Grenze International Journal of Engineering and Technology, June Issue

Study on Compressive Strength of Concrete Subjected to Sustained Elevated Temperature with different Grades of Concrete

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***Abstract*—Concrete structures often face challenges under elevated temperatures, which can compromise their mechanical properties and durability. Understanding the behaviour of different concrete grades under such conditions is crucial for ensuring their performance in high-temperature environments. This study investigates the thermal behaviour and mechanical performance of concrete grades M20 and M30 under sustained elevated temperatures. Experimental trials examined compressive strength, mass loss, and visual changes in specimens subjected to temperatures of 250°C, 275°C, and 300°C for two hours. Results reveal distinct trends in weight loss and compressive strength across temperature intervals. M20 grade concrete exhibited higher vulnerability, with a pronounced reduction in strength and weight compared to M30. M30 grade concrete displayed superior thermal resistance, attributed to its enhanced mix design. Both grades showed comparable degradation patterns at higher temperatures, with an overall compressive strength reduction of approximately 35%. Visual observations highlighted discoloration, microcracks, and chalky textures as indicators of thermal stress. The findings underscore the significant influence of material composition on concrete's thermal performance, emphasizing the importance of selecting appropriate grades for high-temperature applications.**

***Keywords*— Portland Pozzolana Cement, Elevated Temperatures, Mass loss, Compressive Strength.**

I. INTRODUCTION

Concrete history dates back to ancient times, with early civilizations using clay as a binding agent, while Egyptians enhanced it with lime and gypsum, and Romans further improved it using hydraulic lime and volcanic ash for structures like the Pantheon and Colosseum [1]. Concrete use declined until the 18th century, when Joseph Aspdin developed Portland cement in 1824, made from burned and ground clay and limestone [2]. Throughout the 19th and 20th centuries, concrete became essential for industrial and civil engineering projects, benefiting from innovations like shotcrete, prestressed concrete, and reinforced concrete. Today, it remains one of the most versatile and widely used building materials worldwide. Due to the advancement of urbanization, the demand for concrete across wide ranging and extreme environments, including high temperatures have grown drastically.

Grenze ID: 01.GIJET.11.2.716

Elevated temperatures associated with infrastructure projects like power plant and industrial facilities, as well as fire prone structures can lead to severe changes to a concrete physical and mechanical properties. Concrete is subjected to drastic transformations when temperature rise, such as experiencing weight loss from water evaporation and components disintegration, while strength loss is a result of micro crack formation and deterioration of cement-aggregate bond stiffness and strength [3], [4]. Especially rapid or uneven changes in temperature can lead to cracking and spalling through contraction and expansion while chemical reactions can cause changes in color or texture[5]. A combination of factors, including cement and aggregate quality, water to cement ratio, curing conditions, and moisture content determine the severity of these temperature effects [6], [7]. Specialized heat-resistant concrete which contain pozzolans and fire proofing compounds help alleviate these detrimental impacts, which need to be the focal point when designing structures built for high temperature or fire conditions [8].

In simpler terms, compressive strength indicates a material's ability to withstand forces that attempt to diminish its dimensions, like measuring the ability of concrete to sustain axial and crushing loads at a laboratory setting [1]. The type of cement being used, it can be Portland, slag, or special types, largely influences the development of concrete's ultimate strength. The properties of coarse aggregates as to their type, size, shape, and gradation affect considerably the strength and structural properties of concrete [9]. In addition, cement's physical and chemical attributes affect the strength significantly, with PPC type being appropriate in construction works under water because of its chemical resistance [10]. Less water in relation to cement is important, for less ratio means stronger binds amongst cement particles, but too much water can negatively affect the concrete's structural capabilities [11].

The literature review covers studies on the behaviour of concrete at elevated temperatures, comparing different types of cement and examining changes in mechanical properties. [12], [11] studies showed that concrete's mechanical properties significantly degrade at high temperatures, with complete tensile strength loss occurring around 800°C and NSC showing up to 73% strength loss. [10] research on HSC revealed that specimens with silica fume experienced explosive failure at 600°C, with strength losses of 44% at 400°C, while flexural and split cylinder strength showed losses of 31-37% at 200°C and 53-66% at 400°C. [4] studied permeability with different concrete mixtures, while Wasim Khaliq [3] found that steel fibers improved high-temperature performance of SCC. [5], [13] research demonstrated that while HSC showed better performance below 400°C compared to NSC, it suffered severe microstructural degradation above this temperature, with HSC's compressive strength decreasing from 91.7 MPa to 28.4 MPa at 800°C.

The main objectives of this paper are to study the property of compressive strength of concrete subjected to sustained elevated temperature of 250°C, 275°C and 300°C for 2 hours of exposure using M20 and M30 grades of concrete. Understanding the changes in concrete behaviour (Strength, colour, weight loss) under higher temperature. Then compare the variation of compressive strength and physical properties of different grades of concrete subjected to elevated temperatures as well as room temperature.

II. MATERIALS AND METHODOLOGY

A. Materials

Portland Pozzolana Cement used in this study conforms to [14], with its properties detailed in Table 1 meeting the requirements of IS 4031. Manufactured sand (M-Sand), with a particle size of less than 4.75 mm, has a specific gravity of 2.65 and a fineness modulus of 2.51. It conforms to Zone II specifications as per [9]. Coarse aggregates, comprising 20 mm downsize and 12.5 mm downsize fractions, with a specific gravity of 2.74, conform to the requirements of [15]. Potable water from local sources, meeting the requirements for concreting and specimen curing as per [1], was used.

TABLE I. PHYSICAL PROPERTIES OF CEMENT

Particulars	**Obtained Value**
Specific Gravity (PPC)	2.81
Consistency	33%
Initial Setting time	45 mins
Final Setting time	100 mins

B. Mix Proportioning

Concrete mix proportioning was conducted in accordance with [16] and [1] for two grades: M20 with a water-to-cement (w/c) ratio of 0.55 and M30 with a w/c ratio of 0.45. To examine the influence of w/c ratio and cement content on concrete grade, mixes were prepared with varying w/c ratios, as detailed in Table 2. Additionally, superplasticizer was used in the M30 grade to achieve the same slump as the M20 mix.

TABLE II: PROPORTIONING DETAILS FOR M20 GRADE CONCRETE MIX

Particulars	Quantity (kg/m^3)	
	M20	M30
Cement	348	336
Fine Aggregate	700	657
Coarse Aggregate	1132	1167
Water	192	148
Superplasticizer	-	1

C. Methodology

After mix proportion trials confirming the consistency in flowability parameter (slump value), cubes were cast for both M20 and M30 grade concrete. The cubical mould dimensions are 150 x 150 x 150 mm. The cubes were demoulded after 24 hrs of casting and put in a curing tank until tested for their properties. After 28 days of curing, the specimens were weighed for their actual mass and tested for compressive strength, with the reported results representing the average of three specimens. Additionally, the specimens were exposed to elevated temperatures of 250 °C, 275 °C, and 300 °C for 2 hours. The weights of the specimens were recorded both before and after exposure to high temperatures. A change in colour of the concrete at elevated temperatures is also observed. After 24 hours of cooling at room temperature, the cubes were tested for compressive strength. Further, residual compressive strength along with percentage mass loss, when it is subjected to different elevated temperatures was estimated. Figure 1 shows the flow diagram of the experimental program.

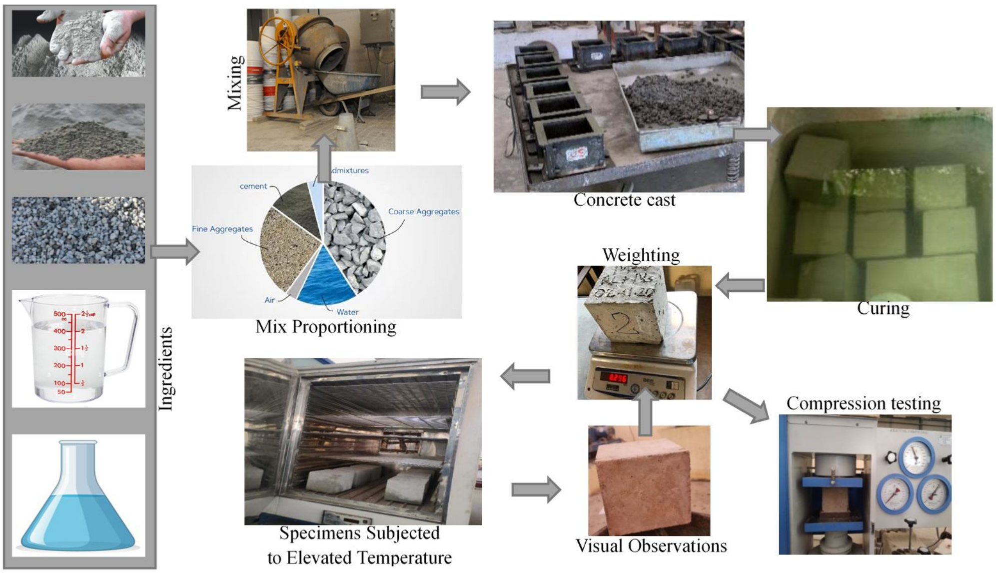

Figure 1: Flow of the experimental program

III. RESULTS

A. Visual observations

Concrete exposed to elevated temperatures undergoes noticeable visual transformations. At 250°C and 275°C, the colour slightly darkens due to dehydration effects. At 300°C, more significant changes become evident, such as a reddish or light brown hue, reflecting alterations in the mineral composition. The surface shows increased discoloration, along with potential microcracks or a chalky texture caused by thermal stress. These visual changes highlight the progressive impact of temperature on the concrete's physical characteristics.

B. Mass loss of specimens

Figure 2 demonstrates the expected mass loss of concrete due to high temperatures. The weight loss of M20 and M30 grade concrete demonstrates specific behaviour which highlights the thermal resistance of these materials. At 250°C, 275°C, and 300°C for two hours, there is a significant reduction in weight which is mostly due to moisture loss and thermal degradation beginning to set in. M20 grade concrete appears to exhibit greater loss of weight between consecutive temperatures, which suggest greater sensitivity to thermal effects. On the other hand, M30 demonstrates a more uniform weight loss profile which is attributed to its improved mix design and ability to resist heat induced deterioration. These outcomes underscore the impact of concrete grade on its thermal performance, where the higher grade concrete (M30) shows greater preservation of structural integrity at elevated temperatures, confirming the relevance of material selection for such scenarios.

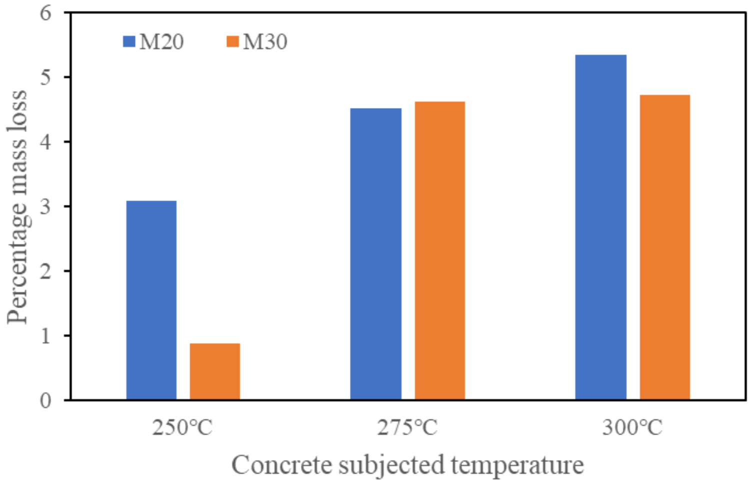

Figure 2: Percentage mass loss for M20 and M30 grades subjected to elevated temperature

C. Compressive Strength

The variation in compressive strength of M20 and M30 grade concrete subjected to elevated temperatures reveals distinct degradation patterns as presented in Figure 3. Initially, at room temperature, the compressive strength is highest, with values of 29.25 MPa for M20 and 38.88 MPa for M30. Upon exposure to 250°C for 2 hours, a significant reduction is observed, with M20 decreasing to 24.44 MPa (16% reduction) and M30 to 30.52 MPa (21% reduction). This drop is primarily attributed to dehydration and the partial decomposition of calcium hydroxide, leading to the formation of microcracks [11]. At 275°C, the compressive strength further decreases to 22.22 MPa for M20 and 27.70 MPa for M30, indicating progressive degradation due to the weakening of the cement matrix and the bond between aggregates and the binder. This interval shows a further reduction of approximately 9% for both grades from 250°C, reflecting a consistent trend in thermal deterioration.

At 300°C, the strength drops sharply to 18.96 MPa for M20 and 25.19 MPa for M30. The reduction from 275°C is approximately 14.7% for M20 caused by the complete decomposition of calcium hydroxide and increased porosity when compared to M30, which is reduced by 9% only. The overall strength reduction from room temperature to 300°C is 35% for M20 and 35.2% for M30, demonstrating similar thermal degradation patterns for both grades. These findings emphasize the impact of elevated temperatures on concrete and underline the need for proper materials selection along with proportioning to the requirements in high temperature applications.

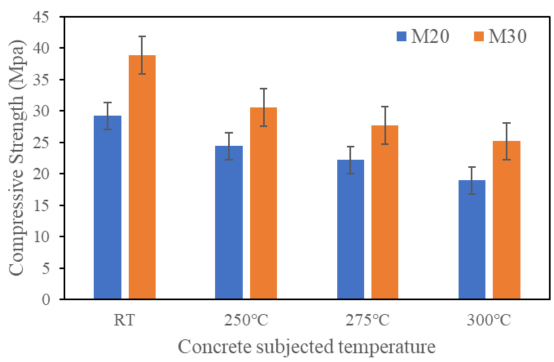

Figure 3: Comparison of compressive strength of M20 and M30 grades subjected to elevated temperature

IV. Conclusion

Overall, this study presents new evidence of the thermal behaviour and performance of concrete at elevated temperatures and identifies some specific development trends for the mechanical and physical properties of concrete. Summary of the key findings are highlighted as follow:

- Exposure to elevated temperatures causes noticeable visual changes in the concrete, such as discoloration, microcracks, and chalky textures, alongside structural alterations like increased porosity and microstructural collapse, which directly affect strength and durability.
- M20 concrete shows increasing loss in percentage with increased temperatures, which indicates that M20 concrete is more susceptible to thermal effect. M30 has a better mix design and uses superplasticizers, resulting in initial weight loss of concrete under thermal stress being less for M30.
- M30 grade concrete demonstrates better thermal resistance compared to M20 at lower temperatures, showing less weight loss at 250°C. However, both grades display similar degradation trends at higher temperatures, reflecting the progressive impact of thermal exposure.
- Both M20 and M30 grade concrete exhibit a significant reduction in compressive strength as the temperature increases. The overall reduction from room temperature to 300°C is approximately 35% for both grades, highlighting their thermal degradation patterns.

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