ENHANCING FIRE SAFETY OF CONCRETE STRUCTURES: ASSESSING THE EFFECTIVENESS OF SUPER ABSORBENT POLYMER (SAP) IN CONCRETE IN DELAYING STRUCTURAL COLLAPSE IN FIRE ACCIDENTS

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ABSTRACT

Concrete structures are at risk of exposure to high temperatures in the event of an accidental fire. The strength of concrete typically decreases when subjected to high-temperature exposure. To increase the strength of concrete, Super Absorbent Polymer (SAP) is added as an internal curing agent. This study examined the effect of sustained high temperatures on the improvement of properties of concrete produced with SAP in delaying structural collapse. The performance of SAP was evaluated through time-temperature profiles, compressive strength tests, tensile strength tests, water penetration tests, and weight loss due to heating. Cylindrical specimens of two types were produced: Normal Concrete (NC) without the polymer and Polymer Concrete (PC) with 0.1% of the polymer relative to the cement weight. The cylindrical specimens, sized at 100 mm×200 mm, were subjected to four different temperatures (200 ºC, 400 ºC, 600 ºC, and 800 ºC) for a relatively long duration ranging from 2.5 to 4 hours in an electric furnace and allowed to cool for an hour in natural air. The temperature of the furnace and specimen was monitored with a data logger equipped with a K-type thermocouple. The time-temperature profiles revealed that the PC specimen absorbed heat slowly during heating and released heat slower than the NC specimen. The compressive and tensile strengths of both NC and PC specimens decreased with increasing temperature, but the PC specimens had higher strengths than the NC specimens at all the temperatures tested. The compressive strength of NC and PC specimens was 31.5 MPa and 32.7 MPa at ambient temperatures of 25°C, 26.7 MPa and 28.6 MPa at 200°C, 18.4 MPa and 20.8 MPa at 400°C, 8.1 MPa and 9.3 MPa at 600°C, 2.4 MPa and 2.9 MPa at 800°C, respectively. The tensile strength of NC and PC specimens was 2.9 MPa and 3.1 MPa at ambient temperatures of 25°C, 1.8 MPa and 2.4 MPa at 200°C, 0.8 MPa and 1.4 MPa at 400°C, 0.5 MPa and 1.0 MPa at 600°C, and 0.3 MPa and 0.7 MPa at 800°C respectively. Similarly, the water penetration depth was lower for the PC specimens than the NC specimens at all temperatures tested. The water penetration depth of NC and PC specimens was 53 mm and 31 mm at ambient temperatures of 25°C, 78 mm and 48 mm at 200°C, 98 mm and 77 mm at 400°C, while they failed to retain water pressure at 600°C and 800°C, respectively. The weight loss of both NC and PC specimens increased with increasing temperature, with the PC specimens experiencing slightly higher weight loss than the NC specimens. Surface cracking started at 600°C and 800°C for both specimen types, with the NC specimen experiencing higher crack intensity than the PC specimen. In all cases, more time allowance is available to take counteractions against fire accidents for PCs. Overall, the study suggests that PC could be a more viable option than NC for improving the properties of concrete structures exposed to high temperatures and providing safety in case of fire accidents.

Keywords: *Concrete Structures, Super Absorbent Polymer (SAP), Internal Curing Agent, Sustained High Temperatures, Time-Temperature Profiles.*

1. INTRODUCTION

Concrete stands out as a widely employed construction material globally, comprising hydraulic cement, aggregates, and water, with potential additives, fibres, and other cementitious substances (ACI Committee, 2008). Its inherent qualities, such as high heat capacity, diminished thermal conductivity, non-combustibility, and absence of smoke or harmful gas emissions, render it fire-friendly (Zhu et al., 2017).

Despite these advantageous properties, exposure to elevated temperatures, such as those generated by accidental fires, can induce undesirable traits in concrete, including spalling and material deterioration (Demirel & Keleştemur, 2010). Nevertheless, owing to its strength, durability, simplicity of production, and non-combustibility, concrete remains a preferred choice for structural elements. Adherence to specified criteria in building codes and regulations is imperative for ensuring fire safety in concrete structures (Yaro et al., 2021).

Given the significant human and economic losses fires can incur, particularly in commercial, industrial, and residential settings, building codes mandate the fire resistance of structural components. Structural integrity becomes the ultimate defence when conventional fire suppression methods falter (Gernay et al., 2021).

Understanding the alterations concrete undergoes at high temperatures is fundamental, as heating can lead to spalling and impact various material characteristics. Researchers and engineers are actively devising strategies to augment concrete's fire resistance, such as incorporating additives like polypropylene fibres to mitigate spalling or adding metakaolin to enhance fire resistance (Tjaronge & Irfan, 2015; Bourdot et al., 2018).

Coating application on the concrete surface is another strategy, offering insulation to prevent deep heat penetration and associated deterioration. Various coatings, including cementitious, intumescent, and epoxy-based coatings, have proven effective in this regard (Ursic et al., 2018). Furthermore, the addition of carbon nanotubes has shown promise in enhancing concrete's fire resistance by improving mechanical properties and thermal conductivity (Li et al., 2017).

SAP, a widely used internal water curing agent in the concrete industry, acts as a reservoir of water, gradually releasing it during curing to maintain the optimal water-to-cement ratio, enhancing cement hydration and reducing shrinkage (Ma et al., 2017). This research holds significance in providing insights into SAP's potential applications in diverse environments, contributing to the development of more resilient and durable concrete structures (Zhihui et al., 2020).

This research seeks to address two primary objectives: determining the endurance limit of concrete and investigating the impact of Super Absorbent Polymer (SAP) in concrete at high temperatures. Previous studies have explored SAP's influence on concrete. Still, this research aims to delve deeper, examining its effects at various elevated temperatures and understanding the physical and mechanical behaviour of concrete with SAP.

The specific aims of the current research include evaluating the performance of polymer concrete (PC) with SAP under high temperatures and investigating the efficacy of PC in delaying structural collapse during fire accidents. In light of the escalating threat of fire disasters globally, the safety of people and structures remains a paramount concern. Concrete's fire-resistant properties, coupled with proper structural design, position it as an excellent material for mitigating fire hazards. As concrete structures are routinely exposed to accidental fires, it is imperative to scrutinise the effects of fire on these structures and explore materials that can complement concrete in reducing fire impact. Such investigations will not only enhance our understanding of using different materials in concrete structures but also pave the way for improved fire resistance, ultimately bolstering the safety of occupants and structures during fire outbreaks.

2. METHODOLOGY

2.1 Materials and Equipment

Cement: In this experiment, Ordinary Portland Cement (OPC) served as the primary binding material for the concrete mixture. Acting as the binding agent, cement holds aggregate particles together, creating a compact and durable mass. The physical properties of the OPC used were determined through laboratory experiments, as presented in Table 1.

Table 1: Physical Properties of Ordinary Portland Cement Used in this Study

Characteristics	Tested value	Standard Value (ASTM C187, 2018)
Normal Consistency (%)	25.2	–
Initial Setting Time (min)	136	≥45
Final Setting Time (min)	255	≤375

Fine Aggregates: Sylhet sand was employed as a fine aggregate in this study to prepare cylindrical specimens. Evaluation of the fine aggregate properties involved conducting tests following ASTM standards, as shown in Table 2. The specific gravity and absorption of the fine aggregate were determined using ASTM C128. The fineness modulus was assessed following the ASTM C136 test procedure, and unit weight was determined according to the ASTM C29 test standard.

Coarse Aggregates: This study utilised black stone chips of 12.5 mm downgrade size as coarse aggregate. Properties of the coarse aggregates were assessed through tests following ASTM standards. Specific gravity and absorption capacity were determined using ASTM C127, while void ratio and unit weight were determined following the ASTM C29 test standard, as presented in Table 2.

Super Absorbent Polymer (SAP): In this study, Sodium Polyacrylate, commonly known as water-lock, was used as the superabsorbent polymer (SAP). The physical properties of SAP are presented in Table 2, and the chemical formula is $[\text{-CH}_2\text{-CH(COONa)-}]_n$. The SAP used had an absorbent capacity of about 32 grams of water per gram of SAP in the concrete environment. To incorporate SAP into the concrete mix, a dosage of 0.1% of the cement mass was used based on previous studies investigating the effects of SAP on concrete's mechanical properties and durability.

Table 2: Properties of Fine Aggregates, Coarse Aggregates, and Super Absorbent Polymer (SAP)

Parameters	Fine Aggregates	Coarse Aggregates	SAP
Nominal Max Size (mm)	4.75 mm	12.5 mm	0.38 mm
Unit Weight (kg/m3)	1385	1340	–
Specific Gravity	2.53	2.80	–
Water Absorption (%)	2.85	2.20	32 (g/g)
Moisture Content (%)	1.25	2.80	–
Fineness Modulus	2.95	6.03	–
Colour	Red	Black	White

Thermocouples: A thermocouple is a temperature sensor composed of two metal wire legs welded at one end to form a junction for temperature measurement. The widely used K-type thermocouple, with a sensitivity of approximately 41 µV/°C, has a temperature range between −200°C and +1350°C / -328°F and +2462°F. This type, named after the German word "Kaltleiter," is made of nickel and chromium. In this study, a 2-meter K-type thermocouple measured concrete temperature during curing and inserted into specimens before casting.

Data Logger: The GreenTech Data Logger GTDL 350 recorded furnace and specimen temperatures connected to a computer. It monitors temperature (-40°C to 70°C), humidity (0% to 100%), and atmospheric pressure (up to 1100 hPa). With a large storage capacity and a 10-year battery life, it offers configurable recording intervals. The software provides graphical data representations.

Digital Camera Microscope: The TQC Digital USB Microscope LD6184, used for high-resolution imaging, inspects surface texture and fine cracks in heated and non-heated specimens. With a magnification range of up to 200x, a 5-megapixel resolution, and a USB 2.0 interface, it transfers images quickly to a computer. TQC's proprietary software enables advanced image analysis, measurement tools, and ergonomic design for ease of use.

2.2 Materials And Equipment

Sieve Analysis: The size of aggregate particles can vary significantly, both among different aggregates and within the same aggregate. Sieve analysis, conducted in accordance with ASTM C136 standards, is a common method to assess particle size distribution for fine and coarse aggregates. The particle size distribution plays a role in determining the packing density of the aggregate, influencing the amount of paste needed in a concrete mixture. Proper gradation is vital for achieving desired concrete properties.

Unit Weight Determination of Aggregate: ASTM C29/C29M-20 outlines a standard method for measuring the unit weight of aggregates. The unit weight, calculated as the difference between the mass of the aggregate plus measure and the mass of the measure alone, divided by the volume of the measure, provides valuable insights into aggregate density.

Moisture Content Determination of Aggregate: Excessive moisture can lead to various issues, including reduced strength, increased shrinkage, and susceptibility to damage. Measurement of moisture content involved the oven-drying method in this experiment, in accordance with ASTM C566.

Mix Proportion of Concrete: Concrete mix proportions, following ACI 211.1 guidelines, are crucial for achieving target strength and desired properties. The mix ratio of 1:1.77:1.85 resulted in a water-to-cement ratio of 0.47, with and without Super Absorbent Polymer (SAP), providing a comprehensive foundation for the subsequent casting and testing procedures.

Mixing Procedure: The concrete mixture preparation involved the thorough mixing of constituent materials using a mechanical mixer, ensuring even distribution. The mixing process laid the groundwork for subsequent testing procedures.

Slump Test: The slump test, a common method to assess concrete workability, involves measuring the vertical displacement of concrete in a cone-shaped mould. It serves as a quality control tool and provides insights into material Consistency and workability.

Casting of Concrete Specimens: Fifty cylindrical concrete specimens were cast using moulds, with identified slumps for normal concrete and SAP concrete. The specimens were labelled accordingly.

Thermocouple Setup, Demoulding, and Curing: K-type thermocouples were inserted into each concrete specimen, ensuring temperature measurement during the curing process. Demoulding occurred after 24 hours, followed by proper curing in a water chamber for 28 days.

Observing Concrete Specimens: Post-curing, the concrete specimens were examined, and dimensions were checked to ensure adherence to the standard size.

2.3 Fire Exposure

Generation of High Temperature: To induce high temperatures for fire exposure in the concrete samples, an electric furnace was employed in this investigation. Radiating channels within the furnace facilitated the exposure, with electric coils generating the necessary temperature. The furnace was connected to an electric line operating at a voltage of 440. A 250×250×300mm electric furnace was utilised for this study, featuring six radiating channels equipped with a 5000-watt electric coil. A total power of 30,000 watts was applied to heat the concrete samples. The channels were constructed using fire bricks, and both the inner and outer surfaces were insulated using glass wool and steel plates.

Heating Process: The cylindrical specimens were positioned within the electric furnace, and the electric coil was activated by switching on the electricity. A lid was placed over the furnace to enclose it. The specimens were exposed to sustained temperatures of 200°C, 400°C, 600°C, and 800°C for varying time periods from 150 to 250 minutes. After this duration, the electricity was turned off, and the furnace lid was opened to initiate cooling for both the furnace and the specimens. The specimens were allowed to cool naturally using ambient air for one hour.

Data Collection Process: For temperature measurement inside the furnace and specimens, four-inch stick K-type thermocouples were employed in this study. A digital data logger connected to a computer was used to monitor and record temperatures.

2.4 Testing of Concrete Specimens

This research encompassed a series of tests on concrete specimens, including heating cylindrical specimens, compressive strength, tensile strength, and water penetration depth of cylindrical specimens. Each specimen was meticulously marked and designated. For example, NC 25 I denotes that normal concrete specimen A was tested at an average room temperature of 25°C, while PC 25 I signifies that SAP concrete specimen A was tested under the same conditions. Similarly, NC 200 I and PC 200 I represent normal concrete and SAP concrete specimens tested after heating at 200°C, respectively.

Compressive Strength Test: The compressive strength testing machine was employed in this study. The test adhered to the ASTM C39 standard for measuring the compressive strength of cylindrical concrete specimens at 28 days. The compressive strength was calculated by dividing the crushing load by the cross-sectional area of the specimen. Three cylindrical specimens were utilised for each temperature condition, and tests were conducted at different temperatures, with the results meticulously recorded.

Tensile Strength Test: In this study, only one cylindrical specimen was used for the tensile strength test. The splitting tensile force of the cylindrical specimen was utilised to include the tensile strength test, deviating from the standard testing procedure. Mechanical properties were generally investigated, and the tensile strength test was conducted on the specimens at 28 days, following ASTM C496. A compressive strength testing machine was employed to determine the tensile strength of cylindrical specimens at ambient and sustained high temperatures. All specimens were longitudinally placed on the load cell and tested sequentially.

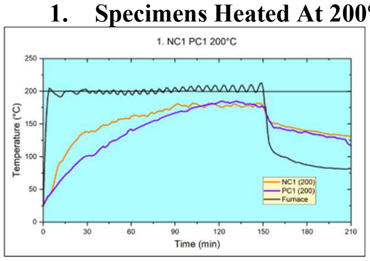
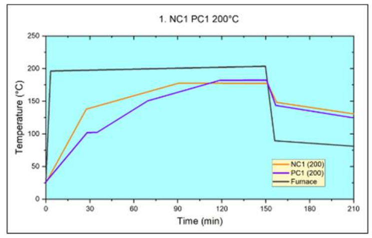
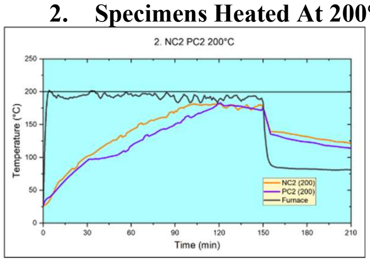
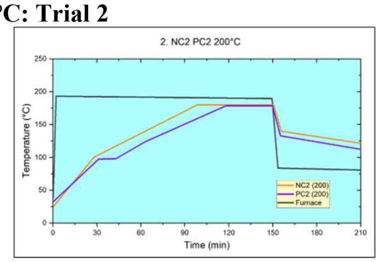
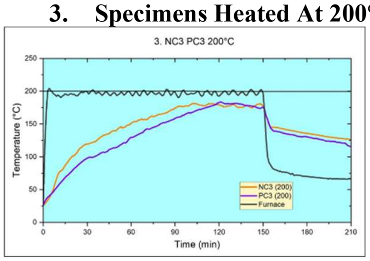
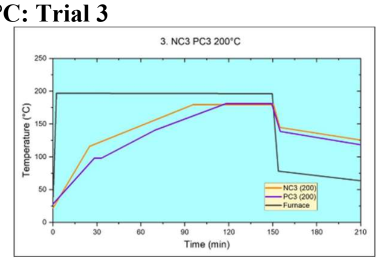
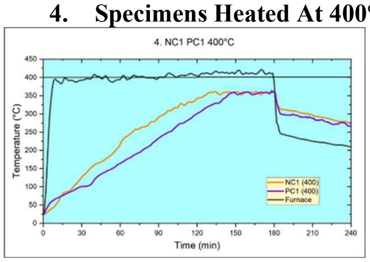
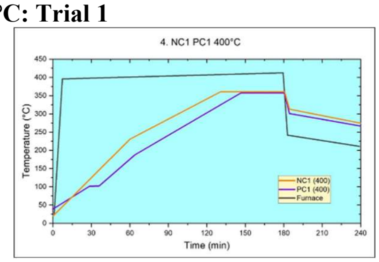
Water Penetration Test: Water penetration testing, crucial for assessing the durability and quality of concrete structures, was performed using the water pressure cell method. This method, as per the BS EN 12390-8 standard, measures the water penetration depth of cylindrical specimens at ambient temperature and exposed to sustained high temperatures at 28 days.

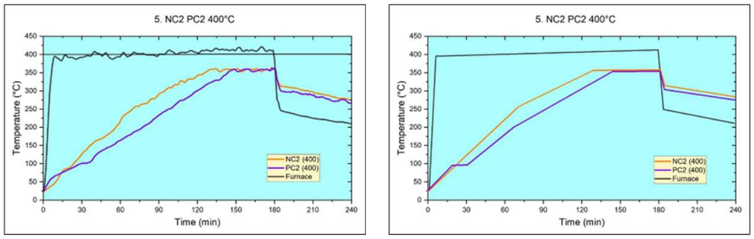
3. RESULTS AND DISCUSSION

3.1 Time-Temperature Profiles of Concrete Specimens

The time-temperature profile of concrete refers to the changes in temperature experienced by the material over a specific period of time during its curing and service life. Various factors influence this profile, including ambient temperature, concrete mix composition, curing methods, and environmental conditions. During the early stages of concrete placement, the exothermic hydration process occurs, leading to a rise in temperature within the concrete mass. This initial temperature increase is followed by a cooling period as the hydration reaction progresses and the concrete gains strength. The time-temperature profiles are derived from the Data Logger, and graphs for different heating temperatures are plotted using these data. The time-temperature profiles and also the generalised time-temperature profiles are then plotted and shown in Table 3 to characterise the properties. The comparison of specimen temperature with heating time is shown in Table 4, and further analysis in Table 5.

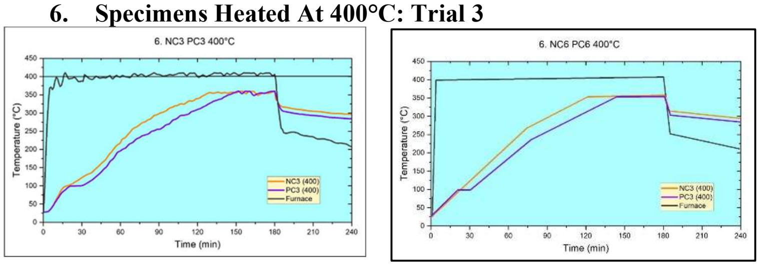
Table 3: Time-Temperature Profiles of Concrete Specimens Heated at Different Temperatures, Their Generalised Time Temperature Profiles, and General Descriptions

Time Temperature Profiles of Concrete Specimens Heated at Different Temperatures	**Generalised Time Temperature Profiles**	**Remarks**
1. Specimens Heated At 200°C: Trial 1		
		The NC specimen experienced a more rapid increase in temperature compared to the PC specimen. The NC specimen reached its maximum temperature in 92 minutes, while the PC specimen took 120 minutes to reach its maximum temperature.
2. Specimens Heated At 200°C: Trial 2		
		The heat gain of the NC and PC specimens is almost similar. The only difference is that there is a pause in the temperature increase for PC at 100°C of the curve due to the evaporation of water, which allows a time delay for PC to reach the maximum temperature. The time to reach the maximum temperature for NC is 100 minutes, and for PC, it is 118 minutes.
3. Specimens Heated At 200°C: Trial 3		
		Here, despite the relatively short time allowance period in the curve for the PC specimen, it still experiences a delayed heat gain compared to the NC specimen. The NC specimen reaches its maximum temperature in 96 minutes, while the PC specimen takes approximately 118 minutes to reach its maximum temperature.
4. Specimens Heated At 400°C: Trial 1		
		Here also, the temperature curves for both the NC and PC specimens exhibit a parallel pattern. The heat gain in both curves follows a similar trajectory resembling strain lines. The NC specimen reached its maximum temperature in 133 minutes, while the PC specimen took approximately 146 minutes to reach its maximum temperature.
5. Specimens Heated At 400°C: Trial 2		



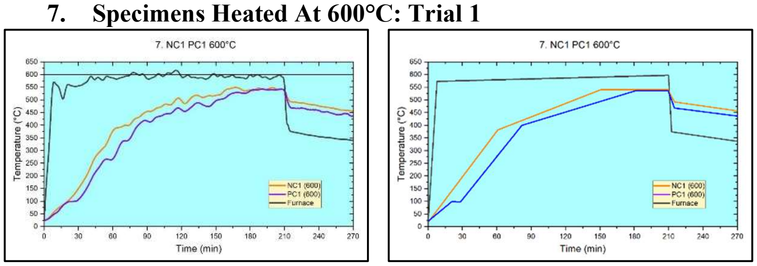
The time allowance period for the PC specimen at 100°C is 13 minutes. There is a delay of 15 minutes in reaching the peak temperature for PC compared to the NC specimen, which is nearly equivalent to the time allowance period. The NC specimen reached its maximum temperature in 117 minutes, while the PC specimen took 132 minutes to reach its maximum temperature.

6. Specimens Heated At 400°C: Trial 3



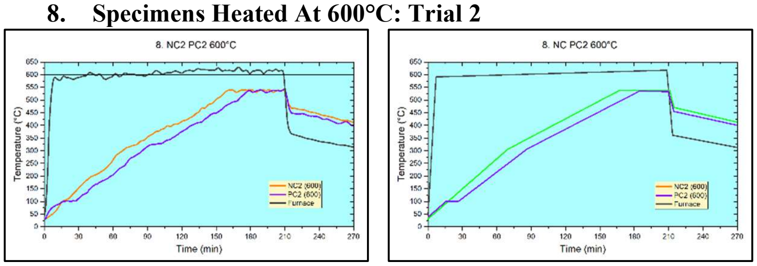
Both curves exhibit a distinct slope change point, indicating the evaporation of all chemically bonded water in concrete. After this point, the curves flatten. The NC specimen reaches its maximum temperature in 122 minutes, while the PC specimen takes approximately 147 minutes to reach its maximum temperature.

7. Specimens Heated At 600°C: Trial 1



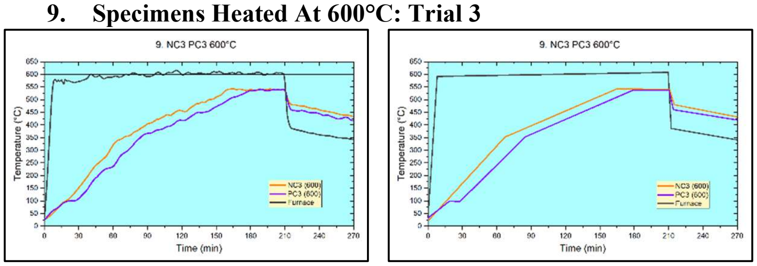
The flattening of the curve occurs significantly after the point of slope change. The NC specimen reaches its maximum temperature in 152 minutes, while the PC specimen takes approximately 177 minutes to reach its maximum temperature.

8. Specimens Heated At 600°C: Trial 2



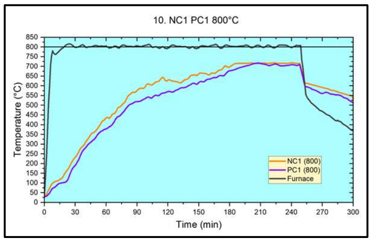
There is no significant difference in the slope of the two curves at high temperatures. The only factor causing a delay in reaching the maximum temperature for PC is the time allowance at 100°C. The NC specimen reaches its maximum temperature in 169 minutes, while the PC specimen takes approximately 186 minutes to reach its maximum temperature.

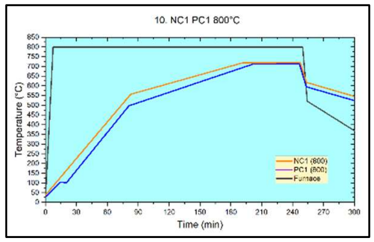
9. Specimens Heated At 600°C: Trial 3



The concrete specimens reached an ultimate temperature of 544°C, which accounts for approximately 90% of the applied heat. This difference is attributed to heat loss in the furnace during the experiment. The NC specimen reached its maximum temperature in 165 minutes, while the PC specimen took approximately 188 minutes to reach its maximum temperature.

10. Specimens Heated At 800°C: Trial 1





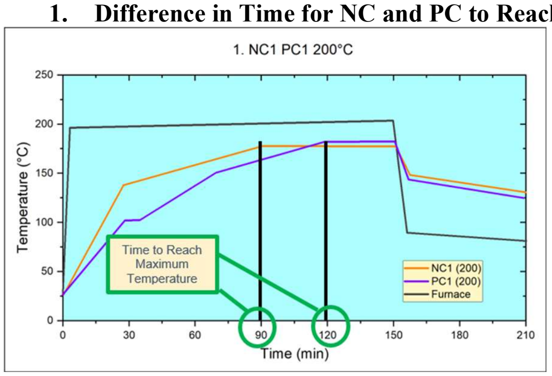
At significantly higher temperatures, using SAP did not provide a substantial advantage in reducing fire hazards, as the delay period was only 9 minutes. The NC specimen reached its maximum temperature in 204 minutes, while the PC specimen took approximately 195 minutes to reach its maximum temperature. Unfortunately, further trials could not be conducted due to damage to the furnace and thermocouples caused by excessive heat.

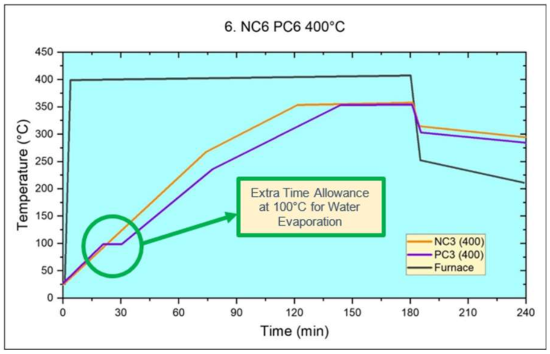
Table 4: Comparison of Specimen Temperature with Heating Time

Furnace Heating Temperature (°C)	Trial No.	Time to Reach Maximum Temperature (min)		Extra Time Allowance for PC (min)	Maximum Temperature Gained in Concrete	Time Heated in Furnace (min)	Time Kept for Colling (min)
		For NC	For PC				
200	1	92	120	28	184	150	60
	2	100	118	18	183		
	3	96	118	22	184		
400	1	133	146	13	364	180	
	2	117	132	15	362		
	3	122	147	25	361		
600	1	152	177	25	549	210	
	2	169	186	8	543		
	3	165	188	23	544		
800	1	195	204	9	719	240	

Indeed, the time allowance or delay in heat gain observed in the PC specimen can be advantageous in mitigating fire hazards in real-life scenarios, as per Table 4. The additional time provided before reaching the maximum temperature allows for a valuable opportunity to implement fire-fighting measures and take necessary actions to control or extinguish the fire. These precious minutes can make a significant difference in terms of response time, evacuation procedures, and overall fire management. Therefore, the heat gain delay exhibited by the PC specimen holds practical significance and can contribute to improved fire safety and response strategies.

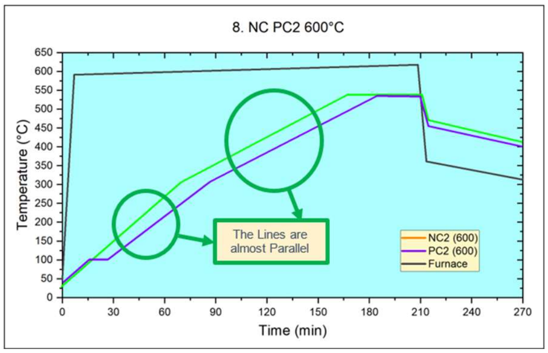
Table 5: Findings from the Generalised Time-Temperature Profiles

Generalised Time Temperature Profiles	Findings
1. Difference in Time for NC and PC to Reach the Maximum Temperature	
	The time required for the NC specimen to reach its maximum temperature is relatively shorter, taking approximately 90 minutes. In contrast, the PC specimen lasts longer to reach its maximum temperature, with the process taking around 120 minutes. This difference in time reflects the distinct thermal behaviour and characteristics of the two specimens under study.
2. Extra Time Allowance for PC	



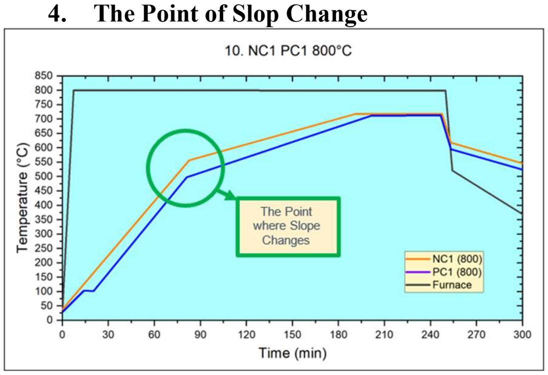
At approximately 100°C, an interesting phenomenon takes place with the PC specimen. The presence of water within the concrete leads to a significant pause in the temperature increase. This pause is caused by the evaporation of water molecules, which requires a considerable amount of heat energy. As the water evaporates, it absorbs a significant portion of the heat, leading to a temporary delay in the overall heat gain experienced by the PC specimen. This delay in temperature rise at 100°C can be attributed to the energy required for the phase change from liquid to vapour, resulting in a distinct behaviour compared to the NC specimen.

3. Similar Heat Gain Characteristics for NC and PC



The temperature curves for both the NC and PC specimens exhibit a nearly parallel trend, indicating similar overall heat gain patterns. The primary distinction between the two curves lies in the occurrence of a pause in a temperature increase at 100°C for the PC specimen. This pause, caused by the evaporation of water, introduces a temporary deviation in the temperature curve for PC while the NC curve continues its steady rise. Aside from this pause, the temperature curves for both specimens remain relatively parallel, reflecting a similar thermal behaviour throughout the heating process.

4. The Point of Slop Change



At a certain point during the heating process, there is a notable slowdown in the increase in temperature of the concrete specimens. This phenomenon occurs when all the available water within the concrete is assumed to have evaporated. At this stage, the rate of temperature rise becomes less steep, indicating that the evaporation of water molecules has been completed. This point marks the assumption that no further water remains in the concrete, and the subsequent temperature increase primarily depends on other factors, such as the material's thermal properties.

3.2 Compressive Strength of Concrete Specimens

Table 6: Comparison of Compressive Strength of Concrete Specimens

Temp. (°C)	Specimen	Compressive Strength (MPa)	Average Compressive Strength (MPa)	Specimen	Compressive Strength (MPa)	Average Compressive strength (MPa)	Increase in Compressive Strength (%)
	NC			PC			
25	NC 25 I	34.12	31.49	PC 25 I	32.21	32.68	3.77
	NC 25 II	29.16		PC 25 II	34.63		
	NC 25 III	31.19		PC 25 III	31.19		
200	NC 200 I	25.85	26.70	PC 200 I	26.99	28.56	7.00
	NC 200 II	29.67		PC 200 II	28.90		

	NC 200 III	24.57		PC 200 III	29.79		
400	NC 400 I	21.26	18.42	PC 400 I	20.75	20.84	13.13
	NC 400 II	17.32		PC 400 II	23.55		
	NC 400 III	16.68		PC 400 III	18.21		
600	NC 600 I	8.15	8.06	PC 600 I	9.68	9.34	15.79
	NC 600 II	7.00		PC 600 II	10.31		
	NC 600 III	9.04		PC 600 III	8.02		
800	NC 800 I	2.41	2.41	PC 800 I	2.93	2.93	21.69

The compressive strength tests conducted on concrete revealed a notable trend: as temperature increased, internal bonding within the concrete deteriorated, causing a significant drop in compressive strength. From Table 6, the concrete, initially at 32.1 MPa at room temperature, weakened sharply to 5.3 MPa at 800°C. This substantial reduction in strength led to brittleness, resulting in the collapse of the structure under load. Further analysis in Figure 1 showed that the concrete specimen with polymer (PC) consistently exhibited higher compressive strength than the one without (NC). At 25°C, the PC specimen had a 3.8% strength advantage, which increased to 21.7% at 800°C. These findings support the thesis's core assumptions, suggesting that incorporating SAP (superabsorbent polymer) in concrete could enhance fire resistance and extend structural durability during fire incidents.

3.3 Tensile Strength of Concrete Specimens

Table 7: Comparison of Tensile Strength of Concrete Specimens

Temp. (°C)	NC		PC		Increase in Tensile Strength (%)
	Specimen	Tensile Strength (MPa)	Specimen	Tensile Strength (MPa)	
25	NC 25	2.85	PC 25	3.12	9.47
200	NC 200	1.79	PC 200	2.39	33.52
400	NC 400	0.79	PC 400	1.40	77.22
600	NC 600	0.47	PC 600	1.04	121.28
800	NC 800	0.27	PC 800	0.65	140.74

The tensile strength of concrete follows a similar pattern of deterioration with increasing temperature. Table 7 shows that the average tensile strength at room temperature is 3.0 MPa, decreasing to 0.46 MPa at 800°C. This substantial decline in tensile strength results in the concrete becoming brittle and structurally weak, leading to collapse. Further analysis in Figure 2 reveals that the concrete specimen with polymer (PC) consistently outperforms the one without (NC) in compressive strength. At 25°C, the PC specimen shows a 9.5% strength advantage, increasing to 140.7% at 800°C. These findings align with the core assumptions of the thesis, supporting the potential use of superabsorbent polymer (SAP) in concrete to enhance fire resistance and extend structural integrity during fire incidents.

3.4 Reduction Of Weight of Specimens After Heating

Table 8: Reduction of Weight of Specimens After Heating

NC					PC				
Specimen	Initial Weight (gm)	Weight after Heating (gm)	Reduction of Weight (%)	Average Reduction of Weight (%)	Specimen	Initial Weight (gm)	Weight after Heating (gm)	Reduction of Weight (%)	Average Reduction of Weight (%)
NC 25 I	3738	-	0	0	PC 25 I	3778	-	0	0
NC 25 II	3840	-	0		PC 25 II	3960	-	0	
NC 25 III	3871	-	0		PC 25 III	4016	-	0	
NC 200 I	3833	3655	4.64	5.53	PC 200 I	3935	3678	6.53	6.96
NC 200 II	3897	3680	5.57		PC 200 II	4068	3798	6.64	

NC 200 III	3788	3546	6.39		PC 200 III	3869	3571	7.70	
NC 400 I	3960	3606	8.94		PC 400 I	3880	3523	9.20	
NC 400 II	3903	3576	8.38	8.45	PC 400 II	3813	3476	8.84	9.18
NC 400 III	3853	3543	8.05		PC 400 III	3955	3579	9.51	
NC 600 I	3919	3541	9.65		PC 600 I	3908	3456	11.57	
NC 600 II	4027	3609	10.38	10.18	PC 600 II	3883	3432	11.61	11.15
NC 600 III	3870	3463	10.52		PC 600 III	3851	3456	10.26	
NC 800 I	4003	3573	10.74	10.74	PC 800 I	3837	3365	12.30	12.30

From Table 8, The weight loss of the concrete specimens heated at 200°C is 5.5% for NC and 7.70% for PC, while at 800°C, the weight loss increases to 10.7% for NC and 12.3% for PC. The weight reduction observation in Figure 3 supports the delayed heat gain in the case of SAP concrete, as a significant portion of heat energy is consumed in the evaporation of the extra water present in PC specimens.

3.5 Water Penetration Test

Table 9: Comparison of Water Penetration of Concrete Specimens

Temp. (°C)	NC			PC		
	Specimen	**Water Penetration (mm) at 0.5 MPa Hydrostatic Pressure**	**Water Permeability (10^3 m/day) at 0.5 MPa Hydrostatic Pressure**	**Specimen**	**Water Penetration (mm) at 0.5 MPa Hydrostatic Pressure**	**Water Permeability (10^3 m/day) at 0.5 MPa Hydrostatic**
25	NC 25	53	17.7	PC 25	31	10.3
200	NC 200	78	26.0	PC 200	48	16.0
400	NC 400	98	32.7	PC 400	77	25.7
600	NC 600	Did not Sustain	-	PC 600	Did not Sustain	-
800	NC 800	Did not Sustain	-	PC 800	Did not Sustain	-

From Table 9, the test results indicate that the PC samples exhibited less water penetration into the concrete in all cases, also shown in Figure 4. However, the tests could not be continued for the samples heated at 600°C and 800°C due to excessive cracks, making it challenging to sustain high water pressure. The presence of SAP in the concrete enables improved internal curing by entrapping water within the inner core of the concrete. This, in turn, leads to fewer pores and cracks inside the concrete. As the temperature increases, the cracks within the concrete become broader and longer. However, due to the presence of SAP, the PC specimens experience fewer internal cracks and decay slower than the NC specimens. As a result, the water penetration in the PC specimens was lower, indicating better resistance to water ingress.

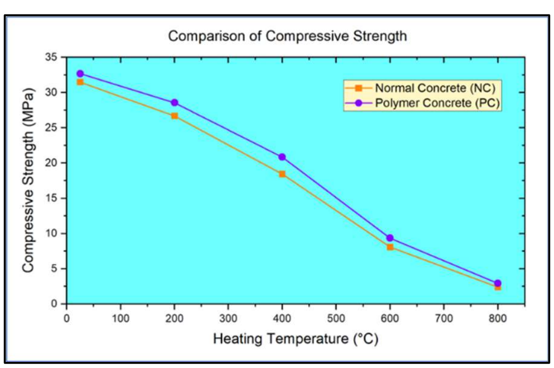


Figure 1: Comparison of Compressive Strengths of Specimens Heated at Different Temperatures

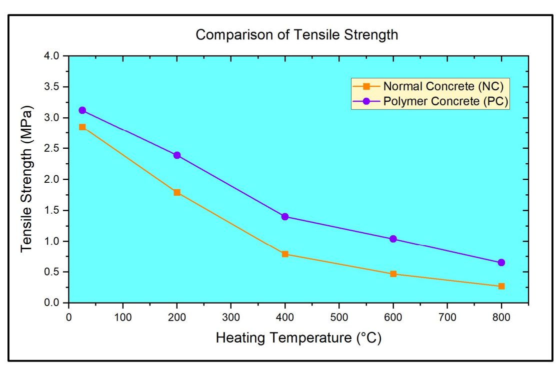


Figure 2: Comparison of Tensile Strengths of Specimens Heated at Different Temperatures

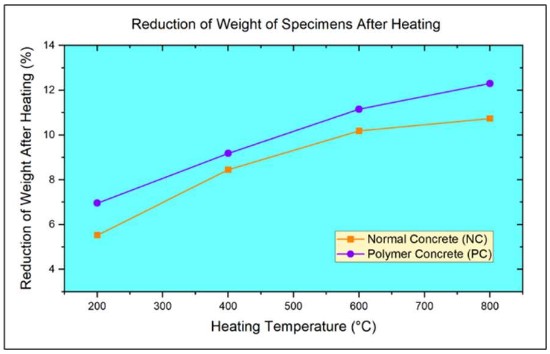


Figure 3: Reduction of Weight of Specimens After Heating at Different Temperatures

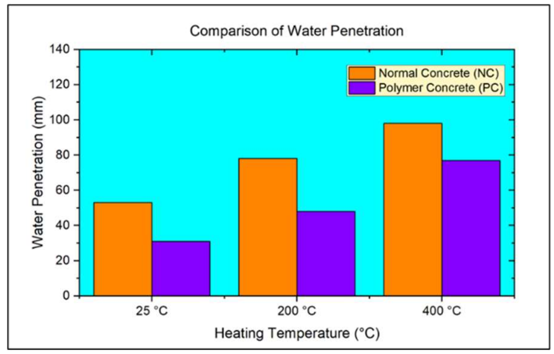


Figure 4: Water Penetration of Concrete Specimens Heated at Different Temperatures

4. CONCLUSIONS

This research focused on evaluating the impact of elevated temperatures on the physical and mechanical characteristics of concrete incorporating super absorbent polymer (SAP). The investigation revealed several key findings. The PC specimen exhibited a slower rate of heat absorption and release compared to the NC specimen, indicating improved thermal behaviour. Additionally, the PC specimen demonstrated higher compressive and tensile strength than the NC specimen, particularly noteworthy at temperatures up to 800°C. Furthermore, the water penetration depth in the PC specimen was consistently lower than that in the NC specimen, especially up to 400°C, suggesting enhanced resistance to water ingress. While both specimens experienced an increase in weight loss with rising temperatures, the PC specimen displayed marginally higher weight loss.

Based on the outcomes of the experimental tests, it can be deduced that concrete incorporating Super Absorbent Polymer (PC) exhibits superior performance compared to normal concrete (NC) across various properties when subjected to elevated temperatures. These findings underscore the potential benefits of utilising SAP in concrete mixes for enhanced resilience in high-temperature environments.

To advance the investigation of the impact of sustained high temperature on the physical and mechanical properties of SAP-based concrete, it is suggested to examine the characteristics of SAP-based concrete at temperatures ranging from 50°C to 1200°C. Additionally, conducting the rapid chloride permeability test (RCPT) would contribute to a more comprehensive investigation. Further research opportunities exist by exploring various SAP contents, including 0.05%, 0.15%, 0.20%, 0.25%, and 0.30%.

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