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Original Article

Experimental Analyzation of Fibre Reinforced Self Compacting Concrete under Elevated Temperature

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Abstract - *The strength of concrete varies depending on the grade of concrete and environmental circumstances, making it one of the most crucial materials to consider while building a structure. Concrete manufacturing involves multi-aggregate, cement, water and granule aggregates. The quality of the materials employed is identified by conducting preliminary tests like fineness, initial setting schedule, particular gravity, plasticity, etc. Usually, as the grade surpasses, Super Plasticizers (SP) is generally mixed with the concrete for higher strength. An appropriate compaction process is necessary to improve conventional concrete's stability. Moreover, in some instances, there are difficulties in the compaction process, leading to the impossibility of attaining full strength. Hence, a novel category of concrete called Self Compacting Concrete (SCC) prevents the abovementioned issue and does not require compaction. The SCC provides better compression and flowability, mainly when compactness is difficult. Besides, the addition of fibre-reinforced concrete improves the integrity of concrete. Similarly, the addition of rubber along with the SCC forms the Self Compacted Rubberized Concrete (SCRC), and the mixing of steel fibres or Polypropylene (PP) forms the Fibre Reinforced SCRC (FRSCRC). However, when subjected to elevated temperature, the concrete structures' durability, elastic modulus, volume deformation and strength considerably decrease. Therefore, various materials are combined with the FRSCC to increase the concrete's strength. In this paper, an analogization is carried out amid the different types of FRSCCs concerning elevated temperature to identify the optimal one.*

Keywords - *Super Plasticizers (SP), Self Compacted Rubberized Concrete (SCRC), Self Compacting Concrete (SCC), Fibre Reinforced SCRC (FRSCRC), Polypropylene (PP).*

1. Introduction

Increasing cement-based substances' mechanical qualities and durability is crucial since they play a significant role in the construction sector. As there are vast developments in the characterization methods, the properties belonging to these composite materials are categorized at various length scales starting from Nano to Macro scale. Understanding the behaviour and structure of cementitious materials is very practical in improving the macro properties. Unlike steel, concrete does not melt in elevated temperatures, i.e., temperatures up to 800ºC.

Moreover, concrete has low thermal conductivity and high specific heat capacity; concrete constructions are more substantial. Extreme temperature exposure causes the surface of a structural part to stay cold for longer than the core of the structural element. Even though concrete performs better in those ways than steel and wood, it experiences significant alternations when exposed to elevated temperatures [1]. Self-compacting concrete, sometimes described as self-consolidating concrete, consolidates without vibration and can maintain homogeneity even if the reinforcement is congested. It comprises a significant amount of powder, essential for maintaining the fresh mix's yield value and viscosity at an appropriate level. As a result, segregation, bleeding and settlement are reduced [2]. It has been demonstrated that adding fibres to SCC enhances its workability. SCC has the benefit of fulfilling expected standards and preserving the durability of concrete. Furthermore, it is workable, capable of high flow, and provides a sturdy finish for the construction [3].

Self-Compacting Concrete (SCC) is a type of concrete that is used in production to raise the functional standards of concrete. When a high amount of strength is necessary, High Strength Concrete (HSC) has also frequently been used in construction projects. To meet the demands of material's durability and mechanical qualities, Fibre-Reinforced Concrete (FRC) also uses a variety of fibre kinds.

The development of Fibre Reinforced High Strength Self Compacting Concrete (FRHSSCC), a novel building material that combines all of the apparent advantages of SCC, HSC and

FRC, has gained more attention. It benefits from the characteristics of HSSCC, an extremely flowable and non-segregating concrete with high workability and performance that vibrates without any mechanical vibration. The concrete's strength and elasticity are both enhanced by adding fibre to the mixture [4]. Self-compacting rubberized concrete is obtained by mixing self-compacting concrete with waste tyre rubber aggregate. By modifying the characteristics of concrete to become more advantageous in specific situations and applications, wastes are reduced, and sustainability is increased in terms of waste rubber. Fibre-Reinforced Self-Compacting Rubberized Concrete (FRSCRC) is generated by combining Steel and PP (Polypropylene) fibres combination with rubber particles in the concrete mixture [5, 6].

Compared to typical concrete, the SCC performance has been enhanced by including glass fibres since they prevent crack growth and assist the concrete in absorbing more energy. Fibre distribution has been identified to similarly establish its relationship to the concrete casting process. Steel fibres were employed to determine various casting techniques for concrete beams. An assessment of fibre distribution has been performed according to the fibre orientation with the central axis. An evaluation of statistics demonstrated that an angle of the fibres is exponentially distributed. The graphical representation is used to determine the fibres' orientation using spherical 4D histograms rapidly.

It has been noticed that SCC outperformed in terms of its mechanical qualities when steel fibres and mineral admixtures were used. Additionally, it can enhance the SCC's strength by adding m-sand-based steel fibres and curing the mixture in fresh water for 7, 28 or 90 days. However, steel fibres are discovered to be restricted for improved performance. Hence, the performance of SCC using better grades of concrete will be enhanced by combining better steel with some other aggregates and industrial effluent [7, 8]. Numerous fibres are frequently added to concrete structures worldwide to improve materials' ability to resist cracking when used in brittle concrete-like materials. These fibres can enhance the flexibility and mechanical qualities of materials that resemble concrete.

Depending on the material and geometrical dimensions of fibres, the fibres also aid in minimizing early age shrinkage or boosting fire resistance. For increasing matrix characteristics to high strain rates connected with dynamic loads, the fibres enable an energy absorption capacity of the materials that closely mimic concrete [9]. Besides, NA is also employed in SCC, which involves chemical components like aluminium and oxygen, as NA has a large surface-to-volume ratio and drastically alters the fresh characteristics of concrete. Table 1 illustrates the merits and demerits of concrete parameters, while Table 2 shows the impact of different temperatures on concrete's physical and chemical parameters.

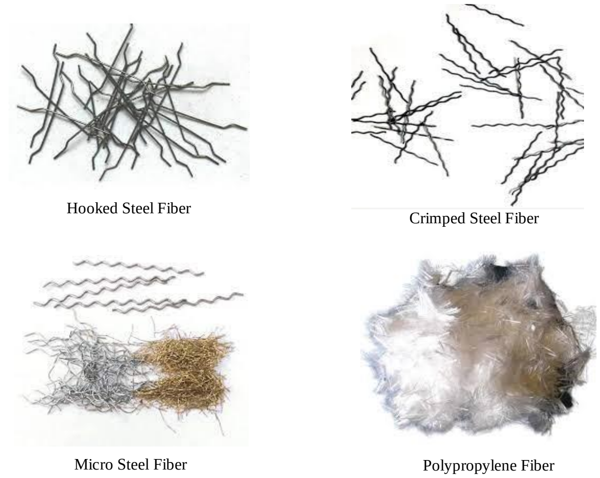

Fig. 1 Different fibres employed in concrete

Although NA has a high volume-to-surface area ratio, it exhibits significant chemical reactivity and catalyzes pozzolanic reactions. NA enhances its mechanical properties when cementitious composites are subjected to high temperatures. According to reports, adding NA to SCC accelerates the generation of hydrated products and improves pore structure while lowering the water absorption capacity of hardened specimens and fresh concrete's workability [10].

Using a relatively thin reinforced scc layer, the U jacketing approach strengthens the samples. Identifying acceptable supporting solutions for speedy implementation at a cheap cost is crucial since difficult conditions, particularly in developing countries, enhance existing damage to Reinforced Concrete (RC) structures [11]. This paper conducts a comparative investigation of different material technologies to identify the optimal one.

Table 1. Merits and demerits of concrete parameters

S. No	Merits	Demerits
1	Speed up construction	Extended de-moulding period
2	Enhancement of the quality of construction	Rise of risk and associated uncertainty
3	Safer working condition	Lower resistance to higher temperatures
4	Expanded services as vibration has been eliminated, life of form functions	High formwork pressure leads to higher formwork costs
5	Higher level of final product quality	Fire behaviour is not entirely comprehended
6	Decreased manpower	On a construction site, maintaining a ready mixture is challenging
7	Improved ecological footprints	Inapplicable in all scenarios

Table 2. Impact of different temperatures over physical as well as chemical parameters of concrete

S. No.	Temperature Range	Investigated Parameter	Impact of Temperature Rise
1	100-800^{0}C	Compressive strength	Linear rate decreases
2	100-800^{0}C Above 100^{0}C	Porosity and pore size	Increase in pore size and porosity. Porosities are better structured and smaller.
3	100-800^{0}C	Elastic modulus	Linear rate decreases
4	100-800^{0}C	Splitting tensile strength	Linear rate is reduced
5	100-800^{0}C	Stress strain relationship	A downward and rightward displacement of the peak stress, flatter stress-strain curves
6	100-800^{0}C	Residual flexural strength	Decreases in a linear rate
7	At 105^{0}C At 400^{0}C	Water evaporation	Physically absorbed and free water disappears, chemically coupled water degrades, and capillary water completely evaporates.
8	Up to 300^{0}C	Hydration	Improved hydration of un-hydrated cement
9	Up to 300^{0}C 200^{0}C 400^{0}C	Microstructure	Zero micro cracks, micro crack intensity increases

2. Recently Performed Investigations on Construction Material Technologies at Elevated Temperature

Cement, aggregates and water make up the majority of concrete, a heterogeneous material. Various cementitious components and additives are added to the concrete at different volumetric ratios to meet greater strength and durability demands. Therefore, the type of concrete significantly impacts how concrete responds to exposure to high temperatures.

Up to 400°C, most types of concrete exhibit a gradual and persistent loss of strength. However, the decline is quicker until the concrete reaches 800 or 1000°C; at this point, it spalls or loses its ability to support any given weight. This assessment emphasizes the need for additional study and code provisions considering various concrete constituent kinds and cutting-edge construction material technologies.

2.1. Crumb Rubber Aggregates and Lightweight Scoria Aggregate in Fibre Reinforced Self-Compacting Concrete (SCC)

The lightweight SCC crumb rubber is used rather than natural aggregates. Here, crumb rubber, lightweight scoria aggregate and macro fibres are combined to substitute the natural aggregate and effectively dispose of the habitat-affecting waste. Moreover, after subjecting concrete to elevated temperature, the main reason is to identify the efficiency of concrete and the resulting mechanical aspects of fibres. An experiment has been conducted in the concrete mix at average and elevated temperatures. The advantages of each fibre at various temperatures were evaluated for steel and polypropylene. An increase in temperature causes a more significant loss in elastic modulus. As a result, the workability of lightweight SCC is comparable to that of standard concrete.

The work demonstrates behavioural characteristics of mixed HFSCC under high temperatures. In this work, from total concrete, 0.5 percent of hybrid fibres are used to find the capability. Compared to SCC, without fibre, load carrying capacity is higher in SCC with fibres.

The outcomes say compressive strength goes low beyond the medium temperature, and the load carrying capacity is in inverse proportion to the increase in temperature. Better upgraded strength is yielded when fibres are used in concrete in elevated temperatures. However, as the strength increases, the spalling occurs in elevated temperatures.

2.2. Hybridization of Steel and Propylene in Fibre Reinforced Concrete

Due to exposure to high temperatures, concrete components must be rebuilt as they deteriorate. This study aims to investigate High-Performance Concrete (HPC), which strengthens concrete by utilizing steel and Polypropylene (PP) fibres as components. Six samples were made by combining 1% of Five-Dimensional steel (5DH) fibres with 0.25 or 0.50 percent of the two polypropylene fibres.

After the samples have been heated to a high temperature and cooled to room temperature, they are examined visually and tested for split tensile strength and compressive strength. The residual mechanical characteristics of HPC combined with ST and PP fibres have improved after 28 days of exposure to high temperatures. However, PP fibres prevent spalling, while steel fibres are ineffective in controlling spalling.

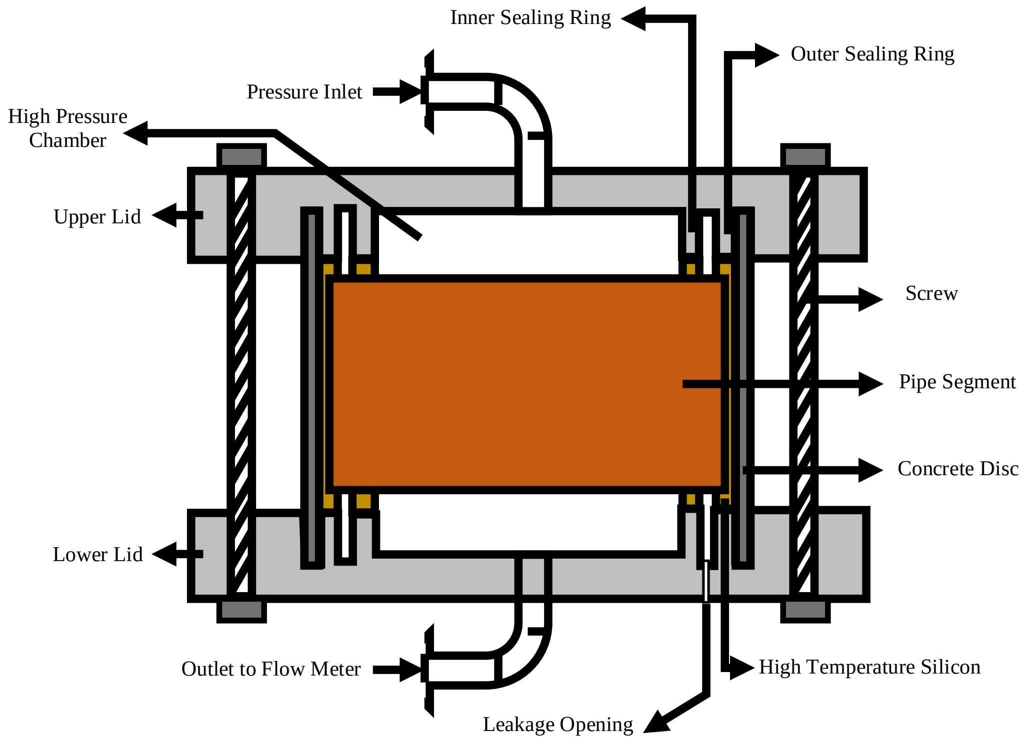

Fig. 2 Permeability test setup

2.3. Hybrid Polypropylene (PP) and Steel Fibres for Ultra-High Performance Concrete (UHPC)

The combined effect of Ultra-High Performance Concrete (UHPC) and these materials is examined in this work using hybrid Polypropylene (PP) and steel at high temperatures. Permeability of UHPC is another element that causes spalling. UHPC microstructures' permeability changes before and after exposure to high temperatures. The permeability test setup is shown in Figure 2. Because of the increased permeability, the experiment found that higher spalling reduction occurs even with lower hybrid PP and steel fibre concentrations. The microstructural analysis combines empty PP fibre tunnels by creating numerous micro cracks in both fibres due to thermal expansion, which enhances the permeability of steel fibre-reinforced UHPC and hybrid PP.

2.4. Individual and Combined Effects of Fibres on UHPC

This work demonstrates the effects of Polypropylene (PP) fibres, steel fibres and aggregate size on the behaviour of spalling and pore pressure in Ultra-High Performance Concrete (UHPC). Heating one side of UHPC at different heights, the temperature is measured continuously, and Pore pressure also increases gradually. To find the spalling permeability, tensile and Compressive tests were conducted. PP fibres play a more significant role in boosting permeability and preventing spalling than larger aggregate and steel fibres.

To increase permeability in concrete, PP fibres and steel fibres, or PP fibres and larger aggregates, are used together. The pore pressure decreases when the permeability increases in the sample. Thus, observed the Vaporization of liquid water and release of water vapour from the temperature history. The temperature of PP fibres is the second change.

The tensile strength more than that of the Maximum pore pressure indicates the hydraulic force at the moister clogged region, which is the reason for spalling. The present device can measure only the gas pressure, and the hydraulic pressure cannot be measured; therefore, better methods need to be found for better study.

2.5. Macro Polypropylene (PP), Polyamide (PA) and Steel (ST) in FRSCC

As Reinforced Self-Compacting Concrete (FRSCC) is exposed to both low and high temperatures, the performance of Polyamide (PA), macro Polypropylene (PP), and Steel (ST) is assessed. The samples with dissimilar accumulation percentages of fibre from 0 to 1 are examined under average, medium and elevated temperatures.

At the hardening stage after curing, at standard temperature, preliminary outcomes of Residual Flexural Strength (RFS), Residual Compressive Strength (RCS), Mass loss, and Residual Toughness (RT) were taken to note and also at the fresh state, L-box parameters, slump flow diameter and T500 time were checked. Scanning with the electron microscope, the modifications in microstructure due to using different fibres are reviewed.

Table 3. Physical and mechanical properties of fibres

Type of Fiber	Length (mm)	Diameter (mm)	Aspect Ratio (Length/ Diameter)	Tensile Strength (MPa)	Specific Gravity	Elastic Modulus (MPa)	Melting Point (°C)
Steel	60	0.9	67	1100	7.85	200,000	1539
Poly Propylene	40	0.75	53	338	0.91	4800	160
Polyamide	54	0.55	98	900	1.14	6800	256

In this study, macro PA and PP are analogues for the mass loss, RCS deviation and RFS deviation in FRSCC. Table 3 lists the mechanical and physical characteristics of fibres. As a result, macro PA at the peak stage contributes to PP in toughness; the macro ST fibres give upgrade RFS and RT. The fewer cracks formed at FRSCC using macro ST at elevated temperatures, the better the result. Although the results have some improvement, the cracks were not controllable.

2.6. Palm Oil Fuel Ash (POFA) with SCC

Palm Oil Fuel Ash (POFA) cement is used instead of some Self-Compacting Concrete (SCC) cement to reduce manufacturing costs, energy consumption problems and environmental harm. The effects of POFA at high temperatures on SCC have not been adequately investigated. At first, the compressive strength is calculated for designing concrete fire resistance at elevated temperatures. As an experiment, the SCC with a 15% substitution of POFA for cement, the microstructure and compressive strength at high temperatures are performed.

After heating the samples in an electric furnace for 120 minutes, from an average temperature to a high temperature, concrete cubes of SCC demonstrate their compressive strength after 28 days. When the heat increases, continuous mass loss in sample cubes is exposed. Compressive strength increases in the medium temperature; the compressive strength values oscillate in thermal rise from medium to elevated temperature for two samples. Numerous factors in the microstructure change Calcium Silicate Hydrate (C-S-H). Utilizing POFA lowers production waste and allows use in constructions with excellent fire resistance. After that, Only 15% of concrete is replaced with POFA.

2.7. Stress–Strain Behaviour of Different Grades of SCCs

To create a novel design mix for use in diverse type grades, this study concentrated on Self Compacting Concrete (SCC), a cutting-edge technology compared to traditional concrete. Various character analysis tests are required for the validation of fresh SCC. The cube test was done on the 28th and 56th day consecutively.

For different grades of SCC, Mechanical characteristics were tested. In low, medium and elevated temperatures, two types of heating are considered for experiments for fire resistance of building components to ensure safety during accidents; in elevated temperature Stress–strain character in different grades of SCC is taken from the test. As a result, the peak strain of SCC grades rises in high thermal exposure. In Energy Absorption Capacity (EAC) terms, the ductile properties of different SCC grades were calculated. When temperature increases, EAC values decrease. However, the properties change from flexible to breakable when the temperature rises.

2.8. Structural Response of SCC

This paper shows Self-Compacting Concrete's (SCC) performance in high thermal exposure. The water getting cooled on the flexural behaviour of the selected grade of SCC is tested for choosing the correct material for fire safety. The effect of increased temperatures on the requisite qualities of SCC was investigated in this experiment using cover thickness and percentages of tensile reinforcement effect. The physical properties of the sample are evaluated when highlighted thermally as per ISO 834; for examining the impact, the cooling samples were cooled by water or air.

When SCC samples are exposed to elevated temperatures, Energy Absorption Capacity (EAC), stiffness and strength are reduced, and the fire safety of beam specimens is enhanced as the cover thickness increases. The failure of force depends on the cooling and percentage tension of reinforcement. As SCC is highly efficient, it is essential to calculate under the condition of fire. This review examines the physical characteristics of SCC under elevated temperatures for the ISO. Therefore, the paper is only for estimating the fire-bearing capability and not for enhancing the property of fire.

2.9. Nano-Alumina (NA) Powder with SCC

In this investigation, Nano Alumina (NA) powder is combined with Self-Compacting Concrete (SCC) and heated. Three samples were prepared by replacing cement with 2% NA, 1% NA and 0% NA for testing the compressive strength and modulus of elasticity consecutively and heated for up to 60 minutes from average temperature to elevated temperature. For reference, the sample was tested at average temperature; in 7 days, sample compressive strength decreased with moderate temperature; when the samples were heated to medium temperature for 10 minutes, compressive strength amplified.

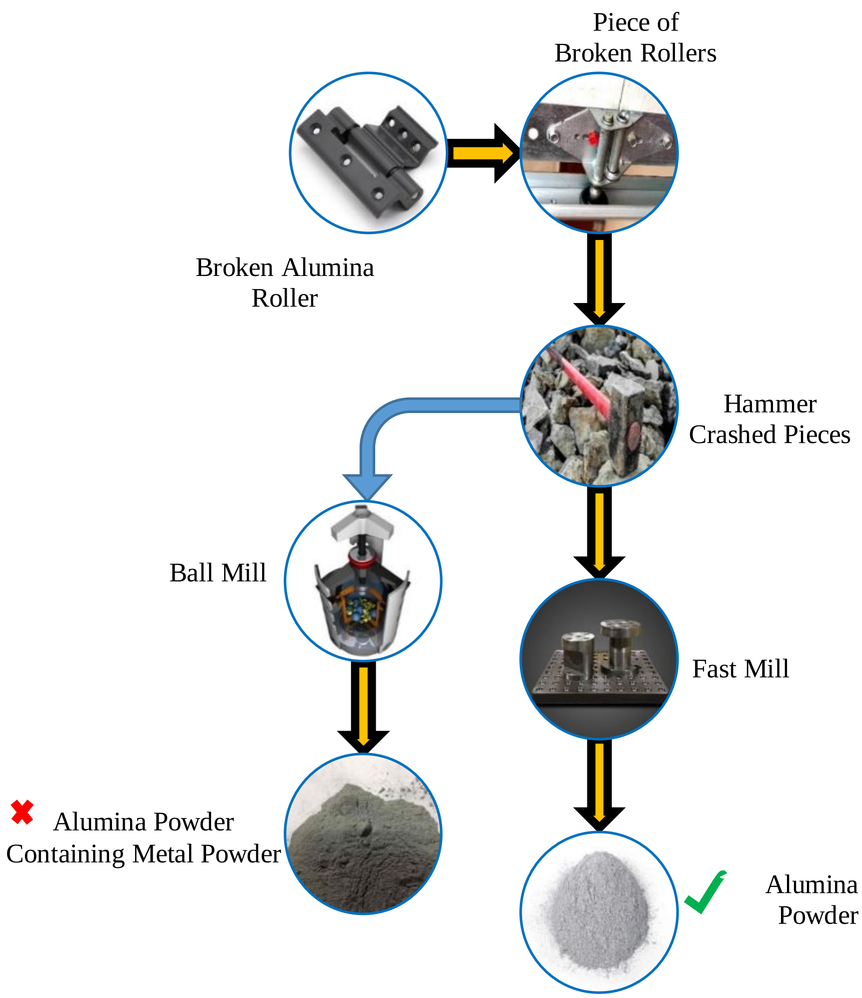

Fig. 3 Preparation of alumina powder

Utilizing pozzolanic activity at low temperatures, the NA increases compressive strength after 28 days. At high thermal exposures, the NA prevents strength loss. Compressive strength with different proportions of NA on the 28th-day test is boosted up to 11.7% and 16.2% by 10-minute heating, 22.4% and 26.5% more power when heated for 60 minutes.

Figure 3 shows the preparation of alumina powder. In average temperature, the Expected Value test results are positive on the 28th day; when subjected thermally to 10 to 60 minutes, NA tends to slow the ruin of expected value. Because of the waste NA impurities, the SCC's 2% NA is more successful at preventing strength loss than NA's 1% composition. One disadvantage of creating nano alumina is the high price of aluminium.

2.10. Unprocessed Waste Fly Ash (UWFA) with SCC

This study implies an impact on its mechanical character; the Self-Compacting Concrete (SCC), when subjected thermally high to raw fly ash, impacts its mechanical character. The cement content in SCC is replaced by 0%, 15% and 30% of basic fly ash in three samples. In particular, residual modulus of elasticity accounts for higher reactivity than other mechanical parameters in high-temperature exposure when there is 15% raw fly ash in SCC. Residual flexural strength has a straight relationship with modulus of elasticity, and by the high thermal exposure, both are affected by crack and propagation. By introducing raw waste powders in concrete production, sustainable products can be produced; it reduces the release of CO_2 and energy for preparation. Moreover, water absorption is high for the raw fly ash used; the activation of raw fly ash is not said in this work.

2.11. Normal Strength Lightweight Self-C Concrete (NSLWSCC) and High Strength Light Weight Self Compacting Concrete (HSLWSCC)

This study illustrates NSLWSCC and HSLWSCC using scoria, perlite and polystyrene. This Lightweight Concrete (LWC) has benefits like lightweight, easier concrete pouring and less construction-related difficulties. The mechanical properties were tested in NSLWSCC and HSLWSCC at elevated temperatures. The samples of six NSLWSCCs and two HSLWSCCs were taken for the study.

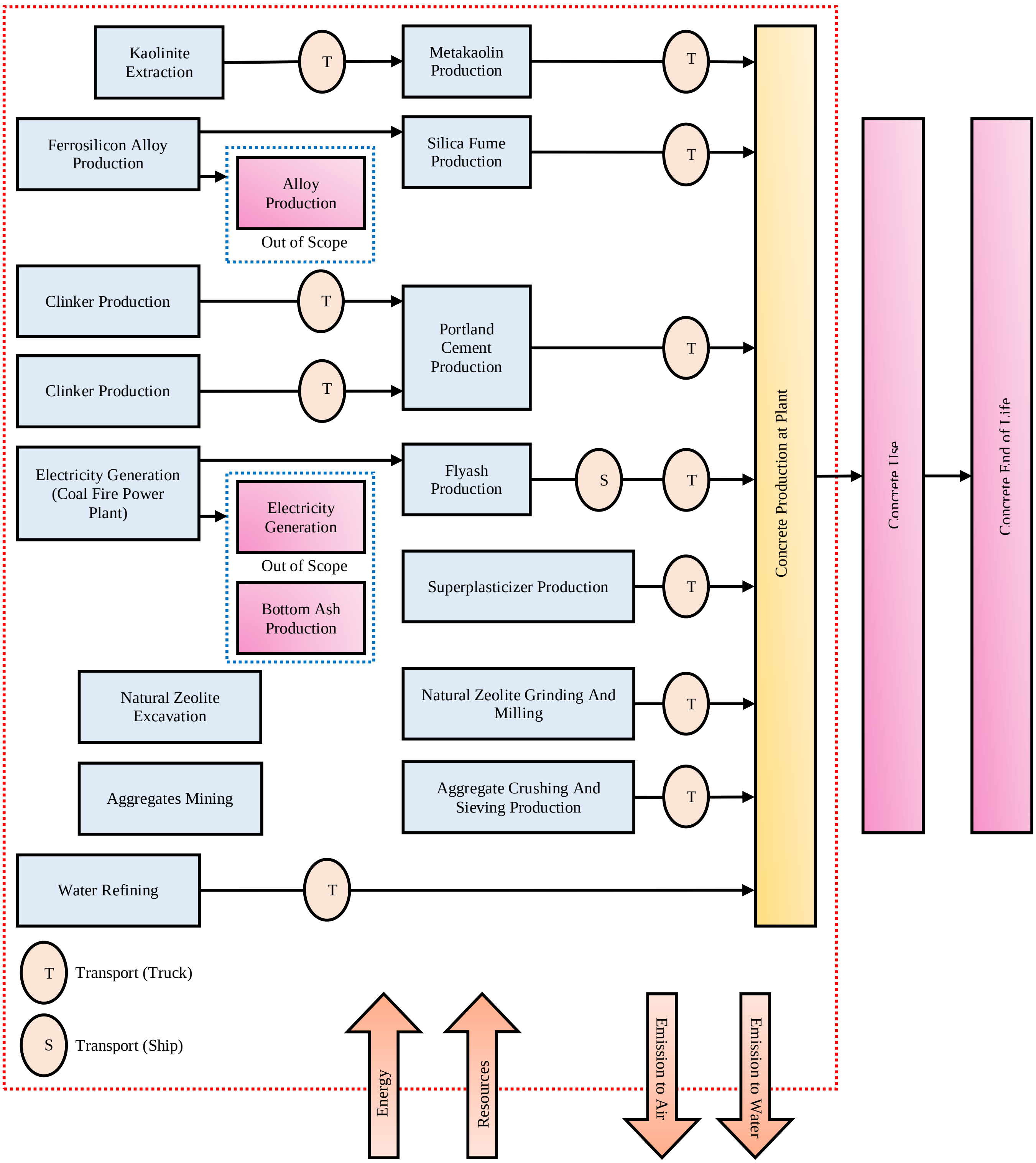

Fig. 4 System boundary of concrete production

In average to high thermal exposure, the deviation is calculated; NSLWSCCs attain more strength in average temperature and slowly decrease in temperature hike, but in HSLWSCCs, the total power was achieved, and explosion caused at medium temperature and in high thermal display little crack, spalling and bubbles were shown out. The outcome shows that the mechanical properties of LWSCC are corresponding to the temperature. However, more addition of perlite content in SCC causes a reduction in strength.

2.12. Course Recycled Concrete Aggregate with Waste Materials in HPSCC

In the current investigation, non-destructive testing was conducted to determine how High-Performance Self-Compacting Concrete (HPSCC) responded to a high temperature. For natural aggregate and cement, reprocessed concrete aggregates were partially replaced in HPSCC.

The 21 samples were tested after being heated from low to elevated temperatures. For checking the relationship amid relative residual ultrasonic pulse velocity and other properties. Relative residual values are considered for calculation rather than the absolute values; by Ultrasonic Pulse Velocity (UPV), numerous tastings were done to evaluate residual strength in elevated temperature here; the effect is low for this combination. After exhibiting high thermal, the standard equations were taken for calculating the non-destructive testing. The relation between relative residual UPV with strength and density of HPSCC is found after revealing the temperature. By using perlite, water drains away quickly and fly ash comes to full power normally slower.

2.13. Ternary Blended Cement

Considering the new and hardened state, the High-Performance SCC (HPSCC) is used in tall buildings. For metakaolin, natural zeolite, silica fume, metakaolin and fly ash, the 19 HPSCC samples are tested at higher temperatures. From low to high heat, the mechanical characteristics were calculated. Life Cycle Assessment (LCA) is conducted for exposure to the environment. Figure 4 illustrates the Ultrasonic pulse test locations.

At standard temperature, the sample of ternary mixture concrete shows less compressive strength than control mixture concrete. Residual compressive forces in both types of fly ash are the same. At medium heat, transition velocity is heavily reduced, according to the UPV test outcomes; there is some relation between both tests in various temperatures, but this is inversely proportional when exposed to heat.

The samples with natural zeolite had a significant loss in its mass when unmasked to high heat. Figure 4 shows the locations of the Ultrasonic pulse test. According to the habitat quality, the Binary fly ash mixture is better than other control mixtures due to the travel distance. Silica fume is a hazard to humans; metakaolin causes more harm to the habitat; therefore, pozzolan can be selected as the habitat-friendly component. However, resistance to corrosion of steel reinforcement is decreased in pozzolan and takes longer setting time.

2.14. Ground Granulated Blast Furnace Slag (GGBFS), Silica Fumes (SF), and Marble Powder (MP) in SCC

Habitat pollution due to the manufacturing procedure of natural aggregate becomes a more significant issue to the construction industry for modification of materials that with the removal of hazards and to make the concrete highly efficient for use. Using Artificial Neural Networks (ANNs), considering additive type, replaced additive percentage, curing days and temperature, the mechanical properties of SSC are calculated.

The SF increased characteristics at low and high heat when %5 and 25% component replacements were tested. 20% and 25% SF replacement is the best amount to upgrade compressive and flexural strengths. Figure 5 illustrates the (a) Compression, (b) Split tensile, and (c) Flexural strength test mechanisms. Comparing MP and SF mix samples to GGBFS samples revealed split tensile, flexural strengths and lower compressive. When more MP is added, the power of the split tensile material decreases. Strength is amplified in heated ones when compared to standard dried samples.

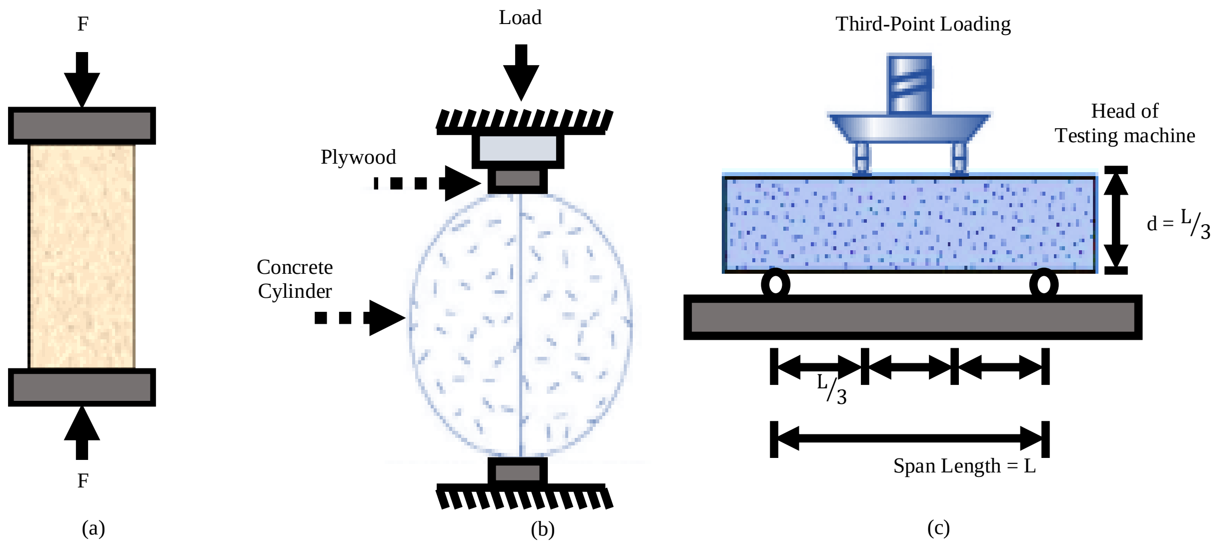

Fig. 5(a) Compression, (b) Split tensile, and (c) Flexural strength test mechanisms.

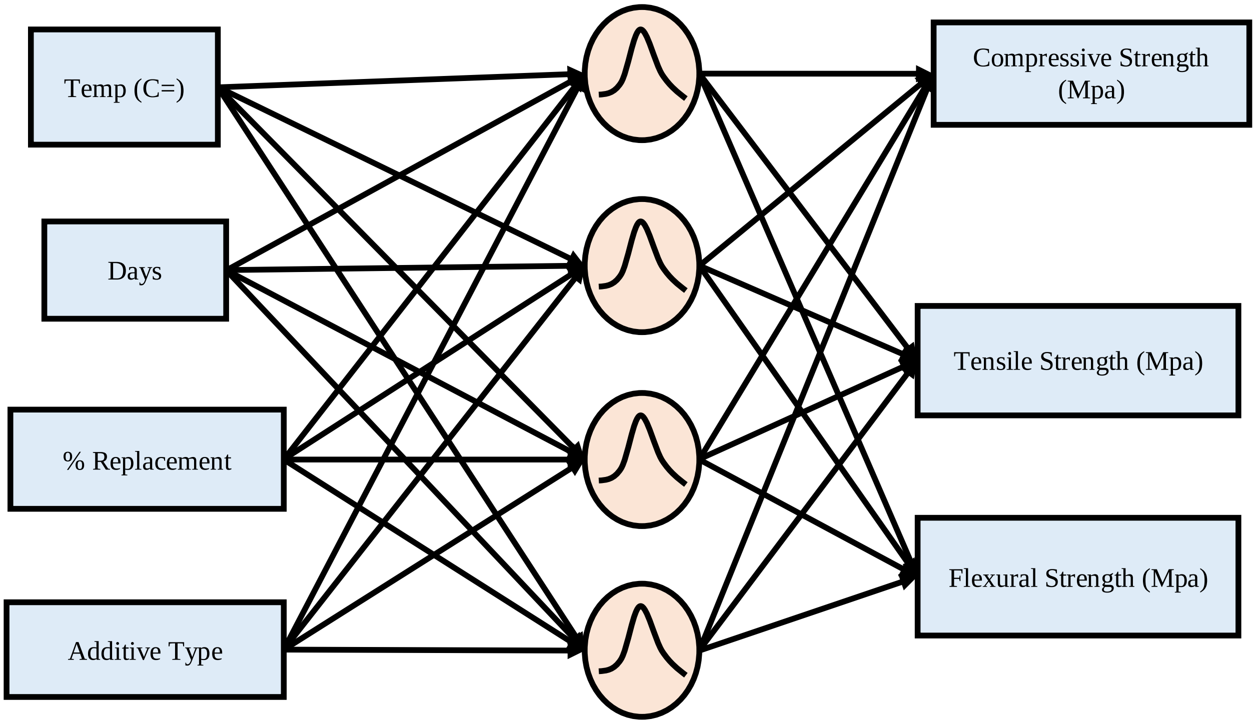

Fig. 6 ANNs structure for SCC

Figure 6 shows the ANNs structure for SCC. Marble powder comes with good results by using ANN. The 25% replacement of cement is achievable for construction. The environmental pollution and cost are reduced by using GGBFS, SF and Marble powder in construction. Strength in medium temperature is good in 28-day samples. However, Marble dust is not available in the place, and higher replacement of GGBFS makes it slower in attaining strength; in Silica fumes, if the external temperature is high, it shrinks and causes cracks.

2.15. SCC Involving Different Types of Recycled Aggregates

Only a few studies have compared the reusability of recycled aggregates in Self-Compacting Concrete (SCC). In traditional concrete, the reprocessed totals show negativeness; in SCC, it offers less impact by using good quality cement, which consumes less aggregates. SCC is made up of reprocessed concrete aggregate, reprocessed brick aggregate and reprocessed concrete block aggregate. The complete replacement of CBA, RCA instead of Natural Aggregate (NA) in SCC doesn't significantly change performance. Still, partial replacement of RBA is suggested due to its low performance. A thick Interfacial Transition Zone (ITZ) is found in SCC and NA, SCC and CBA combinations and with SCC and RCA combination, some pores and cracks were formed.

Compressive and flexural strength in SCC with Recycled Aggregate (RA) is lower than in NA combination at lesser heat due to the wet condition of cement; more power increased in SCC with NA, SCC with CBA, SCC with RCA combinations, at medium temperature SCC-RBA due to fire retardant properties the strength increased further. At further increase in heat compared to NA composition, CBA and RBA have higher compressive strength; therefore, after exposure to high heat, RBA is suggested due to its fire retardant properties and compressive strength. Moreover, due to its porous structure, RBA observes more water.

2.16. Recycled Coarse Aggregate (RCA) and Unprocessed Waste Powder Materials with Self-Compacting High-Performance Concrete (SCHPC)

Industrial wastes were used in place of natural aggregates to create SCHPC, a type of concrete that provides superior strength and fire resistance. To test SCHPC's mechanical qualities under extreme heat, Recycled Coarse Aggregate (RCA), fly ash, and perlite powder were added. Instead of some NA, 50% of The Reprocessed Concrete Total (RCA), Waste Perlite Powder (WPP), and Waste Fly Ash (WFA) are used. Table 4 depicts the changes occurring at the moment of firing.

After being subjected to elevated temperature, residual mechanical properties are boosted with 50% of RCA because of sustainable aggregate mortar and their similarity of thermal expansion. Therefore, replacing cement up to 15% with WPP fire resistances is boosted, but with WFA residual flexural strength is enabled beyond medium temperature and fewer surface cracks formed. However, the waste fly ash gains slower strength, and salt scaling is included. The waste perlite powder drains water quickly.

Table 4. Transformations during firing

Temperature (^oC)	Action
100	Weight loss starts due to water evaporation and ettringite decomposition.
200	Dehydration of Calcium-Silicate-hydrates starts and causes a small loss.
500	Endothermic dehydration pf $Ca(OH)_2$ occurs
700	Calcium-Silicate-hydrates dehydrates

2.17. Kaolin (K) and Calcined Kaolin with Self-Compacting Mortars (SCMs)

To determine durability and mechanical properties from regular to elevated temperatures, this study demonstrates that Kaolin (K) and Calcined Kaolin (CK) were partially added to self-compacting mortar in place of cement. The examples were created by substituting kaolin and calcined kaolin for 0%, 5, 10, 15 and 20% of cement. Table 5 illustrates the Fibre Properties. Mechanical properties were tested on 3, 28 and 90 days at average temperature and on 28 days at high thermal exposure; mechanical properties were tested.

Compared to the controlled sample, on the 28th-day test, 18.40% compressive strength reduction was found in K, 8.42% and 14.65% flexural strength came down in K and CK.

At elevated temperature, by adding CK 5%, 10%, 15% and 20%, compressive strength decreases 31.94%, 25%, 22.51%, 24.68% and 74.30%, 69.17%, 67.35% and 68.28% consecutively. When K, CK content, and temperature are raised, slight compressive strength improvement is updated. However, the cost of calcined kaolin and the energy consumption of calcination are the demerits.

2.18. Raw Vermiculite (RVM) and Expanded Vermiculite (EVM) with Self-Compacting Mortars (SCMs)

During severe temperature exposure, EVM and RVM are used to test the tensile strength and mechanical characteristics of Self-Compacting Mortars (SCMs). Nine sample series were made with RVM and EVM at 0%, 5%, 10%, 15% and 20% replacement of cement. The durability of SCMs was tested with 54 cubes, and Strength properties were tested with 81 cubes. A mini-V funnel flow test and a slump diameter test were undertaken to identify the properties of fresh mortar. A viscosity test is used to identify rheology. The complex samples were subjected to medium to elevated temperature on the 28th day.

As a result, RVM and EVM mixtures enhance, at standard temperature, compressive and flexural strength reduced in all ages of curing, RVM at 90th day, flexural strength declaim significantly less compared to flexural strength on 28th day. The EVM-contained sample is more fire retardant than RVM. Hence, the cost of transportation and the product being expensive are vermiculite's demerits.

Table 5. Fibre properties

Grade of Concrete	28 Days Compressive Strength	56 Days Compressive Strength	Split Tensile Strength	Flexural Strength	Modulus of Elasticity
	N/mm^2				
M25	32.25	35.52	2.72	5.39	30.580
M30	37.39	41.05	3.56	5.91	33.014
M35	43.80	46.11	4.02	6.42	35.611
M40	48.55	50.66	4.45	6.95	36.245

Table 6. Compositions of the CC and UH PFRC combinations

Mixture	Cement	Water	SF	CG	FG	Sand	SP	W/C	Fibre
Kg/m^3									
CC	370	144	30	560	89	1153	2	0.36	0%
UHPFRC1	1050	244	350	0	0	678	42	0.16	1%
UHPFRC2	1050	244	350	0	0	678	42	0.16	2%

2.19. Conventional Concrete (CC) and Ultra-High Performance Fibre Reinforced Concrete (UH PFRC)

Three metrics, residual compressive strength, weight losses and thermal expansion coefficient, have been used to compare the performance of CC with UH PFRC under high temperatures. The compressive strength of CC and UH PFRC samples is essential for determining cement hydration, pozzolanic processes involving silica fume at initial curing, low temperatures, testing age, moisture content and adding admixtures to the concrete mix at high temperatures.

The compositions of the CC and UH PFRC combinations are depicted in Table 6. The UHPFRC samples lost weight dramatically in heated models when temperatures were between 200 and 500 °C, although the rate of weight loss remained gradually at higher temperatures. Because once fibres are added to the mixture, the behaviour of concrete after cracking is significantly less brittle and practically flexible, making it more prone to an appropriate distribution of flexural stresses. It is significant to mention that the starting water content of the samples varied, and its effect has to be considered.

2.20. Three Approaches Based on High-Temperature Evaluation

Ultrasonic Pulse Velocity (UPV) measurements have been used to analyze the fluctuation in concrete physical characteristics and the decrease of compressive strength with increasing temperature. Four mechanical elements have been used to analyze the CACC specimens' post-fire performance. According to the study, three techniques are employed to gauge how well concrete can tolerate high temperatures: unstressed testing, unstressed residual strength testing, and stressed testing.

The strain increases until the specimens fail after the samples have attained the necessary temperature. For assessing the post-fire qualities of concretes, the unstressed residual strength testing method produces the highest results. As temperature increases, the concrete sample's mechanical rates decrease. However, due to the transformation of hydro garnet and an increase in porosity between 400 and 600°C, the mechanical properties were significantly diminished.

2.21. SCM Specimens on Evaluated Temperature

It has been studied how high temperatures affect the mechanical characteristics of SCMs that contain RVM. According to the findings, all SCM mixtures' compressive and flexural strengths reduced as RVM rates increased during water curing for all ages.

The mixing ratios of SCMs corresponding to these RVM rates were established by conducting tests on the V funnel and lump flow diameter. The viscosities of all SCM combinations were consistently reduced from 1 rpm to 100 rpm.

Compared to the control and other RVM mixes, RVM30 demonstrated high viscosities. With increasing rotational speed, all mixtures' viscosities decreased. In all SCM mixes, RVM20 presented the most outstanding viscosity characteristic at a single rotating speed. The viscosities value usually decreases as vermiculite concentrations increase and when contrasted with control and other RVM mixes. Furthermore, SCM specimens' flexural and compressive strengths significantly decreased as RVM content increased.

2.22. Four Parameters for High-Temperature Evaluation

Creating a light aggregate, high-temperature, self-compacting Portland cement/alkali-activated slag composite. Four elements were considered: water content, the proportion of lightweight aggregate to regular total, the ratio of slag to cement and the balance of alkali activator to binder. Measurements of compressive strength started to decline as the temperature rose. On the other hand, the increased compressive strength of a combination made up entirely of GBFS was still there even after being exposed to temperatures as high as 1000 °C.

The substantial drying shrinkage in PC replacement mixtures led to an increase in micro cracks. In addition to the environmental benefits, implementing GBFS in producing AAMs offers some significant technological gains. Some of these benefits include an early emergence of mechanical qualities, diminished porosity, lowered heat of hydration, and enhanced longevity. High shrinkage, fast curing and a significant rate of salt efflorescence development are some drawbacks, respectively. Using lightweight pumice aggregate instead of regular total significantly lowered mixture densities.

2.23. Residual Properties Based on Evaluated Temperature

Conducting a detailed investigation of BFC's features following exposure to high temperatures is advised. Mechanical, thermal and deformation properties of constituent materials and how these properties vary in response to high temperatures impact how well concrete performs. Strength, moisture levels, density, temperature range and additives all have a noticeable impact on mechanical qualities. The hemp fibres considerably enhanced the concrete's elastic modulus by 1.5% to 3% compared to the control.

Due to the effects of high temperatures on damaged bio-fibre concrete, some specific activities continue to carry out some additional residual attributes. Weight loss, cracks, spalling and ultrasonic pulse velocity values, which indicate porosity, are characteristics that help classify these processes. The detrimental reaction of concrete to high temperatures is defined by the strength failure and increased pore pressure that result in spalling, cracking and exposure of reinforcing steel in the concrete. However, adding bio-fibres to concrete has reduced the amount of explosive spalling and cracking activity.

3. Comparative Analysis

A comparative analogization was carried out amid the different SCC and FRSCC to investigate its performance with respect to the elevated temperature levels. Table 7 and Table 8 illustrate the comparative analysis of the different SCCs and FRSCCs.

Table 7. Comparative analysis of SCC

S.No.	Author & Reference	Methodology	Advantages	Drawbacks
1.	Faisal Aldhafairi et al. [12]	This study aims to provide an experimental and theoretical framework for examining how rising temperatures affect self-compacting, highly durable and regular concrete beams. Six steel jacket approaches were developed to increase the effectiveness of retrofitting during high-temperature acquaintance.	There is an elevated level of concord between theoretical and experimental findings for modified beams using different steel jackets.	Steel plate retrofitting is not highly recommended; The steel plate retrofitted beam does not function well compared to other techniques.
2.	Saif K. Mezzal et al. [13]	This study examines the mechanical, rheological and hardening assets of vast-capacity self-compacting concrete through methodical experimental research of discarded hybrid steel fibres.	The FRHSCC performs hugely better than the HSCC at both average and higher temperatures.	Heating to high temperatures exposes the link between fibres and cement matrix to severe breakage.
3.	Larissa C. de A. Mello et al. [14]	This work aims to mimic a state of SCC by heating cement consisting of metakaolin and sugarcane bagasse ash to exceptionally high temperatures.	The SCC's pitting and buckling process was less severe than it was for SCC without additives.	In the SCC, concrete microcracking at high temperatures significantly impacted wave pulse propagation.
4.	T. Rajah Surya et al. [15]	The compression resistance of self-compacting concrete under high temperatures is being investigated in this study.	The machine is simple to use and maintain due to the technology-attention towards efficiency in both construction and performance.	The strength decreases as the temperature rises.
5.	Faiq M. S. Al-Zwainy et al. [16]	An ANN model for forecasting a material's residual strength following exposure to high temperatures will be given. This is one of the study's goals. Sensitivity analysis will be used to identify the input variables that will have the most significant effects on the model.	The calculated compressive strength and the actual value, as well as the correlation coefficient and determination coefficient, have excellent correlations.	One of the frequent concerns is examining concrete's behaviour in high temperatures.

Table 8. Comparative analysis of FRSCC

S.No.	Author & Reference	Methodology	Advantages	Drawbacks
1.	Muhammad Talal Afzal et al. [17]	In this paper, a High-strength concrete was enhanced with carbon nanofibres to assess the fire resistance of an existing matrix.	CNFs in a concrete matrix increase compressive strength before and after fire exposure.	Prospectively, the mathematical equations may help predict the performance of CNFs reinforced HSC under fire conditions.
2.	Ahmed Hassan et al. [18]	The development of an experimental programme will look at how different temperature	In several deteriorated beams, a reinforced	The failure mode fracture widened compared to

		ranges impact the most significant types of concrete and how other retrofitting techniques affect the durability of reinforced concrete beams.	concrete jacket performed as expected.	RCJs with two bars as the load increased.
3.	Trilok Gupta et al. [19]	The mechanical, gamma-ray and neutron attenuation properties of concrete shields made of limestone, barite and siderite and reinforced with polypropylene fibre were examined in this work with the effects of high temperatures.	Due to its exceptional linear attenuation coefficients at all gamma-ray energies, barite concrete looks to be an ideal kind to employ when there is a possibility of high temperatures.	Future development of improved polypropylene fibre-reinforced concrete shields, especially those exposed to temperatures exceeding 600 C, will require binders with suitable heat resistance. As an alternative, calcium aluminate cements and geopolymers may be used.
4.	Carlos A. Benedetty et al. [20]	The current work describes an experimental study on the behaviour of hooked-end, half hooked and straight steel fibres pulling out of a self-compacting concrete mix with high-strength fibre reinforcement.	Half-hooked fibres displayed excellent performance regarding energy dissipation capacity and peak load.	Lowering the quantity of fibre bents can make the production process simpler and more cost-effective.
5.	Ali Sadrmomtazi et al. [21]	An experimental programme was put into place to investigate the effects of steel fibres, fly ash and curing conditions on a mechanical characteristics, fracture energy and microstructure of self-compacting concrete at higher temperatures.	Steel fibres increased the specimens' residual strength by reducing the cracking rate under flexural or tensile loads.	The interfacial zone has gradually developed more cracks, holes and gaps of fibre aggregates cementitious matrix indicated.

Table 9. Comparative analysis of other techniques

S.No.	Author & Reference	Methodology	Advantages	Drawbacks
1.	Ming-Zhi Guo et al. [22]	The current work examines the stress-strain behaviour of a self-compacting mortar with RG SCM glass under increasing temperature conditions.	The elastic modulus benefited more from ITZ enhancement than compressive strength.	Due to the sample weakening during exposure to high temperatures, the advantageous melting property of RG changed into a negative effect.
2.	Raad A. Al-Ameri et al. [23]	An experimental investigation is done in this paper to determine the impact of elevated temperatures on the frequent impact strength of standard-strength concrete.	Additionally, compared to compressive strength, the compressive temperature deduction trend is more directly linked to the flexural strength trend.	The loss of the unheated samples and the failure of the samples heated up to 300 C were also comparable.
3.	I. Demir et al. [24]	In this paper, an attempt has been made to bridge this gap by developing explicit expressions using an artificial neural network approach.	The statistical characteristics for training data sets show that the ANN was trained flawlessly and without going overboard.	The durability characteristics of rubberized concrete subjected to high temperatures can be foreseen using the proposed ANN methodology.

4.	Osman Gencel et al. [25]	An experiment was performed to determine whether rice husk ash would behave as cement. On transport properties of foamed concrete due to high temperatures and freeze-thaw cycles and on a microstructural, mechanical, replacement and waste marble powder as sand replacement.	WMP and RHA were added, which decreased the slump values.	As a result, the mixture missing WMP performs poorly in the F-T test with an 80 kg/m3 foam content.
5.	Yousef R. Alharbi et al. [26]	This study investigates the behaviour of using EAFS as a partial or complete replacement for coarse aggregate under elevated pressure and weight when used in varying proportions of 0%, 15%, 30%, 50% and 100% in concrete temperatures.	Using slag to replace traditional aggregate ultimately improves the quality of concrete.	However, the breakdown of aggregate calcium carbonate does occur in a control mixture and is impacted by temperature in addition to C-S-H dehydration.

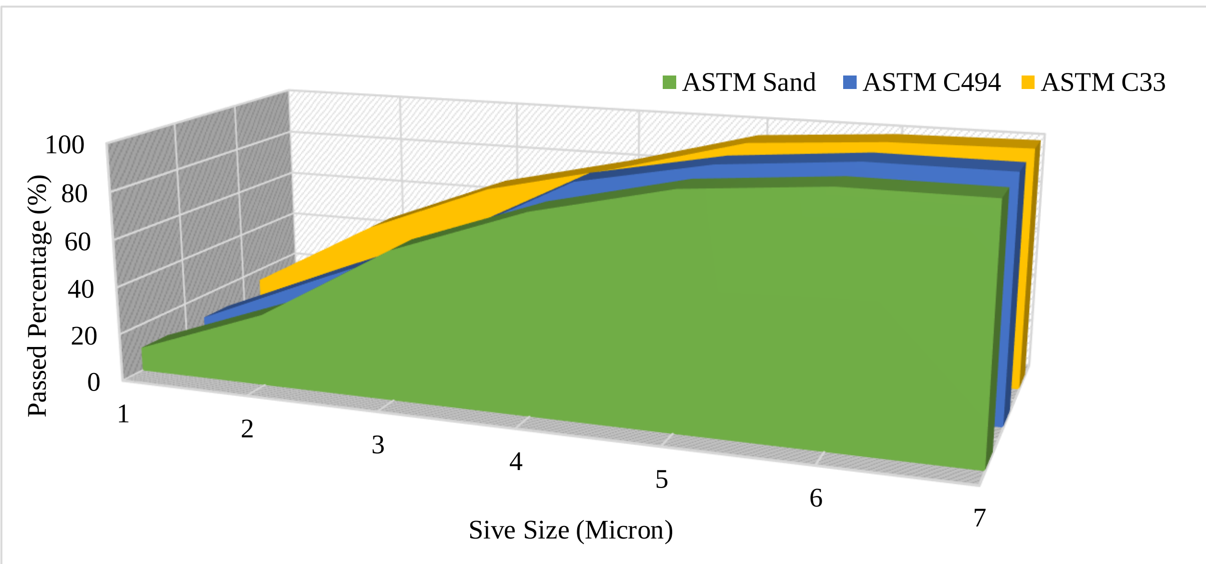

Fig. 7 Gradation curve for different aggregates

Table 10. Mass loss of different SCCs concerning different temperatures

Temp (°C)	Mass Loss (%)		
	SCC-SF	R20M20	RRAC-4 CUBE
200	5	4.7	5.8
400	8	8.5	7.1
600	12	8.8	7.6
800	17	11.2	8.2

Figure 7 illustrates the gradation curve of different aggregates: ASTM C33, ASTM C494 and ASTM Sand. From the analogization, it is concluded that ASTM C494 has the highest pass percentage than others like ASTM C33 and ASTM Sand. Table 10 illustrates the Mass losses occurring in different SCC topologies, like SCC-SF, R20M20 and RRAC-4 CUBE, for different temperature ranges. From the Table, it is concluded that the reduced mass losses occur in SCCs with additive contents, and the comparative results show that the RRAC-4 CUBE has lower mass loss than others like SCC-SF and R20M20. Moreover, as the cubic specimens possess low fire resistance, the rubber particles have a higher impact over the cubic samples. Therefore, limiting the rubber contents range within limits makes it possible to improve the bursting resistance of the RAC further. Figure 8 illustrates the compressive strength comparison amid different materials like SCC_10, SCC_REF and SCC-StF. The comparative results show that the SCC-REF possess high compressive strength compared to other material topologies like SCC_10 and SCC_StF.

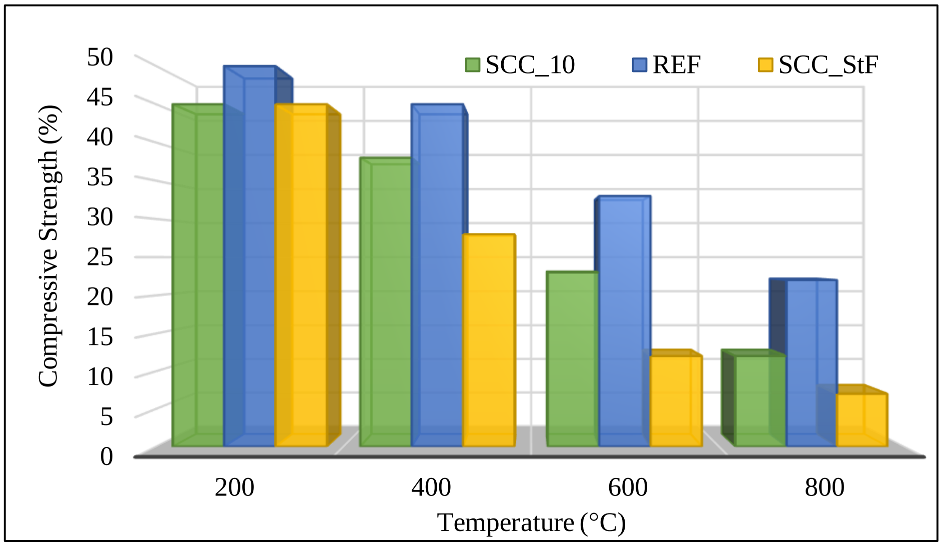

Fig. 8 Compressive strength comparison

Hence, from the investigation, it is identified that the ASTM C494 has a higher pass percentage than ASTM C33 and ASTM Sand. Similarly, the RRAC_4 CUBE possess fewer mass losses than SCC-SF and R20M20. Moreover, in the case of compressive strength, the SCC_REF has better compressive strength than SCC_10 and SCC_StF.

4. Conclusion

In general, the SCC is mainly developed for reducing the durability problems occurring in substantially Reinforced Concrete Structures due to a lack of skilled employees and insufficient communication between the design engineers and the designers. The SCC has many benefits: reduced labour costs, noise pollution, less construction time, and the capability to fill thin portions and crowded portions significantly. However, at extreme temperatures, the properties of concrete change, leading to reduced concrete strength and spalling, further leading to substantial failure. Moreover, based on the grade of concrete, the strength loss differs.

Therefore, many different kinds of material mix, like fibre, steel, etc., are added to the SCC to improve the strength and durability of the concrete. In this paper, an analogization is carried out amid the different material topologies of concrete. It is identified that the ASTM C494, RRAC_4 CUBE and SCC_REF perform better in terms of pass percentage, compressive strength and mass loss. Moreover, by using novel material combinations in future, it is possible to improve the strength of concrete.

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