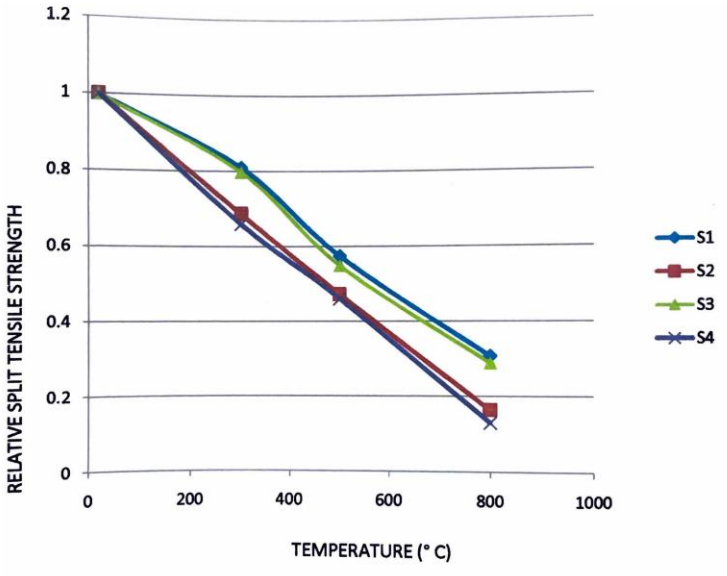


Graph 5.5 : Relative Compressive Stress v/s Strain

SPLIT TENSILE STRENGTH

Table 5.7 Split tensile strength of concrete specimens (In N/mm²)

		CUBE AT TEMPERATURE			
GRADE	**TIME**	**20°C**	**300°C**	**500°C**	**800°C**
M-35	1	3.8204	3.097	2.195	1.483
	3	3.819	2.624	1.803	0.664
M-45	1	5.113	4.090	2.812	1.176
	3	5.106	3.374	2.351	0.627

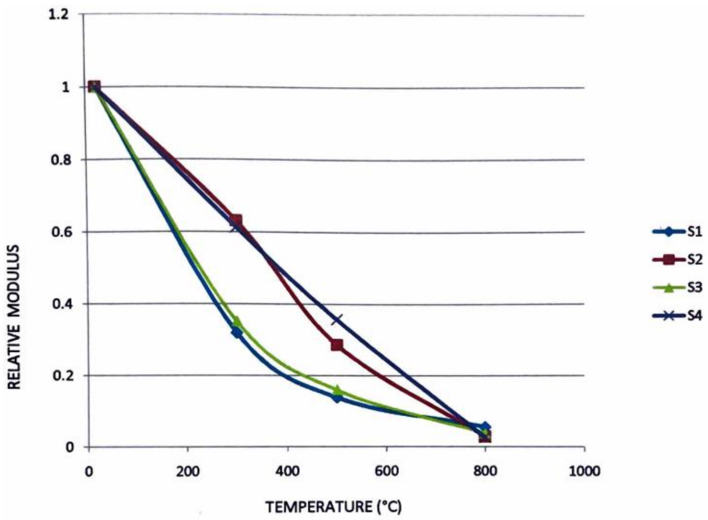


Graph 5.6: Relative Spilt Tensile Strength v/s Temperature

MODULUS OF ELASTICITY

Table 5.8 Modulus of Elasticity for concrete specimens (in N/mm²)

		CUBE AT TEMPERATURE			
GRADE	**TIME**	**20°C**	**300°C**	**500°C**	**800°C**
M-35	1	$2.28X10^4$	$0.738\ X10^4$	$0.139\ X10^4$	$0128\ X10^4$
	3	$2.292\ X10^4$	$1.45\ X10^4$	$0.660\ X10^4$	$0.068\ X10^4$
M-45	1	$2.642\ X10^4$	$0.93\ X10^4$	$0.424\ X10^4$	$0.105\ X10^4$
	3	$2.640\ X10^4$	$1.623\ X10^4$	$0.946\ X10^4$	$0.071\ X10^4$



Graph 5.7: Relative Elastic Modulus v/s Temperature

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6. CONCLUSION

Based on the experimental investigations conducted, several conclusions can be drawn:

1. Heating the concrete up to 300°C for one hour did not have a significant effect on the compressive and tensile strength. However, as the temperature and exposure time increased, noticeable losses in both compressive and tensile strengths were observed.
2. The reduction in compressive strength was found to be lower for M-35 grade concrete compared to M-45 grade concrete. This suggests that M-35 grade concrete exhibits better resistance to high-temperature effects.
3. Discoloration of concrete was observed at temperatures higher than 300°C, while minimal color change was observed at temperatures below 300°C.
4. Prominent crack patterns were observed in the concrete specimens subjected to temperatures above 500°C. No such significant cracks were observed in specimens subjected to temperatures below 500°C. This indicates that higher temperatures lead to more pronounced cracking and damage in the concrete.
5. The loss in mass of the concrete specimens increased with the increase in temperature. This is consistent with the evaporation of water and the release of chemically bound water within the concrete as it is exposed to higher temperatures.

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