



Impact of High Temperatures on Concrete Performance

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Abstract

The fire safety of concrete structures is a major concern, as exposure to severe thermal environments causes significant degradation of the material's mechanical properties and integrity. This study aims to evaluate the impact of high temperatures on concrete in order to identify critical degradation thresholds and analyze the associated physicochemical mechanisms. A concrete mix was prepared using cement and local aggregates to achieve an average concrete strength of three distinct test groups with an overall mean initial compressive strength of 41.8 MPa. Concrete cores were subjected to temperature stages set at 200°C, 400°C, 600°C and 800°C for periods of 60 and 120 minutes, followed by compressive strength tests and mass loss measurements. The results obtained reveal a slight decrease in the characteristics of the concrete at temperatures below 400°C. Above this temperature, there is a drastic drop in the physical and mechanical performance of concrete, particularly in terms of compressive strength. In fact, there is an almost exponential decrease in compressive strength, which drops from 41.8 MPa before firing to 8 MPa and 4.9 MPa for firing at 800 °C for 60 and 120 minutes. This thermal degradation is due to the decomposition of portlandite, which leads to a decline in density, increase in porosity and loss of bonds between aggregates, as well as the appearance of micro cracks in concrete test specimens.

Keywords: Compressive Strength, Concrete Performance, High Temperatures, Mass Loss, Thermal Degradation.

Introduction

Concrete is widely recognized as the primary material for structural engineering due to its remarkable mechanical strength, versatile moldability and intrinsic fire resistance. However, when subjected to extreme thermal environments such as those encountered during severe residential, industrial, or infrastructure fire events, it undergoes complex chemical, physical and microstructural transitions that can drastically jeopardize overall structural stability and material safety (1). These changes directly affect the load-bearing safety of infrastructure during and after fire exposure (2). The rapid rise in temperature triggers a series of highly destructive, multi-scale internal reactions: beginning with the rapid evaporation of free water within the capillary pores, followed by the gradual chemical dehydration of the primary binding matrix, the Calcium Silicate Hydrate (C-S-H) gel network and the structural decomposition of early hydration products like ettringite, alongside a mismatch in thermal expansion coefficients between the expanding aggregate phase and the contracting cementitious paste (3, 4). These coupled thermal

and mechanical processes are the fundamental causes of a drastic reduction in the material's macroscopic tensile strength, compressive strength and modulus of elasticity; frequently culminating in explosive spalling that directly exposes internal steel reinforcements to structural failure (5-7). The resistance of concrete to such extreme thermal stresses has historically been a focal subject of rigorous scientific investigations aimed at correlating the catastrophic loss of macroscopic properties with underlying microstructural and mineralogical changes (8). Traditionally, concrete was perceived by designers as a material that was naturally insulated against heat due to its low thermal conductivity. However, extensive modern research has established that this substantial thermal inertia actually masks severe, highly destructive internal temperature gradients across structural cross-sections, inducing deep, irreversible localized damage well before the structural core reaches thermal equilibrium with the environment. Over time, the study of thermal degradation has evolved from a purely phenomenological approach to a detailed,

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high-resolution analysis of mineralogical phases and crystal network transformations. In particular, past studies have established robust empirical relationships between temperature rise and residual compressive strength, confirming that the mechanical behavior of concrete under fire is closely linked to critical shifts in its capillary porosity and internal crack distribution (9). Recent advanced work has significantly deepened our understanding of these decomposition mechanisms, highlighting that high-temperature structural failure is not a localized mechanical collapse, but rather results from widespread chemical disintegration of the binding cement matrix above the critical 400°C threshold. Despite this large body of historical work, existing literature exhibits notable limitations that restrict its direct applicability to real-world infrastructure diagnostics (10, 11). A large portion of historical fire-safety databases focuses heavily on high-performance, ultra-high-strength concrete formulations or, conversely, low-grade mortar mixes. This leaves a substantial research gap concerning mid-range structural concrete mixtures—specifically class B30 concrete formulations with a design strength exceeding 30 MPa—which constitute most standard global building frames, bridge columns and urban infrastructure components. Furthermore, past methodologies often segregate physical parameters (such as mass loss profiles) from direct destructive mechanical diagnostics, failing to establish unified, synchronized correlation graphs under identical heating step conditions and exposure durations. This knowledge gap poses a serious challenge for engineering structural safety assessments, as post-fire forensic investigations require high-fidelity, matching reference datasets to determine whether a fire-damaged frame must be demolished or can be safely rehabilitated. To address this explicit limitation, the overarching aim of this research is to comprehensively evaluate and model the physical and mechanical response of standard class B30 concrete exposed to extreme temperature stages of up to 800°C. The specific objectives designed to achieve this aim are to systematically quantify the exact residual compressive strength capacity and corresponding relative percentage mass loss at specific thermal stages set at 200°C, 400°C, 600°C and 800°C and secondly to directly isolate and evaluate the impact

of prolonged thermal exposure by comparing soaking durations of 60 minutes against 120 minutes, while establishing a definitive correlation profile mapping macroscopic load capacity loss directly to key physicochemical microstructural transformations, such as the dehydration of cement hydrates and the breakdown threshold of portlandite (12). The fundamental novelty of this investigation lies in its rigorous execution using a highly standardized, locally optimized structural mix formulation incorporating exclusively regional crushed sand and distinct gravel variants. By performing precise, synchronized physical mass-tracking alongside compressive testing on uniformly ground, high-fidelity core specimens under tightly controlled laboratory firing steps and this research deliver precise empirical correlation data. Ultimately, this work provides a valuable, localized reference framework for structural engineers conducting post-fire diagnostics, building code calibration and the targeted integration of protective fibers to mitigate explosive spalling in standard infrastructure concrete.

Materials and Methods

Materials

The aggregates used in this study are crushed sand, Gravette GI and GII gravel. These materials were sourced from the MCTT TRANS quarry on the Oued Ouargha in JorfMelha, Morocco located at coordinates (34°29'24" N, 5°30'36" W"). The tests carried out as part of this study follow a rigorous standard protocol to ensure the reliability of the results on concrete and its components.

The characterization study of aggregates was carried out in accordance with Moroccan standards. This step guarantees the quality of the reference concrete before it is subjected to thermal stress and is based on the following standards:

The particle size analysis is performed by sieving in accordance with ASTM C136/C136M-25 (13) to define the size distribution. The flatness coefficient is determined by ASTM D4791-19R23 (14) in order to evaluate the shape of the aggregates, a key parameter for mechanical interlocking. The cleanliness of the constituents is verified by two tests: the 10% fines sand equivalent test, in accordance with ASTM D2419-22 (15) to measure the purity of crushed sand and the presence of clay lumps and friable particles, evaluated in

accordance with ASTM C142/C142M-17(2023) (16). The detection of organic matter is carried out in accordance with standard ASTM C40/C40M-20 (17), ensuring the absence of impurities harmful to cement hydration. The density and absorption characteristics, which are essential for calculating volumetric dosages, were governed by bulk density and apparent density, according to ASTM C29/C29M-23 (18) and ASTM C127-25 (19). Water absorption is measured using ASTM C128-25 (20), allowing the effective water/cement ratio to be adjusted.

$$Y = 50 - \sqrt{D} + K \quad [1]$$

Where, D: Maximum aggregate size; K: Correction factor based on cement dosage, vibration power and angularity of the aggregates.

Preparation of Test Specimens

Cylindrical test specimens measuring 16 cm x 32 cm were prepared and stored in the laboratory at 20°C. At 28 days and given the dimensions of the oven, cores were taken from these test specimens to obtain cylinders measuring 7 cm x 14 cm. These test specimens were ground and prepared in three groups of samples before mechanical and thermal testing. Following standard 28-day laboratory curing and prior to high-temperature thermal execution, all core specimens were subjected to an unvented laboratory environment conditioning stage maintained at $20 \pm 2^\circ\text{C}$ and a relative humidity of $60 \pm 5\%$ for 48 hours to establish a uniform, repeatable initial moisture state across all test blocks. This controlled baseline prevents premature random hydraulic spalling from oversaturated interstitial capillary water while preserving realistic unbound water levels within the C-S-H structural matrix.

Thermal Exposure

To ensure absolute experimental reproducibility and uniform thermal loading, a highly standardized heating protocol was executed inside a laboratory electric muffle furnace equipped with a programmable digital temperature controller ensuring a temperature uniformity of $\pm 5^\circ\text{C}$. The test pieces were exposed to temperature stages of 200°C, 400°C, 600°C and 800°C in a high-temperature furnace. For each stage, the samples were kept for exposure times of 60 minutes and 120 minutes. The heating profile was implemented at a controlled, constant heating rate of $\pm 5^\circ\text{C}/\text{min}$ to minimize immediate thermal shock gradients

Concrete formulation

The concrete studied is class B30, dosed at 400 kg/m³ of CPJ45 (composite Portland cement), with a desired consistency of firm concrete workability: (slump of 100- 150 mm).

The method used to determine the optimal composition of the concrete is that of Dreux-Gorisse, using the granular reference curve formula given in Equation [1], with final mix proportions detailed in following Tables:

prior to reaching target isotherms. Core specimens were placed upright and uniformly spaced in the center of the furnace chamber to allow homogenous, omnidirectional heat penetration. Following the completion of the 60-minute or 120-minute thermal soaking duration, the furnace was deactivated and the concrete specimens underwent slow, natural cooling inside the sealed furnace chamber until reaching ambient room temperature ($20 \pm 2^\circ\text{C}$). This natural cooling approach was strictly maintained to isolate the structural damage caused purely by high thermal exposure rather than rapid quenching shocks. After exposure and cooling, the relative mass loss P (%) was measured and the compressive strength R_c was determined according to standard ASTM C39/C39M-24 (21).

Thermal and Mechanical Performance

The integrity of the material under stress was validated by Thermal stability (Loss on ignition) - Measured according to standard ASTM D7348-21 (22) to assess the initial response of constituents to heat.

Results and Discussion

The physical and mechanical quality of the concrete constituents was evaluated prior to mix formulation to ensure standard compliance and performance repeatability. Table 1 summarizes the granular cleanliness and shape characteristics of the aggregates:

Crushed Sand: Exhibited a fines content (<0.080) of 3.5%, a Fineness Modulus (MF) of 2.85 and a Sand Equivalent value at 10% fines (ES at 10%) of 79. These values confirm appropriate particle

sizing and a high level of cleanliness, preventing excessive water absorption or localized weakening during cement hydration.

Coarse Aggregates (Gravel GI and GII): Both aggregate fractions demonstrated excellent geometric properties, each recording a low Flatness

Index (FI) of 8 and high cleanliness indices of 0.1 and 0.2, respectively. A low Flatness Index guarantees a cuboidal particle shape, minimizing internal stress concentrations and enhancing mechanical interlocking within the hardened matrix.

Table 1: Granular and Cleanliness Characteristics of Aggregates

Aggregates	Crushed sand			Gravel GI		Gravel GII	
Granular characteristics	% <0.080 mm	MF	ES at 10%	FI	Cleanliness	FI	Cleanliness
	3.5	2.85	79	8	0.1	8	0.2

Note: MF = Fineness Modulus, ES at 10% = Sand Equivalent test conducted with 10% fines, FI = Flatness Index.

Table 2 outlines the physical and mechanical mass parameters of the aggregates:

Specific Mass: Ranged consistently between 2.67 t/m³ (GII) and 2.69 t/m³ (GI), with crushed sand registering 2.68 t/m³.

Bulk Density: Stood at 1.72 t/m³ for crushed sand and 1.48 t/m³ for both gravel fractions.

Los Angeles Abrasion Resistance: Both GI and GII gravels yielded a Los Angeles (LA) value of 21%. This mechanical resistance to impact and abrasion verifies that the parent rock possesses high structural integrity, ensuring that premature aggregate crushing will not govern failure during subsequent mechanical loading.

Table 2: Physical and Mechanical Properties of Concrete Components

Components	Crushed sand	Gravel GI	Gravel GII
Specific mass(t/m ³)	2.68	2.69	2.67
Bulk density(t/m ³)	1.72	1.48	1.48
Los Angeles (%)	-	21	21

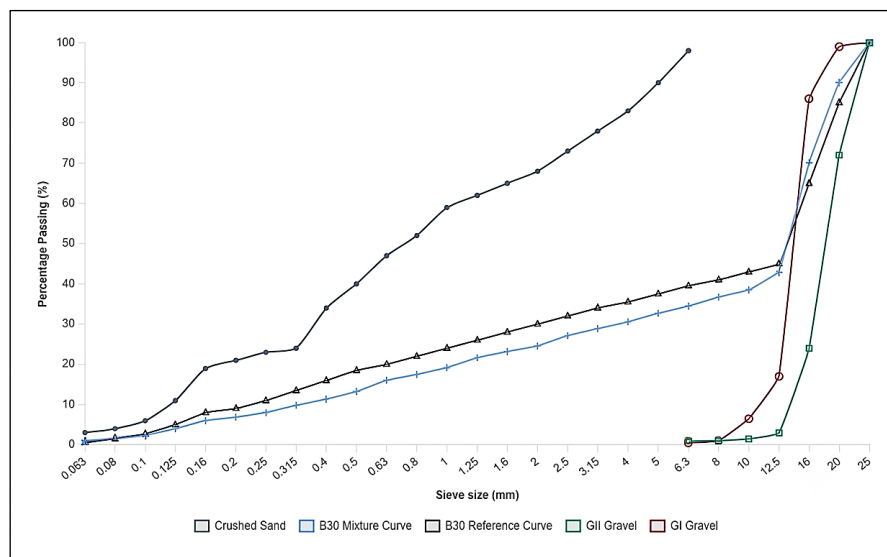


Figure 1: Grain Size Curves for Aggregates

Figure 1 and the tables show the particle size distributions for all components. The cleanliness, density and angularity values recorded for each particle size class are satisfactory. The fineness modulus of crushed sand is 2.85. These results justify the choice of these materials for concrete.

The optimized class B30 concrete mix design developed using the Dreux-Gorisse method is

presented in Table 3. To produce 1m³ of concrete, the proportions required were:

- 768 kg/m³ (470 L/m³, 42% volume) of crushed sand
- 522 kg/m³ (333 L/m³, 28% volume) of Gravel GI
- 566 kg/m³ (370 L/m³, 30% volume) of Gravel GII

d) 400 kg/m³ of CPJ 45 composite Portland cement

e) 180 kg/m³ of water, yielding a Water/Cement (W/C) ratio of 0.45 and a Gravel/Sand (G/S) mass ratio of 1.42

Table 3: Optimal Composition Ratios for B30 Concrete (Dreux Gorisse-Method [1])

Constituents	Weight dosage (kg/m ³)	Volumetric Dosage (L/m ³)	Granule Dosage (%)
Crushed sand	768	470	42
Gravel GI	522	333	28
Gravel GII	566	370	30
CPJ 45 cement	400	400 kg/m ³	-
Water	180	180	-
W/C	0.45	0.45	-
G/S	1.42	-	-



Figure 2: Specimen Preparation Process. (A) Extracted Class B30 Concrete Core Specimens (7 Cm X 14 Cm), (B) Precision End-face Grinding Machine

Concrete cores were taken and ground illustrated in Figure 2 where both circular ends of the 7cmx 14cm specimens must be ground completely flat, smooth and perpendicular to the longitudinal axis in accordance with current standards, This critical specimen preparation step ensures that when the cores are subsequently placed in the hydraulic

press for compressive strength testing, the destructive load is distributed perfectly uniformly across the cross-section, preventing premature localized failure or stress concentration during testing. The initial dimensions, masses and densities of the samples are detailed in Tables 4-6.

Table 4: Core Measurements, Group I

G I	Diameter (cm)	Height (cm)	Weight (g)	Volume (cm ³)	Density (kg/L)
a	7.3	13.0	1288.0	543.824	2.368
b	7.3	13.2	1313.0	552.191	2.378
c	7.3	13.7	1335.0	573.107	2.329
d	7.3	13.6	1334.5	568.924	2.346
e	7.3	13.6	1319.5	568.924	2.319
f	7.3	13.6	1359.5	568.924	2.390
g	7.3	13.8	1371.0	577.291	2.375
h	7.3	13.4	1321.0	560.558	2.357
i	7.3	13.3	1293.0	556.374	2.324
j	7.3	13.4	1335.0	560.558	2.382
k	7.3	13.5	1390.5	564.741	2.462

Table 5: Core Measurements, Group II

G II	Diameter (cm)	Height (cm)	Weight (g)	Volume (cm ³)	Density (kg/L)
a	7.3	13.6	1365.9	568.924	2.401
b	7.4	13.5	1401.8	580.319	2.417
c	7.4	13.6	1358.7	584.618	2.324
d	7.4	13.5	1368.0	580.319	2.357
e	7.4	13.4	1355.5	576.020	2.353
f	7.4	13.4	1356.0	576.020	2.354
g	7.4	13.6	1402.5	584.618	2.399
h	7.4	13.4	1351.5	576.020	2.346
i	7.4	13.0	1323.0	558.826	2.367
j	7.4	13.7	1433.5	588.916	2.434
k	7.4	13.7	1376.0	588.916	2.336
l	7.4	13.7	1322.0	588.916	2.245

Table 6: Core Measurements, Group III

G III	Diameter (cm)	Height (cm)	Weight (g)	Volume (cm ³)	Density (kg/L)
a	7.2	12.6	1206.0	512.749	2.352
b	7.2	12.5	1201.0	508.680	2.361
c	7.2	13.3	1253.0	541.236	2.315
d	7.2	13.5	1337.5	549.374	2.435
e	7.2	12.7	1252.0	516.819	2.423
f	7.2	12.7	1244.0	516.819	2.407
g	7.2	13.5	1281.0	549.374	2.332
h	7.2	13.6	1307.5	553.444	2.362
i	7.2	13.4	1278.0	545.305	2.344
j	7.2	13.3	1254.0	541.236	2.317
k	7.2	13.6	1325.0	553.444	2.394

Across the 34 extracted cores detailed in Tables 4-6, the concrete density remained highly consistent, displaying an overall average density of 2.36kg/L with a low overall standard deviation of 0.04kg/L. This physical uniformity verifies that the core sampling, grinding and consolidation techniques

were highly reproducible, minimizing any physical variability before thermal exposure.

The average compressive strength at 28 days measured on the unexposed specimens is 41.8MPa in Table 7.

Table 7: Compression Test on Hardened Concrete Before Exposure

Test Specimens	Compressive Strength at 28 days (MPa)			Average (Mpa)
	1	2	3	
Group I	40.6	41.1	41.5	41.1
Group II	38.2	38.8	40	39
Group III	46	45.1	44.8	45.3
				41.8



Figure 3: Thermal Exposure and Physical Degradation of Concrete Test Specimens. (A) Concrete Specimen During Thermal Exposure At 800 °C Inside the Muffle Furnace, (B) Concrete Specimen Undergoing Cooling at Ambient Room Temperature, (C) Microstructural Cracking and Surface Deterioration After Extreme Thermal Exposure

Concrete specimens were placed upright and uniformly spaced in the center of the furnace chamber to allow homogenous, omnidirectional heat penetration presented in Figure 3A. After thermal soaking duration, the concrete specimens underwent slow, natural cooling inside the sealed furnace chamber as shown in Figure 3B. Figure 3C shows the concrete test specimen after exposure. Deep longitudinal cracks can be seen, resulting from extreme differential expansion between the cement paste (due to chemical shrinkage) and the aggregates (which are undergoing thermal expansion). Surface spalling due to material loss at the edges and the detachment of surface plates

indicate the weakening of the interfacial transition zone. The powdery texture, as the concrete surface becomes brittle to the touch, is a sign of a total loss of cohesion in the cement matrix.

Post-thermal Exposure Evaluation and Performance Breakdown: Tables 8-11 present individual specimen performance metrics following exposure to elevated target temperatures (200°C, 400°C, 600°C and 800°C) for 60-minute and 120-minute holding periods. Table 12 aggregates these findings, summarizing mean residual compressive strength, standard deviation, Coefficient of Variation and relative percentage mass loss.

Table 8: Mechanical and Physical Results after Exposure to 200°C

Duration	Specimen ID	Initial Weight Pi (g)	Final Weight Pf (g)	Mass loss P (%)	Load (kN)	Resistance (MPa)	Loss of Strength (%)
60 mins	III 7	1279.8	1260.2	1.6	125.1	29.9	28.47
	II 8	1350.6	1329.2	1.6	117.4	28.2	32.54
	III 8	1305.1	1277.6	2.2	119.3	28.5	31.82
120 mins	I 2	1311.5	1282.5	2.3	93	22.2	46.89
	II 6	1355.7	1316.7	3.0	140.2	33.5	19.86

III 2	1198.7	1168.0	2.6	93.5	22.4	46.41
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Table 9: Mechanical and Physical Results after Exposure to 400°C

Duration	Specimen ID	Initial Weight Pi (g)	Final Weight Pf (g)	Mass loss P (%)	Load (kN)	Resistance (MPa)	Loss of Strength (%)
60 mins	I 1	1285.3	1236.6	3.9	111.6	26.7	36.12
	II 1	1403.3	1346.7	4.2	118	28.2	32.54
	III 1	1204.1	1156.8	4.1	95.1	22.7	45.69
120 mins	I 3	1333.2	1289.5	3.4	92.8	22.2	46.89
	II 3	1299.4	1247.3	4.2	111.2	26.6	36.36
	III 3	1251.0	1198.0	4.4	86.6	20.7	50.48

Table 10: Mechanical and Physical Results after Exposure to 600°C

Duration	Specimen ID	Initial Weight Pi (g)	Final Weight Pf (g)	Mass loss P (%)	Load (kN)	Resistance (MPa)	Loss of Strength (%)
60 mins	I 5	1315.6	1257.1	4.7	58.1	13.9	66.75
	II 5	1354.0	1287.1	5.2	69	16.5	60.53
	III 5	1250.1	1185.6	5.4	52.3	12.5	70.10
120 mins	I 6	1356.7	1292.4	5.0	51.8	12.4	70.33
	II 4	1360.1	1293.8	5.1	68	16.3	61.00
	III 4	1335.6	1266.5	5.5	48.5	11.6	72.25

Table 11: Mechanical and Physical Results after Exposure to 800°C

Duration	Specimen ID	Initial Weight Pi (g)	Final Weight Pf (g)	Mass loss P (%)	Load (kN)	Resistance (MPa)	Loss of Strength (%)
60 mins	I 7	1367.7	1295.9	5.5	34.5	8.2	80.38
	II 7	1400.7	1318.5	6.2	38.1	9.1	78.23
	III 11	1322.9	1229.2	7.6	28.4	6.8	83.73
120 mins	I 9	1289.7	1206.4	6.9	30.6	7.3	82.54
	II 10	1430.6	1331.7	7.4	10.6	2.5	94.02
	III 9	1275.3	1169.4	9.1	N.M	N.M	N.M

Note: N.M = Not Measurable.

Table 12: Results after Thermal Exposure

Temperature	Exposure Time	Average Rc (MPa)	Standard Deviation (SD)	Coefficient of Variation (CoV)	Average Mass Loss P (%)	Mass Loss SD
20°C	-	41.8	3.21	7.68%	0.00	0.00
200°C	60 mins	28.9	0.93	2.58%	1.6	0.00
	120 mins	26.0	6.47	24.88%	2.6	0.35
400°C	60 mins	25.9	2.87	10.25%	3.4	0.15
	120 mins	23.2	3.01	15.05%	4.4	0.53
600°C	60 mins	14.3	2.05	12.81%	5.0	0.36
	120 mins	13.4	2.41	20.08%	5.5	0.26
800°C	60 mins	8.0	1.15	12.78%	6.9	1.08
	120 mins	4.9	3.39	48.43%	9.1	1.20

We executed a multi-variable regression analysis using our raw synchronized dataset. The mathematical relationship governing standard Class B30

concrete under targeted thermal stress is expressed as in Equation [2]:

$$R_c/R_{c0} = -0.1064 \cdot P + 1.011 \quad (R^2 = 0.942) \quad [2]$$

Where, R_{c0} = 41.8 MPa represents the initial baseline reference strength.

Structural Interpretation: This linear-inverse correlation yields an exceptionally high coefficient of determination ($R^2 = 0.942$) showing that for every 1% increase in bulk mass loss due to

structural dehydration, Class B30 concrete experiences an average reduction of approximately 10.6% of its original baseline load capacity. This quantitative equation provides a

highly practical tool for structural engineers conducting post-fire forensic field evaluations via non-destructive core mass profiling.

Figure 4 illustrates the relative loss of strength, while Figure 5 details the absolute evolution of residual compressive strength (R_c) as a function of exposure temperature and soaking time. A quasi-exponential decrease in residual load capacity is observed, marked by a steady decline up to 400°C followed by an accelerated collapse between 400°C and 600°C as portlandite decomposes. This trend of strength loss as a function of temperature is consistent with the empirical relationships established in the literature. Prolonged exposure (120 min) accentuates this loss, particularly at 800°C, where the specimens undergo spalling (23) and the compressive strength drops to 4.9 MPa.

Our finding that a critical performance threshold exists between 400°C and 600°C yielding a ~65% drop in R_c shows clear structural consistency with

the fundamental chemical disintegration patterns observed by Khoury. However, a notable performance discrepancy is found when evaluating the 20°C to 200°C stage under prolonged duration (120 min), where our mix exhibited a sharp strength loss down to 26 MPa (37.8% degradation). While traditional models by Kodur report negligible strength losses below 200°C due to minimal chemical matrix degradation, our specific use of highly angular regional Moroccan crushed sand and gravel variants from the Oued Ouargha quarry generates severe localized internal confinement. The prolonged thermal soaking for 120 minutes amplifies the mismatch in thermal expansion coefficients between these specific regional aggregates and the contracting cement paste, provoking accelerated micro-fissuring along the interfacial transition zone (ITZ) well before portlandite decomposition initiates.

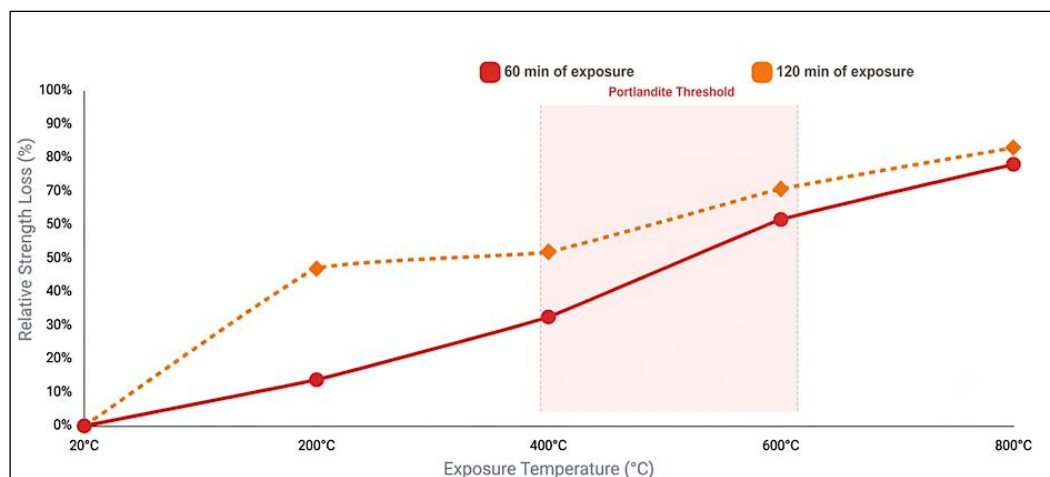


Figure 4: Variation in Strength Loss as a Function of Temperature and Exposure Time

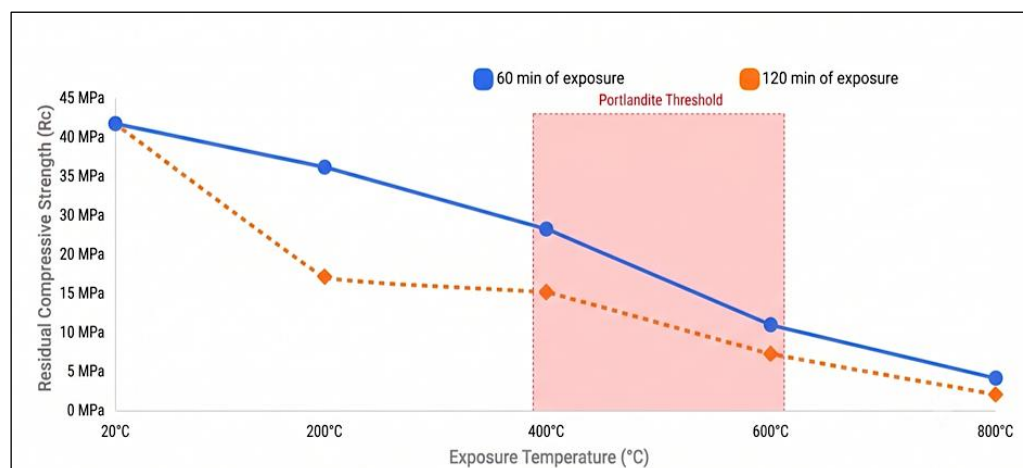


Figure 5: Variation in Strength as a Function of Temperature and Exposure Time

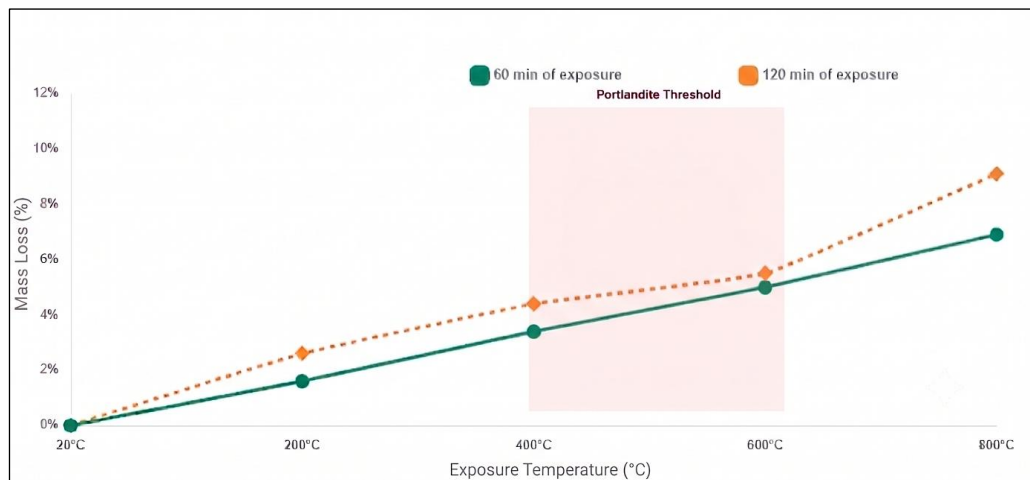


Figure 6: Variation in Mass Loss P% as a Function of Temperature and Exposure Time

Correlation between Rc and Degradation Mechanisms

Analysis of the results highlights the strong correlation between the loss of mechanical strength and the microstructural transformations of concrete identified in the literature:

- a) **20°C to 200°C:** The moderate loss of Rc (~20%) is mainly due to the evaporation of free water and weakly bound water. Partial dehydration has little effect on the overall structure. The fracture study shows that some materials can retain structural capacity up to 185°C, which corresponds to the upper limit of this first phase of degradation.
- b) **200°C to 400°C:** The loss of strength accelerates (~40%). This range corresponds to the gradual decomposition of calcium silicate hydrates (C-S-H) and the appearance of micro cracks due to differential expansion (24, 25).
- c) **400°C to 600°C (critical threshold):** A drastic drop in Rc (~65%) is observed. This is directly related to the decomposition of portlandite (Ca(OH)_2), which transforms into calcium oxide (CaO) and releases chemical water. This process weakens the paste/aggregate interface and breaks the crystal lattice (26).
- d) **600 °C to 800 °C:** Residual strength is minimal (~80% total loss). Lime (CaO) undergoes high shrinkage, leading to widespread cracking. The concrete becomes very porous and loses its mechanical rigidity, in line with thermal analyses.

Figure 6 shows that mass loss P (%) follows an upward curve consistent with the drop in Rc. It increases from approximately 1.6% at 200°C to more than 9% at 800°C for long exposures. This

mass loss is a direct reflection of the expulsion of chemically bound water and the decomposition of portlandite, drastically increasing the porosity of the cement network and facilitating the propagation of thermal micro cracks.

The duration of exposure (120 min vs. 60 min) clearly accentuates degradation at high temperatures, as it allows for better heat penetration into the core of the specimens and more complete dehydration.

Conclusion

This investigation successfully characterized and modeled the physical and mechanical degradation profiles of standard Class B30 structural concrete incorporating regional Moroccan aggregates under severe thermal exposure. The following insights highlight the primary contributions and outcomes of this work:

a) Core Research Overview and Contributions:

The study successfully mapped matching macroscopic compressive strength losses directly to physical mass degradation profiles. We confirmed a critical threshold between 400°C and 600°C where the rapid decomposition of portlandite triggers an exponential collapse of material structural capacity, reducing residual strength to minor levels (9 MPa and 7 MPa) at 800°C.

b) Engineering Consequences and Practical Impacts:

By defining a high-fidelity empirical correlation equation ($R_c/R_{c0} = -0.1064 \cdot P + 1.011$) [2], this work provides structural engineers with a direct diagnostic framework to calculate residual mechanical capacity from non-destructive field core mass evaluations during post-fire safety assessments.

c) Research Limitations: While these empirical insights are robust for standard Class B30 frameworks, the findings are constrained by the specific mineralogical composition of the regional crushed sand and gravel variants utilized, alongside the slow natural cooling rate executed inside the furnace chamber. Real-world fires often involve sudden water-quenching shock profiles (firefighting interventions) which were not addressed here. To build upon these findings, future research will focus on, optimizing the precise volumetric dosage of polypropylene (PP) fibers within this localized mix to prevent micro-cracking and explosive spalling, quantifying the secondary impact of rapid water-quenching thermal shocks on the residual structural performance of the material and conducting high-resolution Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) tracking to map the physical ITZ phase changes along the aggregate boundary lines.

Abbreviations

ASTM: American Society for Testing and Materials, C-S-H: Calcium silicate hydrates, CPJ: Composite Portland cement, FI: Flatness Index, GI: Gravel GI, GII: Gravel GII, G/S: Gravel/Sand ratio, PP: Polypropylene, Rc: Compressive strength, W/C: Water/Cement ratio.

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Author Contributions

Yahia Zakaria: Conceptualization, Study Design, Data Collection, Formal Analysis, Interpretation of Results, Writing and Reviewing Article, Contribution to the Final Version of the Manuscript, Selma El Bergui: Data Collection, Formal Analysis, Interpretation of Results, Raja Moussaoui: Conceptualization, Study Design, Formal Analysis, Interpretation of Results, Reviewing Article, Contribution to the Final Version of the Manuscript, Otmane Khaldi: Data Collection, Formal Analysis, Interpretation of Results, Driss El Hachmi: Conceptualization, Study Design, Data Collection, Formal Analysis, Interpretation of Results, Reviewing Article, Contribution to the Final Version of the Manuscript.

Conflict of Interest

The authors declare that there are no conflicts of interest related to this research.

Data Availability

Data for the study are available on request.

Declaration of Artificial Intelligence (AI) Assistance

The authors declare this manuscript was prepared without the assistance of generative AI. All conceptualization, analysis, interpretation and writing were developed independently by the authors. The authors must take full responsibility for the content's originality, interpretation and accuracy.

Ethics Approval

Not applicable.

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