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Assessment Of Elevated Temperature Effects on Bagasse Ash Modified High Strength Self-Compacting Concrete Using Non-Destructive Testing Methods

Aderomose Kayode Stephen [a,*], John Wasiu [b], Ibrahim Abdulrazaq Olayinka[b], Adie Ushie Emmanuel [b]

[a] *Afe Babalola University Ado-Ekiti, Nigeria*
[b] *Edo state university Iyamho Edo-State Nigeria*

[*] **Corresponding Author Email:** aderomose@abuad.edu.ng

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ABSTRACT

Concrete, a fundamental construction material, is vulnerable to physical, chemical, and mechanical degradation under extreme thermal conditions, such as fires. Assessing the residual integrity of heat-damaged concrete is essential for ensuring long-term safety and serviceability. Non-destructive testing methods, particularly Ultrasonic Pulse Velocity (UPV), offer an efficient and non-invasive alternative to traditional destructive approaches. This study evaluated the impact of high temperatures on concrete's structural integrity using UPV, aiming to understand changes in physical properties and verify UPV's effectiveness in detecting and quantifying thermal damage. M70-grade self-compacting concrete (SCC) cubes (100 × 100 × 100 mm) were cast, water-cured for 7, 14, 21,28, 35 and 42 days, and subjected to baseline UPV tests. Specimens incorporating bagasse ash replacement levels of 0%, 2.5%, 5%, 7.5%, and 10% were subsequently exposed to elevated temperatures. After thermal exposure, UPV test was carried out. Results showed significant degradation with increased temperature, particularly in "After Cooling" scenarios under rapid cooling at lower RC percentages. These findings confirm that UPV is a reliable and practical method for identifying and quantifying thermal damage in concrete, with results clearly correlating temperature exposure, cooling regimes, and changes in concrete integrity.

1. INTRODUCTION

Concrete is the most widely used material in the construction industry, and its long-term durability remains a critical area of research and development. Conventional concrete requires adequate compaction to achieve the desired strength and performance; however, this process often depends on skilled labor and may not always be performed effectively. The cement industry contributes about 8% of global CO_2 emissions, while the building and construction sector accounts for 39% of energy-related emissions. This has driven a global shift toward sustainable energy sources to support carbon-neutral construction (Athira et al., 2021). Shifting from traditional construction materials to low-carbon, energy-efficient alternatives is widely seen as an effective way to reduce CO_2 emissions and address the climate crisis (Arif et al., 2016). Studies show that roughly 3 tonnes of bagasse are produced for every 10 tonnes of sugarcane processed. Additionally, burning one tonne of sugarcane yields about 0.62% ash (Arenas-Piedrahita et al., 2016) (Kolawole et al., 2021).

The introduction of Self-Compacting Concrete (SCC) has addressed this limitation by enabling concrete to flow under its own weight, filling all voids and spaces around reinforcement and formwork corners without the need for external vibration, thereby improving overall durability (Wasfy, Khalil and Badawy, 2024). Self-Compacting Concrete (SCC) is designed to flow easily around steel reinforcement and completely fill formwork corners without leaving voids or causing segregation. Segregation is prevented by incorporating mineral fillers, fine materials, or specific chemical admixtures. SCC and conventionally vibrated concrete with equivalent compressive strength exhibit comparable properties in their hardened state. This similarity enables SCC to be used in applications traditionally served by conventional concrete. However, SCC differs mainly in its composition, which significantly influences its behavior in the fresh state, while its hardened properties remain relatively similar to those of ordinary concrete (Saafan, Etman and Bait AL-Shab, 2020).

Although Self-Compacting Concrete (SCC) offers excellent workability, its properties can deteriorate notably under high temperatures. Most existing studies on thermal effects have concentrated on conventional concrete, with limited research examining the behavior of SCC under heat using non-destructive testing (NDT) techniques (Alabdulhady et al., 2025). Concrete loses strength and undergoes structural damage when exposed to high temperatures, such as during a fire. Traditional destructive testing methods used to assess this damage are costly, time-consuming, and can weaken the structure. (Wróblewska and Kowalski, 2020). Non-Destructive Testing (NDT) methods like the Ultrasonic Pulse Velocity offer a faster, safer alternative, but their reliability in evaluating heat-damaged concrete is not well established. This study aims to assess how high-temperature exposure affects concrete using NDT techniques to improve accuracy in post-fire evaluation.

This research aims to assess the effect of high-temperature exposure on the properties of concrete using non-destructive testing techniques. The study involves producing concrete samples and exposing them to different temperature levels to observe the resulting changes in strength and quality. Non-destructive testing using the Ultrasonic Pulse Velocity (UPV) method was employed to evaluate the condition of the heat-exposed concrete. The results obtained from these tests will be compared with those of control samples to determine the extent of degradation. Finally, the study seeks to establish a relationship between temperature exposure and the residual properties of concrete.

2. MATERIALS AND METHODS

This study will be carried out through experimental investigation to assess the effect of high-temperature exposure on the properties of concrete using non-destructive testing techniques. The research involves several key stages, including material selection, mix design, specimen preparation, temperature exposure, testing.

This methodology also incorporates both slow cooling and rapid cooling procedures to better understand the thermal response of the concrete specimens. After exposure to elevated temperatures, selected samples were allowed to cool gradually under ambient laboratory conditions, representing slow cooling. In contrast, other specimens were subjected to rapid cooling to simulate sudden temperature drops These samples were cured for 7, 14, 21, 28, 35 and 42 days. The use of both cooling methods provides a broader understanding of how the material behaves under different thermal shock scenarios and allows for a more comprehensive evaluation of its residual mechanical and durability properties.

The workability of the self-compacting concrete was evaluated using the V-funnel and L-box tests. For the V-funnel test, the cleaned apparatus was placed on a level surface and filled with fresh concrete without vibration. The trapdoor was opened, and the time required for complete discharge was recorded as the flow time, indicating the mix's viscosity and flowability. The L-box test measured the passing ability of the concrete. The cleaned apparatus was filled in the vertical section and allowed to rest for one minute. The sliding gate was then lifted to allow horizontal flow through the reinforcement bars. The heights at the vertical (H_1) and horizontal (H_2) sections were measured, and the blocking ratio (H_2/H_1) was calculated to assess the mix's resistance to blocking and segregation.

The Ultrasonic Pulse Velocity (UPV) test was conducted to examine the internal quality of the concrete. After curing, specimens were air-dried for 24 hours, cleaned, and tested using the direct transmission method in accordance with ASTM C597. Pulse velocity was calculated from the recorded travel time, and the average of multiple readings was taken as the representative value.

The elevated temperature test was performed using an ELE International Muffle Furnace to study thermal resistance. Air-dried cubes were heated gradually, with temperature readings recorded every 20 minutes, and then heated to a target temperature of 1200°C at a controlled heating rate of 5°C per minute, Although temperatures above 1000°C are rare in typical building fires, the selected temperature was adopted to evaluate the ultimate degradation limit of high-strength self-compacting concrete under extreme thermal exposure.. The furnace was periodically opened to observe visible changes such as colour alteration or crack formation.

3. RESULTS AND DISCUSSION

3.1 Self-Compacting Concrete (SCC) Test

The workability tests were carried out to confirm that the fresh self-compacting concrete (SCC) mixtures met the required standards for flowability, passing ability, and resistance to segregation key properties needed for proper placement without vibration. The workability values reported in Table 1 reflect mean workability values for mixtures containing 0 – 10% bagasse ash, as differences among the mixes were negligible and conformed within the prescribed limits for self-compacting concrete.

Table 1: SCC Results

Workability Test	**Research Results**	**Code Range**	
		Minimum	**Maximum**
V-funnel	10 secs	6 secs	12 secs
L-box	0.88	0.8	1.0
Slump Flow	750	650	800

3.2 Ultrasonic Pulse Velocity Test

Prior to thermal exposure, the ultrasonic pulse velocity of all mixtures ranged between 3.69 and 4.72 km/s, as presented in Table 2, indicating good-quality concrete across all bagasse ash replacement levels in accordance with the classification criteria shown in Table 3. For the control mixture (0% bagasse ash), pulse velocity increased with curing age up to 28 days, attaining a maximum value of 4.72 km/s, which reflects continued cement hydration and progressive densification of the concrete matrix. The transient decrease observed at 35 days before heating is likely associated with moisture redistribution within the concrete or minor microstructural rearrangements prior to further hydration and densification at later curing ages.

Concrete incorporating bagasse ash showed comparable performance. At 2.5% and 5% BA, pulse velocity values at 28 and 42 days remained within 4.07– 4.33 km/s, indicating that low to moderate BA replacement did not compromise the quality of the concrete. These values suggest effective pozzolanic activity, which likely contributed to the progressive refinement of the pore structure.

A significant reduction in pulse velocity was recorded after elevated temperature exposure across all mixtures. For the control concrete, pulse velocity dropped from 4.52 – 4.72 km/s before heating to 0.23 – 0.63 km/s after heating a reduction exceeding 85%. This sharp decline reflects extensive microcracking and thermal damage caused by high-temperature exposure. Concrete containing BA demonstrated similar trends. At 2.5% BA, pulse velocities ranged between 0.33 – 0.65 km/s after heating, while 5% BA mixtures recorded 0.29 – 0.54 km/s. Although still significantly reduced, mixtures containing 2.5 – 5% BA showed slightly higher residual velocities compared to the control. After heating, differences between slow cooling (SC) and rapid cooling (RC) became more pronounced. RC specimens consistently recorded lower pulse velocity values compared to SC specimens across all ages and BA levels. This is expected, as rapid cooling induces thermal shock, leading to the formation of additional microcracks and surface fractures.

Table 2: Pulse Velocity in km/s for thermal temperature

		Pulse Velocity (km/s)											
		7 DAYS		**14 DAYS**		**21 DAYS**		**28 DAYS**		**35 Days**		**42 Days**	
		SC	**RC**	**SC**	**RC**	**SC**	**RC**	**SC**	**RC**	**SC**	**RC**	**SC**	**RC**
0%	**Before Heating**	4.18	4.17	2.69	4.52	4.52	4.57	4.72	4.39	3.69	4.52	4.52	4.29
	After Heating	0.46	0.23	0.32	0.45	0.57	0.48	0.63	0.55	0.32	0.45	0.53	0.45
2.5%	**Before Heating**	3.70	3.92	4.02	4.07	4.05	4.07	4.13	4.07	4.02	4.07	4.33	4.27
	After Heating	0.41	0.33	0.40	0.41	0.51	0.43	0.55	0.51	0.40	0.41	0.65	0.51
5%	**Before Heating**	3.86	3.83	4.15	4.07	4.02	4.17	4.12	4.24	4.15	4.07	4.22	4.14
	After Heating	0.43	0.32	0.29	0.41	0.50	0.44	0.44	0.42	0.29	0.45	0.54	0.52
7.5%	**Before Heating**	4.15	4.12	4.22	4.20	3.83	3.77	3.91	3.86	4.22	4.20	3.91	3.86
	After Heating	0.46	0.34	0.50	0.42	0.48	0.40	0.52	0.48	0.50	0.42	0.62	0.58
10%	**Before Heating**	4.22	4.22	4.17	3.82	4.20	4.13	3.85	3.88	4.17	3.82	3.85	3.88
	After Heating	0.25	0.17	0.49	0.38	0.53	0.43	0.42	0.37	0.49	0.38	0.42	0.37

Table 3: Velocity Criterion for Concrete Quality Grading

S/NO	**PULSE VELOCITY BY CROSSING PROBE (KM/SEC)**	**CONCRETE QUALITY GRADING**
1.	ABOVE 4.5	EXCELLENT
2.	3.5 TO 4.5	GOOD
3.	3.0 TO 3.5	MEDIUM
4.	BELOW 3.5	DOUBTFUL

4. CONCLUSION

This study investigated the influence of elevated temperatures on high-strength self-compacting concrete incorporating bagasse ash using ultrasonic pulse velocity as an evaluation tool. Thermal exposure caused a marked reduction in pulse velocity across all mixtures, indicating the development of internal cracking; however, the severity of damage varied with bagasse ash content. Mixtures containing 2.5 – 7.5% bagasse ash demonstrated higher residual pulse velocities after heating compared to the control mix, reflecting enhanced thermal resistance attributed to microstructural densification arising from the pozzolanic activity of the ash. In contrast, the 10% replacement level produced inconsistent performance, suggesting that excessive bagasse ash may adversely affect the cementitious matrix. Although significant degradation was observed in all mixtures following thermal exposure, the comparatively superior performance of mixes with 2.5 – 7.5% bagasse ash supports their application in sustainable high-strength self-compacting concrete subjected to elevated temperatures.

NOMENCLATURE

A	Cross-sectional area of specimen (m^2)
L	Path length between UPV transducers (m)
t	Transit time of ultrasonic pulse (s)
V	Ultrasonic pulse velocity (m/s or km/s)
T	Temperature (°C)
$f'c$	Compressive strength of concrete (MPa)
m	Mass of concrete specimen (kg)

Abbreviations

BA	Bagasse Ash
SCC	Self-Compacting Concrete
UPV	Ultrasonic Pulse Velocity
NDT	Non-Destructive Testing
SCM	Supplementary Cementitious Material
ASTM	American Society for Testing and Materials
RC	Rapid Cooling
SC	Slow Cooling

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