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Experimental Investigation of the Thermo-Mechanical Performance of High-Strength Self-Compacting Concrete Incorporating Bagasse ash

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Abstract:- The environmental impact of Portland cement production has intensified the need for sustainable supplementary cementitious materials in high-performance concrete. While bagasse ash has been explored in conventional concrete, experimental data on the thermo-mechanical performance of high-strength self-compacting concrete incorporating bagasse ash under elevated temperature conditions remain limited. This study experimentally investigates the thermo-mechanical behaviour of HSSCC with bagasse ash as a partial replacement for Portland cement. Bagasse ash was calcined at 550 °C, finely ground, and incorporated at replacement levels of 0–10% by mass, while maintaining a constant binder content of 600 kg/m³ and a water-to-binder ratio of 0.29. Fresh properties were evaluated using slump flow, V-funnel, and L-box tests, while compressive strength was measured up to 42 days. Thermal performance was assessed through controlled furnace exposure, and microstructural characteristics were examined using SEM–EDS. All mixes satisfied self-compacting concrete workability requirements. Elevated temperature exposure reduced compressive strength due to dehydration and thermal microcracking; however, increasing bagasse ash content significantly enhanced residual strength. The 10% replacement level achieved the highest residual compressive strength of 14.00 N/mm² at 42 days. The findings demonstrate that bagasse ash enhances the thermo-mechanical performance and fire resistance of high-strength self-compacting concrete while reducing cement consumption, supporting its application in sustainable and fire-resilient structural concrete.

Keywords*:* Self-compacting concrete, Bagasse cement, Thermo-mechanical performance, Elevated temperature, Sustainable building.

1. Introduction

Self-compacting concrete is a modern type of concrete that spreads and settles on its own, without the need for vibration. It flows naturally under its own weight, easily filling the formwork and surrounding dense reinforcement to achieve a smooth, well-compacted finish (Ramanathan et al., 2013). Concrete remains a fundamental material in the contemporary built environment. Continuous advancements in concrete technology, driven by extensive research, have expanded its performance capabilities and contributed to its widespread adoption. However, anticipated growth in global population and accelerating urbanization present significant environmental challenges associated with the increasing demand and use of concrete (Fayed et al., 2023; Zhou et al., 2023). Anticipated increases in global population and urbanization over the coming decades indicate potentially significant environmental impacts arising from the extensive and continued use of concrete (Belaid, 2022; Siregar, 2023). Although concrete has a lower unit embodied carbon than materials such as steel and glass, its large-scale production has made the concrete industry a major source of anthropogenic greenhouse gas emissions. These emissions are largely driven by the production of Portland cement, the primary binder in cementitious materials, of which concrete alone accounts for approximately 70% of total cement consumption (Adesina & Zhang, 2024).

Technological advancement, rising living standards, accelerated urbanization, and population growth have collectively intensified demand for natural resources within the construction industry, leading to increasing resource scarcity. In response, research efforts have focused on the utilization of solid waste from commercial, industrial, domestic, and agricultural sources as alternative raw materials for concrete production (Temitope et al., 2024). India produces more than 600 million tonnes of agricultural waste each year, presenting serious disposal and environmental challenges. Converting this waste into supplementary cementitious materials for concrete not only reduces waste management issues but also provides an economical construction material. Moreover, the use of SCMs in concrete helps lower CO_2 emissions and supports environmentally sustainable construction practices (Reddy et al., 2025).

The construction industry faces increasing pressure to reduce the environmental impact of Portland cement while meeting the demand for high-performance materials (Barbhuiya et al., 2024; Ilayarsi et al., 2025). Although self-compacting concrete offers superior workability, its high binder content increases carbon emissions (Wagh et al., 2024). Bagasse ash has emerged as a sustainable alternative, but limited research exists on the thermo-mechanical performance of high-strength self-compacting concrete incorporating this material, particularly under elevated temperatures. This knowledge gap necessitates experimental investigation to assess its structural performance and suitability for sustainable construction.

The disposal of sugarcane bagasse ash (SCBA) poses significant challenges due to its eco-hazardous characteristics and the growing shortage of dumping sites associated with population expansion. Unsuitable disposal practices result in environmental pollution through the emission of particulate matter and other airborne contaminants, which pose serious risks to human respiratory health when inhaled (Zhang et al., 2016; Kawashima et al., 2020).

The aim of this research is to experimentally investigate the thermo-mechanical performance of high-strength self-compacting concrete incorporating bagasse ash as a partial replacement for Portland cement. This study presents a laboratory-based investigation into the thermo-mechanical behaviour of high-strength self-compacting concrete incorporating bagasse ash, with emphasis on fresh properties, mechanical strength, and residual performance following thermal exposure.

2. Materials and Research Methods

2.1 Materials Used

Dangote Portland Cement, conforming to the specifications of BS EN 197-1 and the Nigerian Industrial Standard NIS 444-1:2018, was used as the primary binder in all concrete mixes. The cement was kept in a dry, airtight condition to prevent moisture absorption and preserve its quality prior to use. Bagasse ash, sourced as a byproduct of sugarcane processing from a local sugar factory, was thermally treated by calcination at 550 °C for one hour to improve its pozzolanic activity and remove impurities. The calcined ash was subsequently ground and sieved to pass through a 45 µm sieve, ensuring compliance with BS EN 450-1 requirements for pozzolanic materials. Natural river sand free from organic impurities was used as the fine aggregate; it was washed, oven-dried, and sieved in accordance with ASTM C33 grading specifications. Crushed granite with a nominal maximum size of 12.5 mm served as the coarse aggregate and satisfied the requirements of BS EN 12620:2013. Clean, potable water devoid of harmful contaminants was used for all mixes, with the water-to-binder ratio carefully controlled to ensure uniformity and consistency. A high-range sulfonated naphthalene formaldehyde (SNF)-based superplasticizer, Hydroplast 240GP, was incorporated to enhance workability and strength development at low water–cement ratios; it was stored at room temperature and protected from freezing and direct sunlight to maintain its effectiveness.

2.2 Methods

The self-compacting performance of the concrete was attained through optimized binder proportions, precise regulation of the water-to-binder ratio, and the incorporation of a high-range water-reducing admixture to improve flowability while maintaining the targeted M70 strength. A uniform reference mix was used for all batches, comprising 686 kg/m³ of fine aggregate, 1028 kg/m³ of coarse aggregate, 12 kg/m³ of superplasticizer, and 174 kg/m³ of water, with a fixed water-to-binder ratio of 0.29, as summarized in Table 1.

Table 1: Constant Mix Design Parameters

Material	Fine Aggregate	Coarse Aggregate	Superplasticizer (S.P.)	Water	W/b Ratio
Quantity (kg/m³)	686	1028	12	174	0.29

Variations in the mix composition were made solely by partially substituting cement with bagasse ash at replacement levels between 0% and 10%, as presented in Table 2. The cement content was correspondingly reduced from 600 kg/m³ to 540 kg/m³ while keeping the total binder content constant at 600 kg/m³. This strategy ensured that any differences observed in the fresh and hardened properties of the concrete were mainly due to the pozzolanic activity and micro-filler effects of the bagasse ash, rather than variations in aggregate content or water demand.

Table 2: Binder Composition at Various Bagasse Ash Replacement Levels

Bagasse Ash (%)	Cement (kg/m³)	Bagasse Ash (kg/m³)
0	600	0
2.5	585	15
5.0	570	30
7.5	555	45
10.0	540	60

3. Methodology

A comprehensive experimental programme was designed to assess the fresh, mechanical, thermal, and microstructural performance of self-compacting concrete (SCC) incorporating bagasse ash. The testing procedures adopted in this study are described below.

3.1 Slump Flow Test

The slump flow test was performed in accordance with ASTM C1611 to determine the flowability and self-compacting capability of the SCC without segregation as seen in Figure

1. The slump cone was positioned centrally; Fresh SCC was gently poured into the cone in a single lift without vibration. After striking off the surface level, the cone was lifted vertically within two seconds to allow free flow. The time taken for the concrete to reach a spread diameter of 500 mm (T_{50}) was recorded. Once flow ceased, the final spread diameters along two perpendicular axes were measured and averaged.

Figure 1. Slump flow test in progress

3.2 V-Funnel Test

The V-funnel test was conducted following EFNARC guidelines to evaluate the viscosity and filling ability of the SCC. The funnel was placed on a stable surface as fin in figure 2, moistened, and checked for proper gate operation. The concrete was remixed and poured into the funnel without compaction. Upon opening the gate, the discharge time was recorded until continuous flow stopped. Observations of blocking, segregation, or air entrainment were noted.

Figure 2. V-Funnel test in progress

3.3 L-Box Test

The passing ability of the SCC through congested reinforcement was assessed using the L-box test. The apparatus as seen in figure 3 was placed on a level surface and moistened internally. SCC was poured into the vertical section in a single lift without vibration, and the sliding gate was raised smoothly to allow flow into the horizontal section. After stabilization, the concrete heights in the vertical (H_1) and horizontal (H_2) sections were measured, and the passing ability was determined using the ratio H_2/H_1.

Figure 3. L-Box test in progress

3.4 Compressive Strength Test

Compressive strength tests were conducted on 100 mm cube specimens as seen in figure 4 at curing ages of 7, 14, 21, 28, 35, and 42 days in accordance with BS EN 12390-2. Specimens were demoulded after 24 hours and cured in water until testing. Prior to testing, specimens were surface-dried, measured, and weighed. Testing was performed using an ELE ADR Touch 2000 compression testing machine. Each specimen was centrally positioned, and load was applied continuously at a rate of 6 kN/s until failure, with load data recorded automatically.

Figure 4. compressive strength test

3.5 Elevated Temperature Exposure

Thermal exposure tests were carried out using an ELE electric muffle furnace as seen in figure 5 with programmable temperature control. At designated curing ages, specimens were removed from water curing, surface-dried, and air-dried for 24 hours to reduce thermal shock. Specimens were heated at a controlled rate of 5 °C/min to the target temperature.

Figure 5. ELE International Muffle Furnace

4. Results and Discussion

4.1 Workability

Workability testing was carried out to confirm that the fresh self-compacting concrete (SCC) mixes satisfied the required performance criteria for flowability, passing ability, and resistance to segregation. The results presented in Table 3 were evaluated against standard code limits to verify compliance with SCC specifications. The V-funnel time of 9 seconds indicates appropriate viscosity and effective filling ability without signs of segregation. An L-box ratio of 0.93 reflects excellent passing ability through congested reinforcement with minimal blocking, while the slump flow diameter of 750 mm confirms adequate flowability and self-compaction. Overall, the findings demonstrate that the SCC mixes meet standard workability requirements and are suitable for practical application without external vibration.

Table 3: Workability result

Workability Test	Research Results	Code Range	
		Minimum	Maximum
V-funnel	9 secs	6 secs	12 secs
L-box	0.93	0.8	1.0
Slump Flow	750	650	800

4.2 SEM–EDS Analysis of Bagasse Ash

The SEM image (Figure 6) shows that the bagasse ash particles have an irregular, angular, and porous morphology with rough surface textures. This heterogeneous structure is typical of agricultural ashes and is beneficial in cementitious systems, as it enhances particle packing, mechanical interlocking, and micro-filling within the cement matrix.

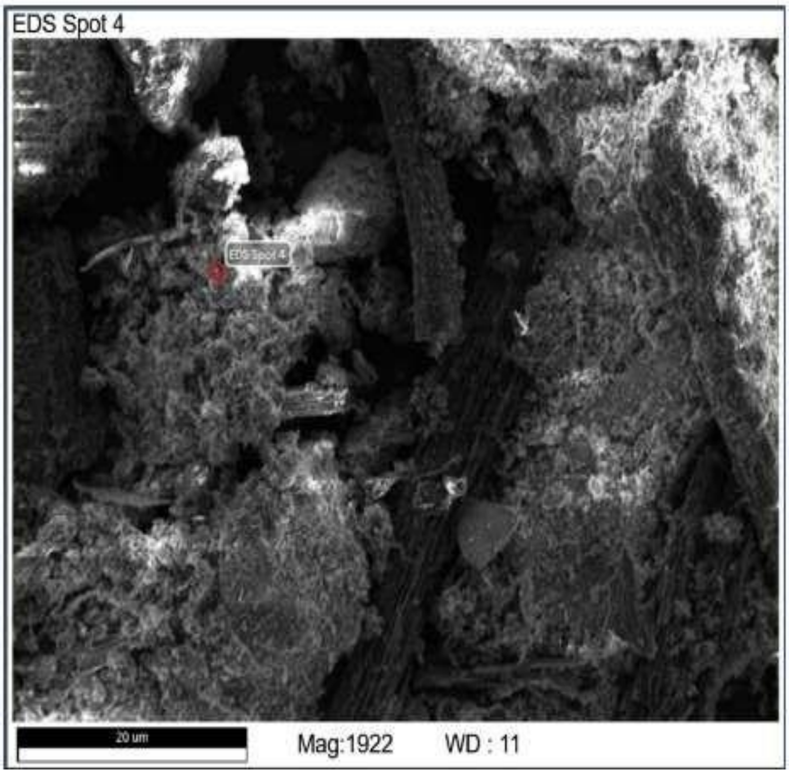


Figure 6. SEM-EDS image of Bagasse

The EDS results (figure 7) indicate that the ash is rich in oxygen (52.32 wt.%), silicon (12.26 wt.%), and calcium (9.86 wt.%), with notable amounts of aluminium (3.86 wt.%). The combined presence of silica and alumina confirms the pozzolanic potential of the bagasse ash, as these oxides can react with calcium hydroxide during cement hydration to form additional strength-giving calcium silicate hydrate (C–S–H) gel. Minor elements such as potassium, magnesium, iron, and sodium were also detected, which are typical of biomass-derived ashes.

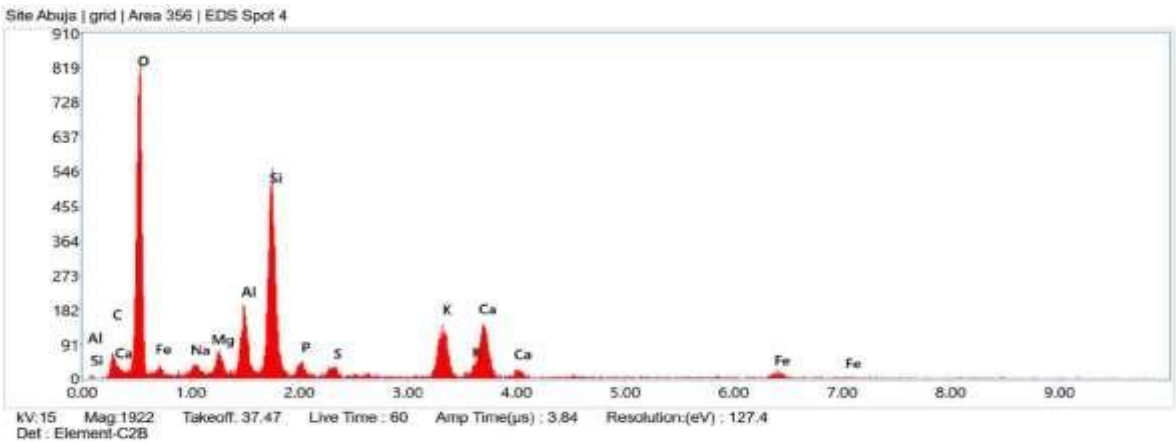


Figure 7. EDS spot results

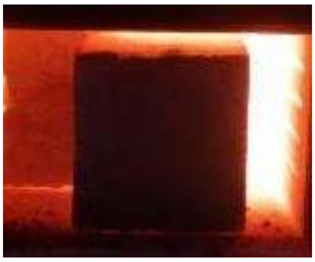
The SEM–EDS results confirm that the bagasse ash used in this study possesses suitable microstructural and chemical characteristics for use as a supplementary cementitious material. The fine, irregular particle morphology supports its micro-filling capability, while the high silica and alumina contents indicate strong pozzolanic potential. These characteristics help explain the satisfactory fresh-state performance observed in the SCC mixes and provide a microstructural basis for the expected improvements in hardened and thermo-mechanical properties of the concrete.

4.3 Elevated Temperature Exposure

The response of high-strength self-compacting concrete incorporating bagasse ash to elevated temperature exposure is summarized in Table 4. As temperature increased, progressive physical and microstructural changes were observed, reflecting the thermo-mechanical behaviour of the concrete under simulated fire conditions. At ambient temperature (27 °C), no visible changes were recorded, indicating stable material integrity prior to heating. At approximately 411 °C, the release of steam from the specimens was observed, which is attributed to the evaporation of free and physically bound water within the pore structure. This stage marks the onset of moisture-related internal pressure, which can influence subsequent cracking behaviour. Furthermore, temperature elevation to about 736 °C resulted in a noticeable colour change of the specimens to white, indicating significant dehydration of hydration products and the decomposition of calcium hydroxide. As the temperature approached 960 °C, the colour of the concrete transitioned from white to red, signifying severe thermal distress and changes in the mineralogical composition of the cement matrix. At temperatures above 1100 °C, the specimens became red-hot, and slight surface cracking was observed, reflecting the combined effects of thermal expansion mismatch, matrix shrinkage, and microstructural breakdown. Despite these visible signs of degradation, the gradual nature of crack development suggests that the incorporation of bagasse ash contributed to improved thermal stability by refining the pore structure and reducing the amount of thermally unstable hydration products. These findings confirm that elevated temperature exposure adversely affects concrete integrity, while bagasse ash enhances the residual thermo-mechanical performance of high-strength self-compacting concrete under extreme thermal conditions.

Table 4: Elevated temperature test

Elevated temperature test			
Time (min.)	**Temperature (°C)**	**Observation**	**Visual Observation**
0	27	No visible change	

Elevated temperature test			
Time (min.)	**Temperature (°C)**	**Observation**	**Visual Observation**
20	411	Steam released from cubes	
40	736	Cubes began to turn white	
60	960	Colour change from white to red	
80	1136	Slight cracks observed as cubes got red	
100	1109	Cubes turned red-hot	

4.4 Compressive Strength Test

Table 5 presents the compressive strength development of high-strength self-compacting concrete incorporating bagasse ash under elevated temperature exposure in comparison with the corresponding unheated control specimens. The results indicate that compressive strength increased progressively with curing age for all mixes, reflecting the continued hydration of the cementitious matrix. However, the thermally exposed specimens consistently exhibited lower compressive strength than the control specimens at every curing age and bagasse ash replacement level. This reduction can be attributed to the detrimental effects of elevated temperature, including moisture evaporation, dehydration of calcium silicate hydrate (C–S–H) gel and calcium hydroxide, thermal incompatibility between the cement pastes and aggregates, and the formation of microcracks within the concrete matrix.

Although thermal exposure reduced the compressive strength, the incorporation of bagasse ash significantly improved the residual strength of the concrete. A gradual increase in residual compressive strength was observed with increasing bagasse ash content from 0% to 10% at all curing ages, with the 10% replacement level consistently exhibiting the highest residual strength. At 42 days, the thermally exposed concrete containing 10% bagasse ash achieved a residual compressive strength of 71.652 N/mm², compared with 65.588 N/mm² for the control mix (0% bagasse ash), representing an improvement of approximately 9.2%. The enhanced performance is attributed to the pozzolanic reactivity and micro-filler characteristics of bagasse ash, which promote the formation of additional calcium silicate hydrate (C–S–H) gel, refine the pore structure, reduce porosity, and improve the thermal stability of the cementitious matrix. Consequently, the incorporation of bagasse ash mitigated the adverse effects of elevated temperature by producing a denser microstructure capable of resisting thermally induced damage. These findings demonstrate that, although elevated temperature negatively influences the compressive strength of HSSCC, the inclusion of up to 10% bagasse ash substantially improves its residual mechanical performance and enhances its overall thermo-mechanical resistance.

Table 5: Compressive Strength (N/mm^2)

		Compressive Strength (N/mm2)				
		0%	**2.5%**	**5%**	**7.5%**	**10%**
7 DAYS	**Thermal**	28.563	30.812	32.451	31.286	29.952
	Control	46.472	48.462	50.623	49.221	47.474
14	**Thermal**	39.214	42.837	45.925	44.613	42.775
DAYS	**Control**	58.586	61.274	64.975	63.791	61.586
21	**Thermal**	51.336	55.742	60.481	58.864	55.981
DAYS	**Control**	66.991	70.186	73.187	72.986	69.054
28	**Thermal**	60.815	65.992	71.438	69.722	66.184
DAYS	**Control**	74.344	78.453	82.161	81.013	78.443
35	**Thermal**	63.926	69.335	74.952	73.186	69.507
DAYS	**Control**	76.582	80.155	84.353	83.153	80.012
42	**Thermal**	65.588	71.274	77.823	75.916	71.652
DAYS	**Control**	78.274	82.138	86.002	85.595	82.816

5. Conclusion

This study experimentally examined the thermo-mechanical performance of high-strength self-compacting concrete incorporating bagasse cement as a partial replacement for Portland cement. The results show that all mixes satisfied self-compacting concrete requirements, demonstrating excellent flowability, passing ability, and resistance to segregation. SEM–EDS analysis confirmed that the bagasse cement possessed fine particle morphology and high silica–alumina content, supporting its pozzolanic activity and contribution to matrix densification. Compressive strength increased consistently with curing age for all mixes, indicating that the inclusion of bagasse cement did not hinder hydration or long-term strength development.

Exposure to elevated temperature caused a reduction in compressive strength due to moisture loss, dehydration of hydration products, and thermally induced cracking. However, increasing the bagasse cement content significantly improved the residual strength of the heated concrete. The mix containing 10% bagasse cement consistently exhibited the highest residual compressive strength, reaching 14.00 N/mm² at 42 days, demonstrating enhanced thermal resistance. Overall, the findings confirm that replacing up to 10% of Portland cement with bagasse cement improves the thermo-mechanical performance of high-strength self-compacting concrete while reducing environmental impact, making it suitable for sustainable and fire-resilient construction applications.

References

[1] Adesina, A., & Zhang, J. (2024). Impact of concrete structures durability on its sustainability and climate resiliency. *Next Sustainability*, *3*, 100025–100025. https://doi.org/10.1016/j.nxsust.2024.100025

[2] Barbhuiya, S., Kanavaris, F., Das, B. B., & Idrees, M. (2024). Decarbonising cement and concrete production: Strategies, challenges and pathways for sustainable development. *Journal of Building Engineering*, *86*, 108861. https://doi.org/10.1016/j.jobe.2024.108861

[3] Belaid, F. (2022). How does concrete and cement industry transformation contribute to mitigating climate change challenges? *Resources, Conservation & Recycling Advances*, *15*(1), 200084. https://doi.org/10.1016/j.rcradv.2022.200084

[4] Fayed, S., Emrah Madenci, Bahrami, A., Yasin Onuralp Özkiliç, & Mansour, W. (2023). Experimental study on using recycled polyethylene terephthalate and steel fibers for improving behavior of RC columns. *Case Studies in Construction Materials*, *19*, e02344–e02344. https://doi.org/10.1016/j.cscm. 2023.e02344

[5] Ilayarsi, R., Mukilan, K., & Thiagamani, S. M. K. (2025). Mechanical and durability properties of self compacting fly ash based geopolymer concrete incorporating ultra fine slag. *Discover Materials*, *5*(1). https://doi.org/10.1007/s43939-025-00363-y

[6] Kawashima, A. B., Martins, L. D., Rafee, S. A. A., Rudke, A. P., de Morais, M. V., & Martins,

[7] J. A. (2020). Development of a spatialized atmospheric emission inventory for the main industrial sources in Brazil. *Environmental Science and Pollution Research*, *27*(29), 35941–35951. https://doi.org/ 10.1007/s11356-020-08281-7

[8] Ramanathan, P., Baskar, I., Muthupriya, P., & Venkatasubramani, R. (2013). Performance of self-compacting concrete containing different mineral admixtures. *KSCE Journal of Civil Engineering*, *17*(2), 465–472. https://doi.org/10.1007/s12205-013-1882-8

[9] Reddy, A. S., Kasa, V. P., Samal, B., Dubey, B. K., Yadav, V., & Pandey, D. S. (2025). Sustainable agricultural waste management in India: Innovations, challenges, and future perspectives. *Biomass and Bioenergy*, *202*, 108261. https://doi.org/10.1016/j.biombioe.2025.108261

[10] Siregar, J. P., Dewi, R., Manalu, J., Numberi, J. J., & Safanpo, A. (2023). The Incorporation of Crumb Rubber in Construction Reinforcement: A Review. *Journal of Innovation and Technology*, *2023*.

[11] Temitope Omotayo, Bankole Awuzie, Temitope Egbelakin, Orimoloye, I. R., Ogunmakinde, O. E., & Adebayo Sojobi. (2024). The Construction Industry's Future. *Routledge EBooks*, 246–254. https://doi.org/ 10.1201/9781003372233-21

[12] Wagh, M., Uday Waghe, Bahrami, A., Ansari, K., Yasin Onuralp Özkılıç, & Anshul Nikhade. (2024). Experimental investigation of mechanical and durability performances of self-compacting concrete blended with bagasse ash, metakaolin, and glass fiber. *Frontiers in Materials*, *11*. https://doi.org/10.3389/ fmats.2024.1351554

[13] Zhang, H., Wang, S., Hao, J., Wang, X., Wang, S., Chai, F., & Li, M. (2016). Air pollution and control action in Beijing. *Journal of Cleaner Production*, *112*(0959-6526), 1519–1527. https://doi.org/10.1016/ j.jclepro.2015.04.092

[14] Zhou, C., Wang, J., Shao, X., Li, L., Sun, J., & Wang, X. (2023). The feasibility of using ultra-high performance concrete (UHPC) to strengthen RC beams in torsion. *Journal of Materials Research and Technology*, *24*, 9961–9983. https://doi.org/10.1016/j.jmrt.2023.05.185