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Research Paper

Sustainable Composite Concrete for Modern Construction Developments

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Abstract: The effects of two cooling regimes (sudden and gradual) were investigated when hybrid fiber reinforced ternary blended (HFRTB) concrete was exposed to constant preeminent temperatures for 3 hours (SET-3hrs). This study's main goal was to find out whether it was possible to improve concrete's performance when it was subjected to high temperatures by adding fly ash, GGBFS, silica fume, galvanised iron fiber, and polypropylene fiber, When HFRTB concrete was exposed to continuous high temperatures for three hours, the influences of two cooling regimes (abrupt and steady) were examined (SET-3hrs). The temperature changes by 100^{o} C increments between 100^{o} C and 1000^{o} C. Two ternary blended (TB) concrete that contains hybrid fibers made of galvanised iron and polypropylene as well as cement, fly ash, and silica fume are contrasted with conventional concrete. The samples were placed through a range of strength and durability tests, with leisurely refrigeration outstripping unexpected and frightening results.

Keywords: cooling regime, durability, fiber, sustained elevated temperatures, strength, ternary blended concrete

1. Introduction

Lifespan protection in the event of a fire is one of the most crucial factors to take into account while building a structure [1,2]. Before using any building material in structural components, it is essential to understand how it behaves [3,4].

Due to the material's extensive use in structures that are susceptible to numerous arrangements of violence, an investigation into concrete's behaviour and durability at high temperatures is required [5,6].

Thermal characteristics of concrete are essential when evaluating how resistant concrete constructions are too high temperatures [7]. The period and strength of the contact, as well as the burnability of the building components, all affect how much damage is done [8,9]. Concrete is incombustible on its own, and its temperature coefficient resembles that of steel quite a little [10]. The thermal expansion coefficient of cement paste in concrete is superior to that of aggregate [11].

1.1. Goal of the Study

This study aims to examine the effects of 2 cooling regimes (rapid and steady) on compressive strength, split tensile strength (T), near-surface properties (water absorption, "w," and sorptivity, "So," and modulus of elasticity, or "E," when M30 traditional concrete, two "TB" concrete (Cement + fly ash + ground granulated blast boiler slag (C+FA+GGBFS) and Cement + fly ash

1.2. Statements of Novelty

Supporting evidence for hypotheses, information about individual efforts, approaches that have been

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recognised, an innovative strategy, as well as breakthroughs in the arena of fiber-reinforced concrete research, have all been published. The reinforcement of ternary blended hybrid fibers is the main topic of the current work. It was found that the work or approach stated in this paper had never been done or used before when this study was compared to earlier research on the topic or work done by others. It follows that while research on conventional concrete subjected to high temperatures is comparable to earlier work in the literature, research on ternary blended hybrid fiber reinforced concrete exposed to two cooling regimes is completely distinct from earlier work.

2. Literature Review

At the cement paste-aggregate interface, the bond breakdown is encouraged by differential expansion caused by a significant variation in thermal coefficient [12]. Concrete finishes of Portland cement are frequently used to construct buildings. It enhances community protection in the aspect of fire hazards [13,14] and once evaluated for fire resistance, the totaling of pozzolanas rises the microstructure and phase composition of concrete [15]. However, steel fibers aid in resisting pore pressure, help to minimise cracking and expansion, and ultimately increase tensile strength [16]. Polypropylene fibers used to concrete minimise spalling brought on by fire [17,18]. Further investigation is therefore required into the behaviour of hybrid fiber-reinforced mixed concrete in high-temperature settings.

3. Materials

3.1. Cement employed is OPC 43 grade and complies with IS 8112:2013 [19] requirements. According to laboratory tests, the material's fineness is 270 m^2/kg, its specific gravity (SG) is 3.15, its commencement and closing setting times are 60 and 320 minutes, its soundness is 2 mm, and its compressive strengths for 3, 7, and 28 days are 27 N/mm^2, 38 N/mm^2, and 44 N/mm^2 respectively.

3.2. Sand Grading Zone II, which complies with IS 383:1970 [20], uses sand. The bulk density is 1827.12 kg/m^3, the fineness modulus is 2.88, the silt content is 1.8%, the specific gravity is 2.60, the bulking is 8.2%, the water absorption is 0.1%, and the specific gravity is 2.60.

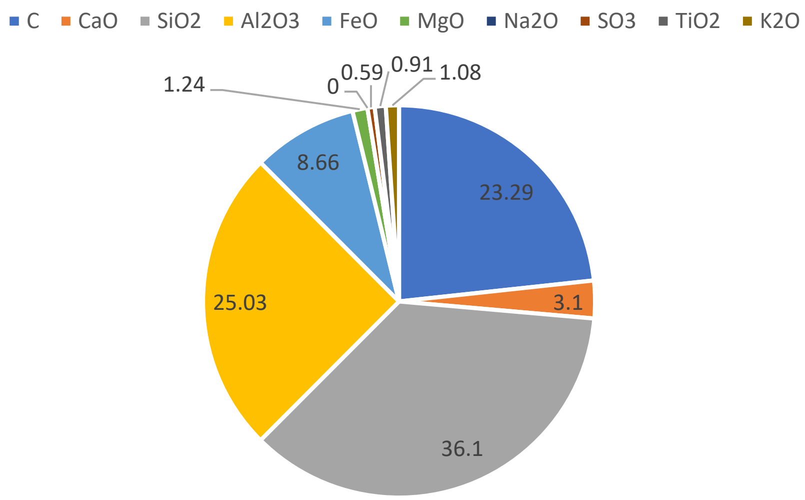

Figure 1. Chemical Composition of Fly Ash

3.3. Coarse aggregate According to IS 383:1970[20], coarse aggregate with a 20 mm and smaller size is utilised and evaluated. The bulk density is 1886.53 kg/m3, the fineness modulus is 6.54, the specific gravity is 2.65, the free moisture content is 0.00, the water absorption is 0.6%, the impact value is 15%, the crushing value is 14.5%.

3.4. Fly ash is transported from a thermal power station and complies with IS 3812 (Part 1):2013 criteria [21]. Fineness = 333 m^2/kg, particles retained on a 45-micron IS sieve by wet sieving = 4.52%, specific gravity = 2.15, compressive strength after 28 days = 23 MPa, and soundness = 0.2% are the results of laboratory testing. Figure 1 displays the fly ash's chemical makeup.

3.5. GGBFS The IS 12089:1987 [22] criteria are met by GGBFS, which is sourced from Pune, Maharashtra. The experimental results are as follows: fineness 350 m^2/kg, compressive strength (MPa) for 7 and 28 days 31.66 and 48.33, soundness 0 mm, starting setting time 120 minutes, specific gravity 2.85.

3.6. Silica fume The Gujarati city of Vadodara produces silica fume that complies with IS 15388: 2003 [23] specifications. According to laboratory tests, the bulk density is 640 kg/m^3, the fineness is 20 m^2/g, the oversize retained on a 45-micron IS sieve is 3.6 percent, the compressive strength at 7 days is 26 MPa, the specific gravity is 2.2, and the color is black.

3.7. Local galvanised iron Locally produced galvanised iron wires were chopped into 50 mm long, 1 mm thick, and 50:1 aspect ratio straight fiber. Its tensile strength is 825 MPa, its density is 7850 kg/m^3, and the colour is a bright, pure white.

3.8. Polypropylene fibers Fibers made of polypropylene were shipped in from Nagpur. Specific gravity is 0.91, alkali, chemical, acid, and salt resistance are all present, denier is 1050, tensile strength is 0.67 kN/mm^2, Young's modulus is 4.00 kN/mm^2, melt point is 165, ignition point is 600, absorption is zero, bulk density is 910 kg/m^3, and the material is fibrillated (mesh) form, usually grey with outstanding scattering.

3.9. Superplasticizer To improve workability and reduce water content, superplasticizer SP430 which complies with IS 9103:1979 [24] is used.

The following are some of the superplasticizer's qualities that have been identified. According to IS 456:2000, the cement has a specific gravity of 1.22, a liquid physical state and zero chloride content, an air entrainment of 1%, a brown color and a mild odor, a concentrated pH of 7-8, and a dose of 0.5 to 2.0 liters per 100 kg that must be mixed with potable water for concreting and curing.

4. Experimental Methods

According to IS 10262:2009 [25], concrete is proposed for M30 grade. After numerous studies, the water-cement ratio was determined to be 0.45, and the 100-mm slump is preserved. Ultimately, the mix ratio is 1:2.02:3.45.
The specific groupings are as follows, with details:

a) C + (GIF+PPF): 100 % cement and 0.5 % GIF plus 0.5 % PPF
b) (C+FA+GGBFS) + (GIF+PPF): 70 % cement plus 15 % fly ash plus 15 % GGBFS and 0.5 % GIF plus 0.5 % PPF
c) (C+FA+SF) + (GIF+PPF): 70 % cement plus 15 % fly ash plus 15 % silica fume and 0.5 % GIF plus 0.5 % PPF

The combinations are calculated as a % by weight of cementitious material and fibers using the volume fraction technique [25–27]. 198 standard right-angled block models of 150 mm were cast for compressive strength and near-surface properties of concrete, and 396 standard cylinder models of 150 mm diameter and 300 mm height were made for split tensile strength and modulus of elasticity. The specimens were incubated at room temperature for 28 days to cure. A SET test is conducted in the heat treatment facility. It uses a 32-kW electrical load and a pit-style electrical furnace with Kanthal wire components. The highest temperature is 1200°C. The furnace has a control panel with a temperature indicator, a tube-shaped construction, and dimensions of 400 mm in diameter by 1.2 m in depth. The time Vs temperature curve of the furnace used to heat the samples closely resembles the ISO 834:2014 standard [28] thanks to its ampere rating and temperature sensor. [29, 30] Three hours were spent keeping specimens stress-free (retention time).

After being removed from the boiler, the concrete samples were immediately submerged in water. On the other hand, they were maintained throughout the progressive cooling as they would be in the natural environment. After temperature testing and chilling procedures, compressive strength is calculated by IS 516:1959 [31] and split tensile strength with IS 5816:1999 [32]. On the samples, near-surface characteristics like water absorption, sorptivity, and modulus of elasticity are also tested.

5. Results and Discussion

The following table contrasts "C", C+FA+GGBFS, and C+FA+SF blends with GIF+PPF hybrid fiber combinations' strengths, near-surface characteristics, and modulus of elasticity for both cooling regimes vs. all maintained elevated temperatures for 3 hours.

Tables 1, 2, and 3 make it clear that all concrete combinations experience a drop in compressive strength, split tensile strength, and modulus of elasticity as the temperature rises. Up to 300o C, the modulus of elasticity, split tensile strength, and compression strength, all showed small decreases. After that, however, they all experienced significant reductions, with the highest loss occurring at 1000o C for all combinations.

Table 1. Compressive strength results for C, C+FA+GGBFS, and C+FA+SF mixes with GIF+PPF hybrid fiber combinations for sudden and slow cooling regimes vs. all SET-3 hours.

SET (^{0}C)	Blend & Fiber Combination					
	C + (GIF+PPF)		(C+FA+GGBFS) + (GIF+PPF)		(C+FA+SF) + (GIF+PPF)	
	Cooling Regime					
	Sudden Cooling	Gradual Cooling	Sudden Cooling	Gradual Cooling	Sudden Cooling	Gradual Cooling
	σ_{avg} (MPa)					
Thirty	46.24	47.31	54.13	54.72	54.92	55.83
Hundred	46.24	46.87	53.60	54.90	54.45	54.76
Two hundred	45.14	45.86	52.94	53.06	53.99	54.64
Three hundred	44.01	44.06	52.35	52.98	53.00	53.30
Four hundred	40.37	40.28	49.72	50.32	50.08	51.10
Five hundred	36.10	36.54	46.87	47.54	47.08	48.08
Six hundred	31.36	31.66	44.12	44.65	44.65	44.80
Seven hundred	26.60	26.29	40.34	40.84	40.87	41.00
Eight hundred	21.80	22.60	36.24	36.87	36.08	36.98
Nine hundred	17.20	17.40	31.89	31.84	32.05	32.66
Thousand	12.50	12.36	27.32	27.62	28.03	28.42

Table 2. Split tensile strength values of C, C+FA+GGBFS, and C+FA+SF blends with GIF+PPF hybrid fiber combination in comparison to all of the maintained elevated temperatures for 3 hours for both quick and slow cooling regimes.

SET (^{0}C)	Blend & Fiber Combination					
	C + (GIF+PPF)		(C+FA+GGBS) +(GIF+PPF)		(C+FA+SF) + (GIF+PPF)	
	Cooling Regime					
	Sudden Cooling	Gradual Cooling	Sudden Cooling	Gradual Cooling	Sudden Cooling	Gradual Cooling
	T_{avg} (MPa)					
Thirty	5.07	5.21	6.08	6.22	6.18	6.28
Hundred	5.00	5.13	6.01	6.17	6.21	6.23
Two hundred	4.93	5.05	5.90	6.05	6.02	6.13
Three hundred	4.71	4.83	5.60	5.74	5.75	5.84
Four hundred	4.30	4.43	5.25	5.40	5.36	5.45
Five hundred	3.84	3.95	4.65	4.77	4.75	4.84
Six hundred	3.15	3.24	4.06	4.15	4.18	4.26
Seven hundred	2.52	2.61	3.57	3.77	3.72	3.81
Eight hundred	1.89	1.94	3.05	3.15	3.22	3.30
Nine hundred	1.32	1.41	2.40	2.52	2.70	2.76
Thousand	0.76	0.81	1.95	2.05	2.26	2.31

Table 3. Results for the modulus of elasticity of C, C+FA+GGBFS, and C+FA+SF blends with GIF+PPF hybrid fiber combination for sudden and gradual cooling regimes vs SET-3hrs

SET (^{0}C)	Blend & Fiber Combination					
	C + (GIF+PPF)		(C+FA+GGBFS) + (GIF+PPF)		(C+FA+SF) + (GIF+PPF)	
	Cooling Regime					
	Sudden Cooling	Gradual Cooling	Sudden Cooling	Gradual Cooling	Sudden Cooling	Gradual Cooling
	E_{avg} x 10^4 (MPa					
Thirty	4.25	4.32	4.69	4.73	4.87	4.82
Hundred	4.18	4.23	4.63	4.68	7.73	4.77
Two hundred	4.09	4.13	4.56	4.60	4.68	4.72
Three hundred	3.92	3.97	4.45	4.55	4.56	4.60
Four hundred	3.68	3.73	4.20	4.24	4.33	4.33
Five hundred	3.44	3.47	3.86	3.91	4.01	4.04
Six hundred	3.08	3.13	3.54	3.58	3.68	3.70
Seven hundred	2.70	2.74	3.17	3.19	3.33	3.36
Eight hundred	2.35	2.39	2.78	2.80	2.95	2.98
Nine hundred	2.01	2.05	2.41	2.43	2.57	2.60
Thousand	1.66	1.69	2.00	2.01	2.20	2.20

Tables 4 and 5 demonstrate that water absorption and sorptivity increase with temperature for all concrete mixes. Increasing temperatures also cause an uneven distribution of cement hydration products, which increases the structure's porosity. With a prolonged curing period, the result is a decrease in compressive strength. Temperature variations can cause concrete to crack. As it gets hotter, concrete expands, and as it gets colder, it contracts. You have definitely learned about a lot of other materials that are similar to this. If concrete tries to expand or contract but is unable to do so, it will probably break. The findings show that increased temperatures enhance concrete's permeability to chloride and fire damage. Up until 400o C, near-surface attributes didn't change much, but after that, they grew significantly, reaching their maximum rise for all combinations at 1000o C. In all temperatures, the performance of the hybrid fiber and C+FA+SF mix concrete is improved.

Table 4. Performances of C, C+FA+GGBFS, and C+FA+SF blends with GIF+PPF hybrid fiber combination for water absorption under rapid and gradual cooling regimes vs all maintained elevated temperatures for three hours

SET (^{0}C)	Blend & Fiber Combination					
	C + (GIF+PPF)		(C+FA+GGBFS) + (GIF+PPF)		(C+FA+SF) + (GIF+PPF)	
	Cooling Regime					
	Sudden Cooling	Gradual Cooling	Sudden Cooling	Gradual Cooling	Sudden Cooling	Gradual Cooling
	w_{avg} (%)					
Thirty	1.09	1.07	0.99	0.98	0.93	0.93
Hundred	1.10	1.08	1.00	0.99	0.94	0.92
Two hundred	1.13	1.11	1.03	1.01	0.95	0.94
Three hundred	1.21	1.10	1.06	1.03	0.99	0.96
Four hundred	1.34	1.32	1.15	1.11	1.05	1.04
Five hundred	1.47	1.46	1.25	1.22	1.16	1.13
Six hundred	1.69	1.67	1.37	1.33	1.26	1.23
Seven hundred	1.98	1.96	1.51	1.49	1.41	1.36
Eight hundred	2.35	2.32	1.70	1.67	1.56	1.51
Nine hundred	2.95	2.92	1.95	1.89	1.76	1.72
Thousand	3.90	3.86	2.29	2.18	2.05	1.99

Table 5. Results of sorptivity tests for C, C+FA+GGBFS, and C+FA+SF blends with GIF+PPF hybrid fiber against all maintained elevated temperatures for three hours, for both rapid and gradual cooling regimes

SET (^{0}C)	Blend & Fiber Combination					
	C + (GIF+PPF)		(C+FA+GGBFS) + (GIF+PPF)		(C+FA+SF) + (GIF+PPF)	
	Cooling Regime					
	Sudden Cooling	Gradual Cooling	Sudden Cooling	Gradual Cooling	Sudden Cooling	Gradual Cooling
	S_{oavg}(mm/min$^{0.5}$)					
Thirty	4.30	4.26	2.88	2.84	2.53	2.48
Hundred	4.48	4.41	2.96	2.90	2.58	2.52
Two hundred	4.68	4.61	3.06	2.99	2.63	2.67
Three hundred	4.94	4.86	3.19	3.12	2.74	2.68
Four hundred	5.34	5.27	3.37	3.30	2.88	2.81
Five hundred	5.87	5.78	3.60	3.53	3.03	2.97
Six hundred	6.50	6.41	3.90	3.82	3.28	3.20
Seven hundred	7.20	7.10	4.26	4.18	3.55	3.47
Eight hundred	8.16	8.04	4.68	4.58	3.85	3.76
Nine hundred	9.34	9.21	5.20	5.12	4.26	4.17
Thousand	11.09	10.88	5.91	5.80	4.72	4.62

In comparison to hybrid fiber and C+FA+SF mix, hybrid fiber and C+FA+GGBFS blend produced somewhat inferior results, and hybrid fiber and traditional concrete produced significantly worse results (C). According to all test results, there is only a little performance difference between the two cooling regimes, with moderate cooling outperforming abrupt cooling for all temperatures and combinations. This is because sudden cooling causes concrete to experience a thermal shock, rupturing the intermolecular bond between the components [35]. When specimens absorb moisture from the environment during gradual cooling, strength might be regenerated in the interim [36]. While concurrently reducing water absorption and sorptivity, the use of a hybrid fiber combination raises compressive strength, split tensile strength, and modulus of elasticity [37, 38, 39]. It was discovered that the trends in test results and comments provided by Peng GF et al. in 2009, Husem M. in 2006, Mohammad I. in 2021, Srinivas Rao K. in 2021, and Aswal. As a result, it can be said that the test findings obtained are consistent with the other results published in the literature.

6. Conclusions

These conclusions can be reached through the investigation.

a) At 30 degrees Celsius, the material has the highest compressive strength, split tensile strength, elastic modulus, and the least amount of water absorption and sorptivity (reference temperature). All concrete mixtures experience a loss in compressive strength, split tensile strength, elastic modulus, and near-surface properties with rising temperatures.
b) Up to 300 degrees Celsius, all three properties—compressive strength, split tensile strength, and "E"—started to fall gradually. At that point, they all began to decline significantly, with the greatest damage happening at 1000 degrees Celsius for all groupings.
c) The performance of the hybrid fiber- and C+FA+SF-produced concrete is superior at all temperatures up to 400 degrees Celsius, after which it significantly improved and reached its peak levels for all combinations at 1000 degrees Celsius.
d) Concrete made with a hybrid fiber and C+FA+SF combination performs better in all temperature ranges.
e) As compared to the hybrid fiber and C+FA+SF mix, the hybrid fiber and C+FA+GGBFS blend provided somewhat inferior results, while the hybrid fiber and traditional concrete produced noticeably poorer results.
f) By combining hybrid fibers, it is possible to increase sorptivity and water absorption while also increasing compressive strength, split tensile strength, and elastic modulus.
g) The performance of the two cooling regimes is only slightly different in all test results; gradual cooling outperforms sudden cooling in all combinations and at all temperatures.

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Authors’ Contributions

The author is a post-Ph.D. researcher, who did the investigations and wrote the manuscript. The author read and approved the final manuscript.

Competing Interests

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1]. T. Du, B. Zhou, B. Liu, H. Ye, and J. Peng, "The influence of opposite-side high temperature on the frozen behaviour of containment concrete under single-side salt freeze-thaw method," *Structures*, vol. 36, pp. 854-863, 2022.

[2]. S. Rawat, C. K. Lee, and Y. X. Zhang, "Performance of fiber-reinforced cementitious composites at elevated temperatures: a review," *Constr Build Mater*., vol. 292, 123382, 2021.

[3]. E. Horszczaruk, P. Sikora, K. Cendrowski, and E. Mijowska, "The effect of elevated temperature on the properties of cement mortars containing nano silica and heavyweight aggregates," *Constr Build Mater*, vol. 137, pp. 420-431, 2017.

[4]. T. Bilir, N. U. Kockal, and J. M. Khatib, "Properties of SCC at elevated temperature: Self-Compacting Concrete: materials, Properties and Applications," *Woodhead Publishing Series in Civil and Structural. Engineering*, pp. 195-218, 2020.

[5]. T. K. Chandramoul Rao, P. Srinivasa, P. Sravana, N. Pannirselvam Sekhar, and T. Seshadri, J. "The effect of weight loss on high strength concrete at different temperature and time," *J Emerg Trends Eng Appl Sci.*, vol. 2, no. 4, pp. 698-700, 2011.

[6]. A. Yaligar Ashish and B. Vanakudre Shrikant, "Effect of sudden and gradual cooling regimes on compressive strength of blended concrete subjected to sustained elevated temperatures," *4th International Conference on Science, Technology and Management (ICSTM–2016).* India International Centre, 2016.

[7]. T. Gupta, S. Siddique, R. K. Sharma, and S. Chaudhary, "Effect of elevated temperature and cooling regimes on mechanical and durability properties of concrete containing waste rubber fiber," *Constr Build Mater*, vol. 137, pp. 35-45, 2017.

[8]. A. Sinha Deepa, "An Experimental Investigation on the Behaviour of Steel Fiber Reinforced Ternary Blended Concrete Subjected to Sustained Elevated Temperature," Ph.D. dissertation, BVM Engineering College. Sardar Patel University, Gujrat, 2013.

[9]. F. A. Selim, M. S. Amin, M. Ramadan, and M. M. Hazem, "Effect of elevated temperature and cooling regimes on the compressive strength, microstructure and radiation attenuation of fly ash–cement composites modified with miscellaneous nanoparticles," *Constr Build Mater.* 2020; vol. 258, 119648, 2020.

[10]. E. D. Shumuye Jr, J. Zhao, and Z. Wang, "Effect of fire exposure on physic-mechanical and microstructural properties of concrete containing high volume slag cement," *Constr Build Mater*, vol. 213, pp. 447-458, 2019.

[11]. S. Peter "Resistance to High Temperatures Significance of Tests and Properties of Concrete and Concrete Making Materials," *STP 169B ASTM* Philadelphia; pp. 388-417, 1978.

[12]. Y. Jiangtao, W. Weng, and Y. Kequan, "Effect of different cooling regimes on the mechanical properties of cementitious composite subjected to high temperatures," *Sci World J. Hindawi Publishing*. pp. 1-7, 2014.

[13]. K. S. Kulkarni, S. C. Yaragal, and K. S. Babu Narayan, "An overview of high-performance concrete at elevated temperatures," *Int J Appl Eng Technol*, vol. 1, no. 1, pp. 48-60, 2011.

[14]. A. Yaligar Ashish and B. Vanakudre Shrikant, "Influence of sudden and gradual cooling regimes on split tensile strength of blended concrete subjected to sustained elevated temperatures," *Int J Adv Res Sci Eng.*, vol. 5, no. 1, pp. 118-126, 2016.

[15]. M. Heikal, "Effect of elevated temperature on the physico-mechanical and micro structural properties of blended cement pastes," *Build Res J.*, vol. 56, pp. 157-172, 2008.

[16]. I. Khurshid, I. Afgan, A. M. Alade, and A. Yacine, "Influence of corium temperature, concrete composition and water injection time on concrete ablation during MCCI: new insights," *Prog Nucl Energy*, vol. 144, 104102, 2022.

[17]. J. C. M. Ho, Ylang, Y. H. Wang, M. H. Laia, Z. C. Huang, D. Yang, Q. L. Zhanga, "Residual properties of steel slag coarse aggregate concrete after exposure to elevated temperatures," Construction *and Building Materials*, vol. 316, 12575, 2022.

[18]. K. Venkatesh and R. Nikhil, “Performance of concrete structures under fire hazards: emerging Trends,” Indian *Concr J.*, pp. 7-18, 2010.
[19]. Specification for 43 Grade Ordinary Portland Cement, IS:8112. *Bureau of Indian Standards*; 1989.
[20]. Specification for Coarse and Fine Aggregates from Natural Sources for Concrete, IS:383. *Bureau of Indian Standards manak bhavan*; 1970.
[21]. Pulverized Fuel Ash; part 1. IS 3812, *Bureau of Indian Standards*; 2013,
[22]. Specification for Granulated Slag for the Manufacture of Portland Slag Cement, IS 12089. *Bureau of Indian Standards* manak bhavan; 1987.
[23]. Silica Fume–Specification, IS 15388. *Bureau of Indian Standards* manak bhavan; 2003.
[24]. Concrete Admixtures–Specification, IS:9103. Bureau of Indian Standards; 1999.
[25]. Concrete Mix Proportioning–Guidelines, IS 10262. *Bureau of Indian Standards*; 2009.
[26]. M. K. Dash, S. K. Patro, P. K. Acharya, and M. Dash, “Impact of elevated temperature on strength and micro-structural properties of concrete containing water-cooled ferrochrome slag as fine aggregate,” *Constr Build Mater.* vol. 323, 126542, 2022.
[27]. A. Sinha Deepa, A. K. Verma, and K. B. Prakash, “Influence of sustained elevated temperature on characteristic properties of ternary blended steel fiber reinforced concrete,” *Indian J Appl Res.*, vol. 4, no. 8, pp. 224-232, 2014.
[28]. Fire Resistance Tests–Elements of Building Construction, part 2: Guidance on Measuring Uniformity of Furnace Exposure on Test Samples, ISO 834–2. *International Organization for Standardization,* 2014.
[29]. A. Arabi NawwafQadi Saoud, “Effect of polypropylene fibers on fresh and hardened properties of self–compacting concrete at elevated temperatures,” *Aust J Basic Appl Sci.,* vol. 5, no. 10, pp. 378-384, 2011.
[30]. M. Saberian, L. Shi, A. Sidiq, J. Li, S. Setunge, and C.-Q. Li, “Recycled concrete aggregate mixed with crumb rubber under elevated temperature,” *Constr Build Mater.*, vol. 222, pp. 119-129, 2019.
[31]. Methods of Tests for Strength of Concrete, IS:516. *Bureau of Indian Standards*; 1959.
[32]. Splitting Tensile Strength of Concrete–Method of Test, IS:5816. *Bureau of Indian Standards*; 1999.
[33]. M. Chen, Z. Sun, W. Tu, X. Yan, and M. Zhang, “Behavior of recycled tyre polymer fiber reinforced concrete at elevated temperatures,” *Cem Concr Compos*, vol. 124, 104257, 2021.
[34]. Y. A. Ashok, P. Siddangouda, and K. B. Prakash, “An experimental investigation on the behavior of retempered concrete,” *Int J Eng Res.,* vol. 1, no. 2, pp.111-120, 2013.
[35]. G. F. Peng, S. H. Bian, Z. Q. Guo, J. Zhao, X. L. Peng, and Y. C. Jiang, “Effect of thermal shock due to rapid cooling on residual mechanical properties of fiber concrete exposed to high temperatures,” *Constr Build Mater*, vol. 22, no. 5, pp. 948-955, 2008.
[36]. M. Husem “The effects of high temperature on compressive and flexural strengths of ordinary and high–performance concrete,” Fire *Saf J.*, vol. 41, no. 2, pp. 155-163, 2006.
[37]. I. Mohammad AL biajawi, RufaidahWahppe Alkasawneh, Sahar A. Mostafa, Izwan Johari, Rahimah Embong; Khairunisa Muthusamy, “Performance of sustainable concrete containing recycled latex gloves and silicone catheter under elevated temperature,” *Journal of King Saud University - Engineering Sciences*, 2021.
[38]. K. Srinivas Rao, M. Potha Raju, and P. S. N. Raju, “Effect of elevated temperatures on compressive strength of HSC made with OPC and PPC,” *Indian Concr J*., pp. 43-48, 2006.
[39]. A. S. M. A. Awal, I. A. Shehu, and M. Ismail, “Effect of cooling regime on the residual performance of high-volume palm oil fuel ash concrete exposed to high temperatures,” *Constr Build Mater*., vol. 98, pp.875-883, 2015.