# Influence of Sudden and Gradual Cooling Regimes on Strength, Near Surface Characteristics and Modulus of Elasticity of Polypropylene Fibre Reinforced Ternary Blended Concretes Subjected to Sustained Elevated Temperatures

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**Abstract**

**It is necessary to study the effect of sudden and gradual cooling regimes on M30 grade blended concrete when subjected to sustained elevated temperatures for three hours. The temperatures considered for the study are 30°C (RT), 100°C, 200°C, 300°C, 400°C, 500°C, 600°C, 700°C, 800°C, 900°C, and 1000°C. There is a comparison between conventional concrete and two ternary blended concretes (cement, fly ash, GGBFS and Cement, fly ash, silica fume) along with the inclusion of polypropylene fibre in each. After temperature test and cooling, concrete specimen was subjected to several strength and durability tests. As a result, all the specimens tested for gradual cooling regime shows better results than those tested for sudden cooling. Ternary blended concrete produced with cement, fly ash, silica fume along with polypropylene fibre combination shows better resistance against all temperatures compared to other two concretes.**

**Keywords: Elevated temperatures, cooling regime, strength, blended concrete, durability.**

## I. INTRODUCTION

Life safety in case of fire is one of the major considerations in the design of structures. It is necessary to have knowledge about the behavior of all construction materials before using them in structural elements. Extensive use of concrete as a material in all the structures exposed to terrorism necessitated the need to study the behavior of concrete at high temperature and its durability [1, 2, 3].

Thermal properties of concrete is an important aspect while dealing with durability of concrete structure exposed to elevated temperature. Damage depends on the intensity, duration of exposure, and also on the combustibility of the materials used in construction [4]. Concrete is itself incombustible and its temperature coefficient is practically the same as that of steel. The cement paste in concrete has higher co–efficient of thermal expansion than the aggregate [5]. Large difference in thermal co–efficient causes differential expansion resulting in the rupture of bond at the interface of cement paste and aggregate [6].

Portland cement concrete is widely used in building construction. It helps to satisfy the need for public safety in face of the hazards of fire [7,8] and also the addition of pozzolanas will enhance the microstructure and phase composition when the concrete is under fire–resistance studies [9]. Similarly, addition of steel fibres helps to resist the pore pressure created and arrests cracks and expansion, thus, increasing the tensile strength and minimizes fire induced spalling of concrete [10]. Thus, it was necessary to study the behaviour of polypropylene fibre reinforced blended concrete when subjected to high temperatures.

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## II. OBJECTIVES

The main objective is to study the effect of two cooling regimes (sudden and gradual) on several strength and durability properties of polypropylene fibre reinforced ternary blended concretes when subjected to sustained elevated temperatures for 3 hours. The temperatures considered for the study are 30°C (RT), 100°C, 200°C, 300°C, 400°C, 500°C, 600°C, 700°C, 800°C, 900°C, and 1000°C.

The strength and durability properties considered are compressive strength, split tensile strength, near surface characteristics (water absorption and sorptivity), and modulus of elasticity.

The concretes used for the study are M30 conventional concrete and two ternary blended concretes (cement, fly ash, ground granulated blast furnace slag (C, FA, and GGBFS), and cement, fly ash, silica fume (C, FA, and SF) along with the inclusion of polypropylene fibre (PPF) in each concrete.

## III. MATERIALS

Cement (C) used in this experiment is OPC 43 grade and it meets the requirements of IS: 8112–2013 [11]. The laboratory tested results are given in table I.

**TABLE I.**
**PHYSICAL PROPERTIES OF OPC 43 GRADE CEMENT (C)**

| Particulars | Test Results | Requirements as per IS: 8112-2013 |
|---|---|---|
| Fineness ($m^2$/Kg) by Blaine's air permeability method | 270 | 225 (min.) |
| Fineness (%) by dry sieving | 4 | |
| Specific gravity | 3.15 | |
| Setting Time | | |
| a. Initial (minutes) | 60 | 30 (min.) |
| b. Final (minutes) | 320 | 600 (max.) |
| Soundness by Le-chatelier's expansion method (mm) | 2 | 10 (max.) |
| Soundness by Autoclave method expansion method (%) | 0.2 | 0.8 (max.) |
| Compressive strength (MPa) | | |
| a. 3 days | 27 | 23 (min.) |
| b. 7 days | 38 | 33 (min.) |
| c. 28 days | 44 | 43 (min.) |

Locally available sand is used as fine aggregate conforming to grading zone II as per IS: 383–1970 specifications. The local crushed stone aggregate is used as coarse aggregate (Greywacke) of 20 mm and down

**TABLE II.**
**SIEVE ANALYSIS OF FINE AGGREGATE AND COARSE AGGREGATE**

| | | Sieve Analysis of Fine Aggregate | | Sieve Analysis of Coarse Aggregate | |
|---|---|---|---|---|---|
| Sl. No. | IS Sieve Size | Cumulative Percentage Passing Finer (%) | Grading Limit for Zone II as per IS: 383-1970 | Cumulative Percentage Passing Finer (%) | Grading Limit for 20mm Nominal Size as per IS: 383-1970 |
| 1 | 40mm | 100 | 100 | 100 | 100 |
| 2 | 20mm | 100 | 100 | 99 | 95-100 |
| 3 | 10mm | 100 | 100 | 45.8 | 25-55 |
| 4 | 4.75 mm | 97 | 90-100 | 0.4 | 0-10 |
| 5 | 2.36 mm | 91 | 75-100 | 0 | - |
| 6 | 1.18 mm | 69 | 55-90 | 0 | - |
| 7 | 600 µm | 41 | 35-59 | 0 | - |
| 8 | 300 µm | 12 | 8-30 | 0 | - |
| 9 | 150 µm | 2 | 0-10 | 0 | - |
| 10 | Pan | - | - | - | - |
| Fineness modulus | | 2.88 | | 6.54 | |

**TABLE III.**
**PHYSICAL PROPERTIES OF FINE AGGREGATE AND COARSE AGGREGATE**

| | Fine Aggregate | | Coarse aggregate | |
|---|---|---|---|---|
| Sl. No. Particulars | Test Results | Permissible Limit as per IS: 2386-1963 | Test Results | Permissible limit as per IS: 2386-1963 |
| 1. Organic impurities | Colourless | Colourless/Straw colour/Dark Colour | - | |
| 2. Silt content (%) | 1.8 | 6-10% (Max.) | - | |
| 3. Specific gravity | 2.60 | | 2.65 | |
| 4. Bulking of sand (%) | 8.2 | 40% (Max.) | - | |
| 5. Free moisture content | 0.0 | | 0.0 | |
| 6. Water absorption (%) | 1.0 | | 0.6 | |
| 7. Bulk density (Kg/$m^3$) | | | | |
| a. Loose condition | 1752.09 | | 1782.64 | |
| b. Compacted condition | 1827.12 | 1886.53 | | |

| | | | | |
|---|---|---|---|---|
| 8. | Impact value (%) | - | 15 | 30% (max.) used for concrete |
| 9. | Crushing value (%) | - | 14.5 | 30% (max.) for surface course |

size and tested as per IS: 383–1970 [12] and IS: 2386–1963 specifications. Sieve analysis of the fine and coarse aggregate is given in table II and the physical properties for the tested fine and coarse aggregate is given in table III.

The fly ash (FA) used in the research work was brought from Raichur thermal power plant, Shaktinagar, Raichur, Karnataka and it satisfies the requirements of IS: 3812 (Part 1)–2013 [13]. The laboratory test results are given in Table IV.

TABLE IV.
PHYSICAL PROPERTIES OF FLY ASH (FA)

| Particulars | Test Results | Requirement as per IS: 3812 (Part 1)-2013 |
|---|---|---|
| Fineness, specific surface area ($m^2$/kg) by Blaine's Permeability method | 333 | 320 (min.) |
| Particles retained on 45 micron IS sieve by Wet sieving (%) | 4.52 | 34 (max.) |
| Specific Gravity | 2.15 | |
| Lime reactivity, average compressive strength (MPa) | 4.68 | 4.5 (min.) |
| Compressive strength at 28 days (MPa) | 23 | |
| Soundness by autoclave test - Expansion of specimen (%) | 0.2 | 0.8 (Max.) |

TABLE V.
PHYSICAL PROPERTIES OF GROUND GRANULATED BLAST FURNACE SLAG (GGBFS)

| Particulars | Test Results | Requirement as per IS: 12089-1987 |
|---|---|---|
| Fineness as specific surface $m^2$/Kg | 350 | 275 (Min.) |
| Compressive strength (Mpa) | | |
| a. 7 days | 31.66 | 12 (Min.) |
| b. 28 days | 48.33 | 32.5 (Min.) |
| Soundness, Le-Chatelier Expansion (mm) | 0.0 | 10 (Max.) |
| Initial setting time (min) | 120 | 30 (Min.) |
| Specific Gravity | 2.85 | |

Granulated blast furnace slag (GGBFS) was procured from Quality Polytech, Baikamady industrial area, Mangalore, Karnataka and meets the requirements as per IS: 12089–1987 [14]. Laboratory results are shown in table V.

Silica fume (SF) was procured from Chimique Corporation, Vadodara, Gujarat, and satisfies requirements as per IS: 15388–2003[15]. Laboratory test results of silica fume are shown in table VI.

TABLE VI.
PHYSICAL PROPERTIES OF SILICA FUME (SF)

| Particulars | Test Results | Requirement as per IS: 15388-2003 |
|---|---|---|
| Fineness as specific surface $m^2$/g | 20 | 15 (min.) |
| Oversize % retained on 45 micron IS Sieve | 3.6 | 10 (max.) |
| Oversize % retained on 45 micron IS Sieve variation from average % | 1.8 | 5 (max.) |
| Compressive strength at 7 days (MPa) | 26 | Not less than 85% of the strength of control sample |
| Specific Gravity | 2.2 | |
| Bulk density (kg/$m^3$) | 640 | 500 to 700 |
| Colour | Black | |

TABLE VII.
PROPERTIES OF POLYPROPYLENE FIBRE (PPF)

| Particulars | Properties |
|---|---|
| Specific Gravity | 0.91 |
| Alkali Resistance | Alkali Proof |
| Chemical Resistance | Excellent |
| Acid & Salt Resistance | Chemical Proof |
| Denier | 1050 |
| Tensile Strength (kN/$mm^2$) | 0.67 |
| Young's Modulus (kN/$mm^2$) | 4.00 |
| Melt Point | 165 |
| Ignition Point | 600 |
| Absorption | Nil |
| Density-Bulk (Kg/$m^3$) | 910 |
| Density-Loose (Kg/$m^3$) | 250-430 |
| Fibre Cut Length (mm) | 20 |
| Form | Fibrillated (Mesh) |
| Colour | Natural white |
| Dispersion | Excellent |

TABLE VIII.
PHYSICAL AND CHEMICAL PROPERTIES OF SUPERPLASTICIZER

| Particulars | Properties |
|---|---|
| Specific Gravity | 1.22 |
| Physical state | Liquid |
| Chloride content | Nil (IS: 456-2000) |
| Air entrainment | 1% |
| Colour | Brown |
| Odour | Slight/faint |
| pH (Concentrate) | 7-8 |
| Boiling point (°C) | >100 |
| Flash point, closed (°C) | None |
| Vapour pressure (kPa @ 20°C) | 2.3 |
| Relative density (@ 20°C) | 1.2 |
| Water solubility | Soluble |
| Dosage | 0.5-2.0 litre/100 kg cement |

Polypropylene fibres (PPF) were brought from Bajaj Reinforcements™, Imambada Road, Nagpur. Its properties are shown in table VII.

To reduce the water content and to improve the workability conplast SP430 superplaticizer conforming to IS: 9103–1979 [16] was used. Procured physical and chemical properties of superplasticizer are shown in table VIII.

## IV. EXPERIMENTAL PROGRAMME

Concrete was designed for M30 grade as per IS 10262–2009 [17]. Based on several trials, the water–cement ratio arrived at was 0.45 and 100 mm slump was maintained. The mix proportion 1:2.02:3.45 was obtained.

The concrete combinations and their details are:

- C + PPF : 100% Cement & 1% PPF
- (C+FA+GGBFS) + PPF : 70% Cement + 15% Fly ash + 15% GGBFS & 1% PPF
- (C+FA+SF) + PPF : 70% Cement + 15% Fly ash + 15% Silica fume & 1% PPF

The blends were calculated as percentage by weight of cementitious material and fibres by volume fraction method [18].

For assessing compressive strength and near surface characteristics of concretes, 198 standard cube specimens of 150 mm, and for split tensile strength and modulus of elasticity 396 standard cylinder specimens of 150 mm diameter and 300 mm height were cast. Specimens were allowed to cure for 28 days.

Sustained elevated temperature test was conducted at Pyrotech Engineers, heat treatment plant, Udyambag, Belagavi, Karnataka. Pit type electrical furnace buried inside the ground consisting of elements of Canthol wire giving electrical load of 32KW was used. The maximum temperature was 1200°C. Furnace is cylindrical in shape having 400mm diameter and 1.2 m deep, having control

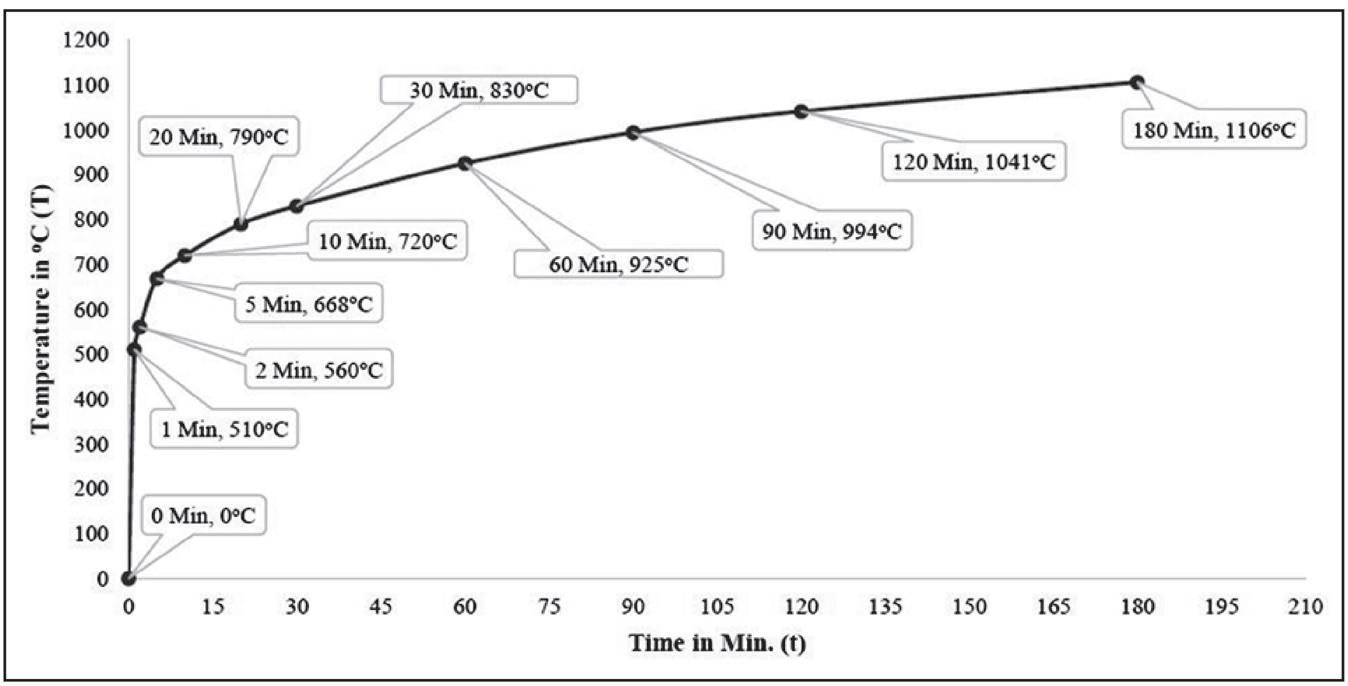


Fig. 1. Time vs Temperature Curve Used for the Furnace

panel with temperature indicator, temperature sensor, and ampere rating. Time vs temperature curve used for the furnace resembles the need of ISO: 834–2014 [19] and it is shown in Fig. 1. Specimens were kept inside the furnace, unstressed for 3 hours (retention period) [20]. Sudden cooling means that after taking the concrete specimens from the furnace, directly dipped in water, while in gradual cooling they were kept as it is in natural environment.

After temperature test and cooling regimes, compressive strength was calculated as per IS: 516–1959 [21], split tensile strength as per IS: 5816–1999 [22]. The specimens were also tested for near surface

**TABLE IX.**
**COMPRESSIVE STRENGTH RESULTS OF C, C+FA+GGBFS, AND C+FA+SF BLENDS WITH PPF MONO FIBRE COMBINATION, FOR BOTH SUDDEN AND GRADUAL COOLING REGIMES VS ALL THE SUSTAINED ELEVATED TEMPERATURES FOR 3 HOURS**

| Sustained Elevated Temperature (°C) | Blend & Fibre Combination | | | | | |
|---|---|---|---|---|---|---|
| | C and PPF | | (C, FA, GGBFS), and PPF | | (C, FA, SF), and PPF | |
| | Cooling Regime | | | | | |
| | Sudden Cooling | Gradual Cooling | Sudden Cooling | Gradual Cooling | Sudden Cooling | Gradual Cooling |
| | Average Compressive Strength (MPa) | | | | | |
| 30°C (RT) | 41.50 | 42.02 | 47.95 | 48.32 | 48.86 | 49.32 |
| 100°C | 40.85 | 41.38 | 47.31 | 47.70 | 48.25 | 48.72 |
| 200°C | 39.72 | 40.32 | 46.50 | 46.92 | 47.65 | 48.18 |
| 300°C | 38.82 | 39.33 | 45.50 | 45.88 | 46.32 | 46.82 |
| 400°C | 35.60 | 36.10 | 43.50 | 43.90 | 44.42 | 44.90 |
| 500°C | 31.50 | 31.95 | 41.11 | 41.50 | 41.95 | 42.40 |
| 600°C | 27.30 | 27.70 | 38.11 | 38.45 | 39.00 | 39.40 |
| 700°C | 23.00 | 23.40 | 34.25 | 34.55 | 35.12 | 35.48 |
| 800°C | 18.80 | 19.20 | 30.51 | 30.75 | 31.24 | 31.55 |
| 900°C | 15.00 | 15.30 | 26.80 | 27.00 | 27.32 | 27.58 |
| 1000°C | 10.80 | 11.00 | 22.82 | 23.00 | 23.62 | 23.85 |

**TABLE X.**
**SPLIT TENSILE STRENGTH RESULTS OF C, C+FA+GGBFS AND C+FA+SF BLENDS WITH PPF MONO FIBRE COMBINATION, FOR BOTH SUDDEN AND GRADUAL COOLING REGIMES VS ALL THE SUSTAINED ELEVATED TEMPERATURES FOR 3 HOURS**

| Sustained Elevated Temperature (°C) | Blend & Fibre Combination | | | | | |
|---|---|---|---|---|---|---|
| | C + PPF | | (C+FA+GGBFS) + PPF | | (C+FA+SF) + PPF | |
| | Cooling Regime | | | | | |
| | Sudden Cooling | Gradual Cooling | Sudden Cooling | Gradual Cooling | Sudden Cooling | Gradual Cooling |
| | Average Split Tensile Strength (MPa) | | | | | |
| 30°C (RT) | 4.51 | 4.65 | 5.52 | 5.66 | 5.62 | 5.75 |
| 100°C | 4.43 | 4.57 | 5.43 | 5.57 | 5.54 | 5.67 |
| 200°C | 4.28 | 4.42 | 5.25 | 5.39 | 5.36 | 5.49 |
| 300°C | 4.05 | 4.18 | 5.04 | 5.18 | 5.14 | 5.27 |
| 400°C | 3.63 | 3.75 | 4.56 | 4.69 | 4.70 | 4.82 |
| 500°C | 2.80 | 3.00 | 4.06 | 4.17 | 4.18 | 4.30 |
| 600°C | 2.10 | 2.25 | 3.60 | 3.71 | 3.68 | 3.78 |
| 700°C | 1.55 | 1.70 | 3.18 | 3.28 | 3.25 | 3.34 |
| 800°C | 1.23 | 1.36 | 2.63 | 2.70 | 2.79 | 2.89 |
| 900°C | 0.80 | 0.95 | 2.10 | 2.20 | 2.26 | 2.40 |
| 1000°C | 0.31 | 0.45 | 1.65 | 1.70 | 1.77 | 1.84 |

## TABLE XI.
## WATER ABSORPTION RESULTS OF C, C+FA+GGBFS AND C+FA+SF BLENDS WITH PPF MONO FIBRE COMBINATION, FOR BOTH SUDDEN AND GRADUAL COOLING REGIMES VS ALL THE SUSTAINED ELEVATED TEMPERATURES FOR 3 HOURS

| Sustained Elevated Temperature (°C) | Blend & Fibre Combination | | | | | |
|---|---|---|---|---|---|---|
| | C + PPF | | (C+FA+GGBFS) + PPF | | (C+FA+SF) + PPF | |
| | Cooling Regime | | | | | |
| | Sudden Cooling | Gradual Cooling | Sudden Cooling | Gradual Cooling | Sudden Cooling | Gradual Cooling |
| | Average Water Absorption (%) | | | | | |
| 30°C (RT) | 1.22 | 1.20 | 1.11 | 1.09 | 1.04 | 1.02 |
| 100°C | 1.27 | 1.25 | 1.14 | 1.12 | 1.06 | 1.04 |
| 200°C | 1.33 | 1.30 | 1.20 | 1.17 | 1.11 | 1.08 |
| 300°C | 1.43 | 1.40 | 1.28 | 1.25 | 1.19 | 1.15 |
| 400°C | 1.58 | 1.54 | 1.40 | 1.37 | 1.29 | 1.25 |
| 500°C | 1.76 | 1.72 | 1.53 | 1.50 | 1.42 | 1.37 |
| 600°C | 2.00 | 1.96 | 1.69 | 1.65 | 1.56 | 1.51 |
| 700°C | 2.35 | 2.30 | 1.89 | 1.84 | 1.75 | 1.69 |
| 800°C | 2.85 | 2.79 | 2.17 | 2.08 | 1.98 | 1.91 |
| 900°C | 3.60 | 3.53 | 2.47 | 2.40 | 2.28 | 2.20 |
| 1000°C | 4.95 | 4.86 | 2.93 | 2.80 | 2.68 | 2.60 |

## TABLE XII.
## SORPTIVITY RESULTS OF C, C+FA+GGBFS, AND C+FA+SF BLENDS WITH PPF MONO FIBRE COMBINATION FOR BOTH SUDDEN AND GRADUAL COOLING REGIMES VS ALL THE SUSTAINED ELEVATED TEMPERATURES FOR 3 HOURS

| Sustained Elevated Temperature (°C) | Blend & Fibre Combination | | | | | |
|---|---|---|---|---|---|---|
| | C + PPF | | (C+FA+GGBFS) + PPF | | (C+FA+SF) + PPF | |
| | Cooling Regime | | | | | |
| | Sudden Cooling | Gradual Cooling | Sudden Cooling | Gradual Cooling | Sudden Cooling | Gradual Cooling |
| | Avg. Sorptivity ($mm/min^{0.5}$) | | | | | |
| 30°C (RT) | 5.00 | 4.92 | 3.50 | 3.42 | 3.06 | 3.00 |
| 100°C | 5.22 | 5.13 | 3.62 | 3.53 | 3.15 | 3.08 |
| 200°C | 5.49 | 5.39 | 3.77 | 3.67 | 3.25 | 3.18 |
| 300°C | 5.82 | 5.72 | 3.96 | 3.86 | 3.38 | 3.30 |
| 400°C | 6.38 | 6.26 | 4.19 | 4.09 | 3.59 | 3.50 |
| 500°C | 7.00 | 6.87 | 4.52 | 4.41 | 3.82 | 3.72 |
| 600°C | 7.77 | 7.63 | 4.90 | 4.78 | 4.15 | 4.05 |
| 700°C | 8.70 | 8.54 | 5.35 | 5.22 | 4.53 | 4.42 |
| 800°C | 9.82 | 9.63 | 5.88 | 5.73 | 4.94 | 4.82 |
| 900°C | 11.39 | 11.15 | 6.67 | 6.50 | 5.55 | 5.43 |
| 1000°C | 13.75 | 13.50 | 7.65 | 7.45 | 6.20 | 6.06 |

**TABLE XIII.**
**MODULUS OF ELASTICITY RESULTS OF C, C+FA+GGBFS, AND C+FA+SF BLENDS WITH PPF MONO FIBRE COMBINATION FOR BOTH SUDDEN AND GRADUAL COOLING REGIMES VS ALL THE SUSTAINED ELEVATED TEMPERATURES FOR 3 HOURS**

| Sustained Elevated Temperature (°C) | Blend & Fibre Combination | | | | | |
|---|---|---|---|---|---|---|
| | C + PPF | | (C+FA+GGBFS) + PPF | | (C+FA+SF) + PPF | |
| | Cooling Regime | | | | | |
| | Sudden Cooling | Gradual Cooling | Sudden Cooling | Gradual Cooling | Sudden Cooling | Gradual Cooling |
| | Avg. Modulus of Elasticity x $10^4$ (MPa) | | | | | |
| 30°C (RT) | 3.72 | 3.80 | 4.09 | 4.16 | 4.35 | 4.39 |
| 100°C | 3.65 | 3.73 | 4.03 | 4.10 | 4.29 | 4.33 |
| 200°C | 3.54 | 3.62 | 3.95 | 4.02 | 4.23 | 4.27 |
| 300°C | 3.38 | 3.46 | 3.81 | 3.89 | 4.10 | 4.15 |
| 400°C | 3.15 | 3.23 | 3.50 | 3.58 | 3.79 | 3.83 |
| 500°C | 2.85 | 2.93 | 3.20 | 3.28 | 3.45 | 3.50 |
| 600°C | 2.52 | 2.59 | 2.90 | 2.97 | 3.10 | 3.16 |
| 700°C | 2.17 | 2.25 | 2.50 | 2.58 | 2.70 | 2.76 |
| 800°C | 1.84 | 1.92 | 2.15 | 2.21 | 2.35 | 2.41 |
| 900°C | 1.50 | 1.59 | 1.79 | 1.84 | 2.02 | 2.07 |
| 1000°C | 1.12 | 1.22 | 1.40 | 1.45 | 1.62 | 1.66 |

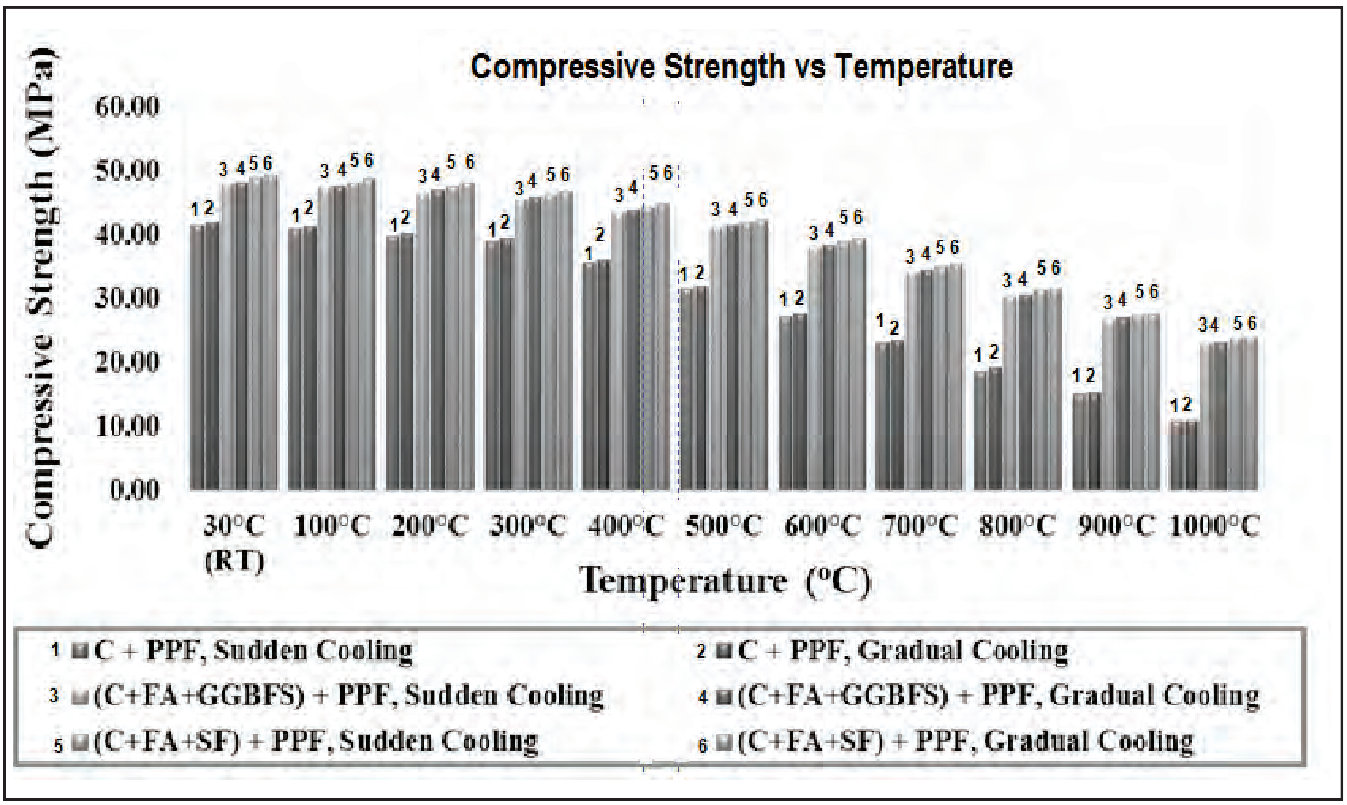


**Fig. 2. Variation of compressive strength results of C, C+FA+GGBFS and C+FA+SF blends with PPF mono fibre combination for both sudden and gradual cooling regimes Vs all the sustained elevated temperatures for 3 hours**

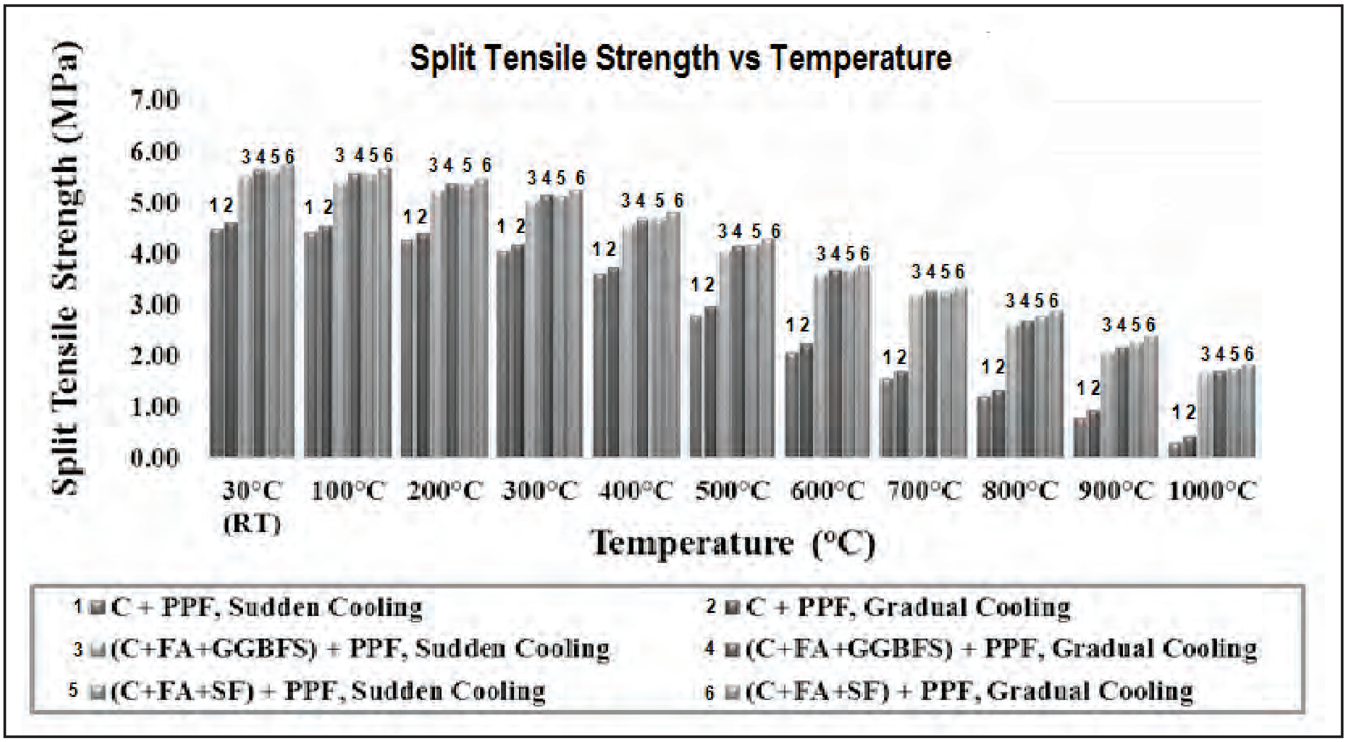


**Fig. 3. Variation of split tensile strength results of C, C+FA+GGBFS, and C+FA+SF blends with PPF mono fibre combination for both sudden and gradual cooling regimes Vs all the sustained elevated temperatures for 3 hours**

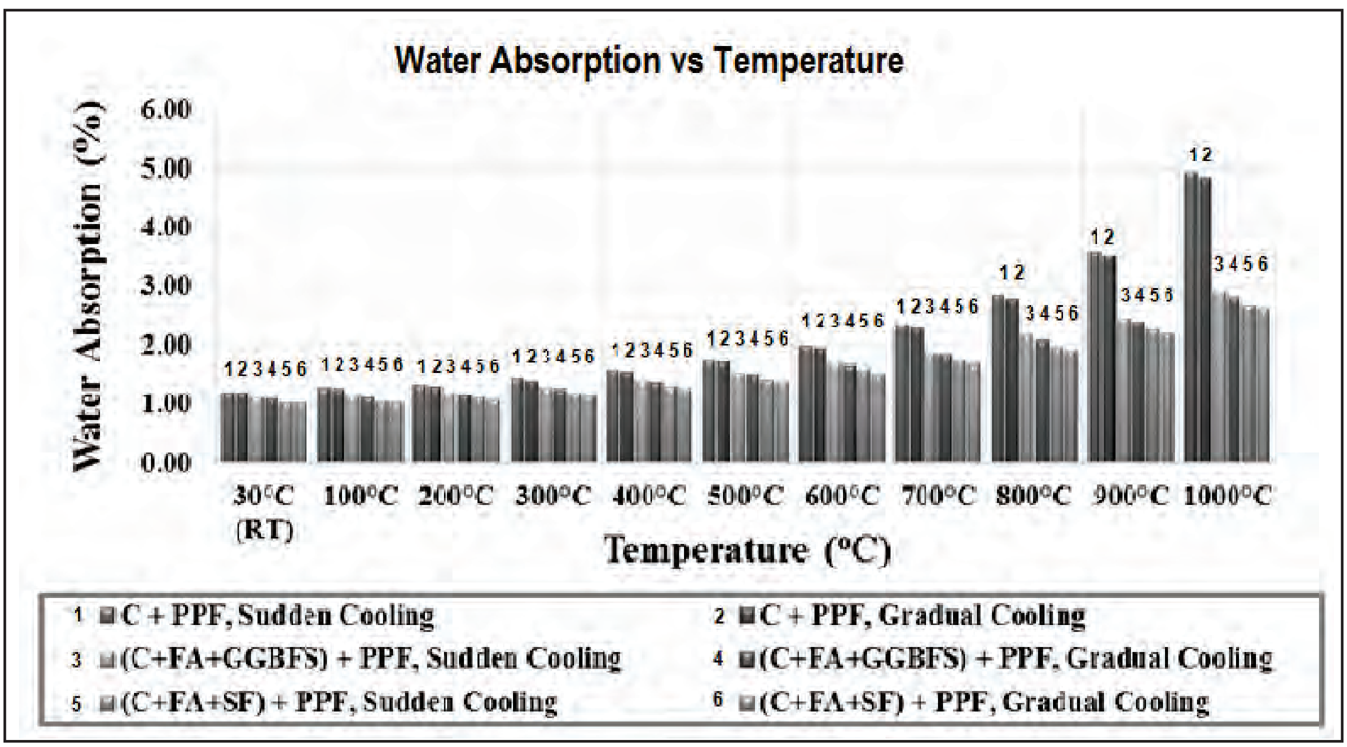


**Fig. 4. Variation of water absorption results of C, C+FA+GGBFS, and C+FA+SF blends with PPF mono fibre combination for both sudden, and gradual cooling regimes vs all the sustained elevated temperatures for 3 hours**

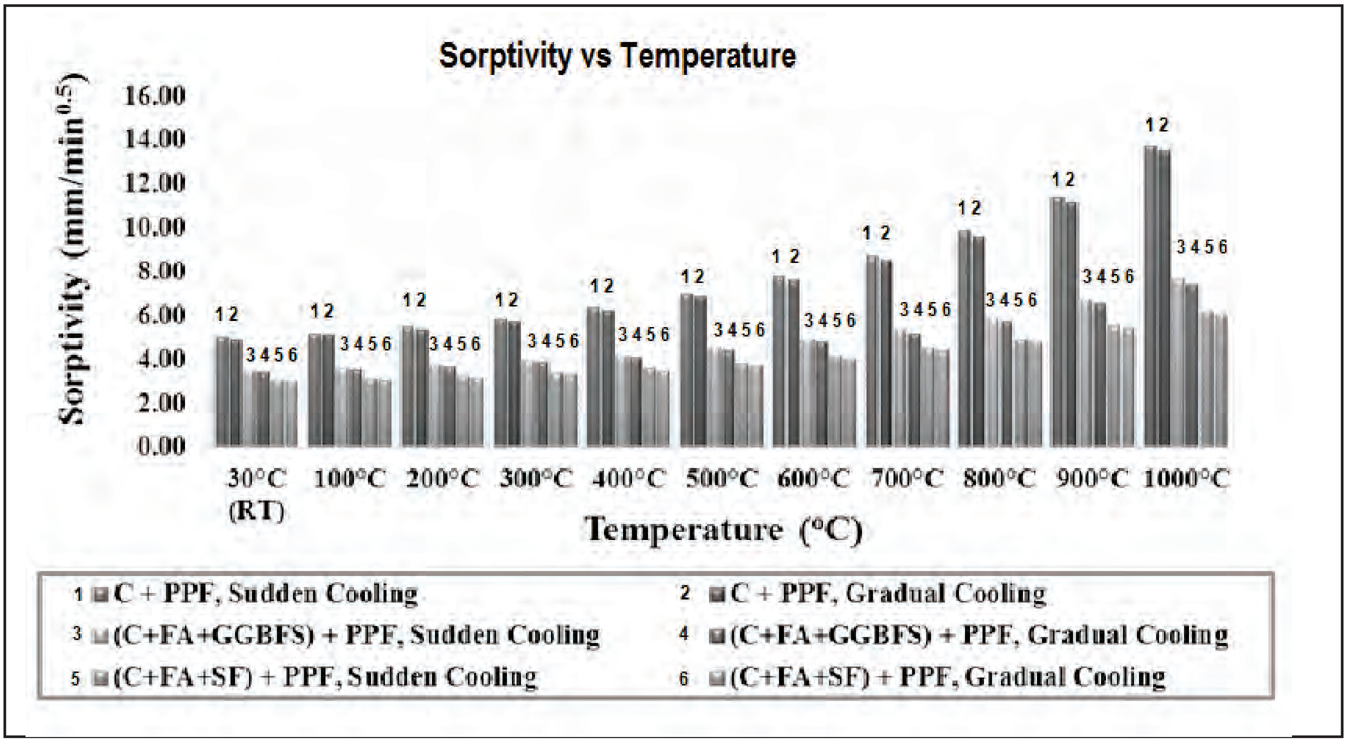


**Fig. 5. Variation of sorptivity results of C, C+FA+GGBFS, and C+FA+SF blends with PPF mono fibre combination for both sudden and gradual cooling regimes Vs all the sustained elevated temperatures for 3 hours.**

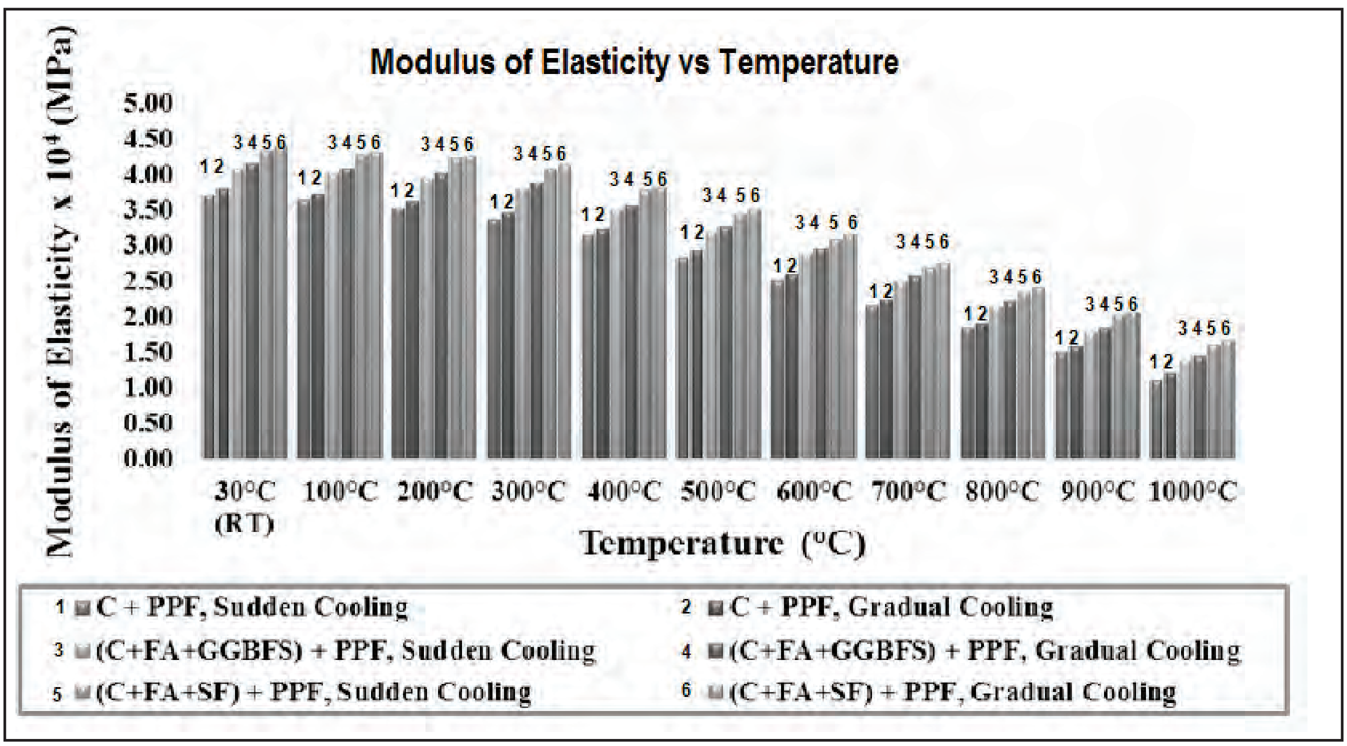


**Fig. 6. Variation of modulus of elasticity results of C, C+FA+GGBFS, and C+FA+SF blends with PPF mono fibre combination for both sudden and gradual cooling regimes Vs all the sustained elevated temperatures for 3 hours**

characteristics (water absorption & sorptivity) [23], and modulus of elasticity.

## V. RESULT AND DISCUSSION

By observing tables IX to XIII and figures 2 to 6, it is clear that as temperature increases, compressive strength, split tensile strength, modulus of elasticity decreases, and near surface characteristics increases for all concrete combinations.

There is slight decrease in compressive, split tensile strength, and modulus of elasticity till 300°C, beyond that they are reduced drastically, and maximum loss was observed at 1000°C for all the combinations. There is slight increment in near surface characteristics till 400°C, beyond that they increase drastically and maximum increase is observed at 1000°C for all the combinations. The concrete produced with polypropylene fibre & C+FA+SF blend shows better results against all temperatures. When compared to the concrete produced with polypropylene fibre & C+FA+SF blend, slightly worst results were observed when concrete produced with polypropylene fibre & C+FA+GGBFS blend and drastic worst results were observed when concrete produced with polypropylene fibre, and conventional concrete (C).

There is slight variation in all the test results between two cooling regimes, gradual cooling shows better results compared to sudden cooling against all the temperatures, and for all the combinations. This is because due to a sudden cooling there is a thermal shock on concrete, thus it ruptures the intermolecular bond between the constituents [24]. Meanwhile, with gradual cooling, specimens absorb moisture from the atmosphere and rebuilding of strength may take place [25]. Addition of polypropylene fibre shows the boost in compressive strength, split tensile strength, and modulus of elasticity and meanwhile, it also helps in the reduction of water absorption and sorptivity.

## VI. CONCLUSIONS

The maximum compressive strength, split tensile strength, and modulus of elasticity, and minimum water absorption & sorptivity is observed at 30°C (RT). As temperature increases, compressive strength, split tensile strength, modulus of elasticity decreases, and near surface characteristic increase for all concrete combinations.

There is slight decrease in compressive, split tensile strength, and modulus of elasticity till 300°C. Beyond that they are reduced drastically, and maximum loss is observed at 1000°C for all the combinations.

There is slight increment in near surface characteristics till 400°C, beyond that these are increased drastically and maximum increase is observed at 1000°C for all the combinations.

The concrete produced with polypropylene fibre, and C+FA+SF blend shows better results against all temperatures.

When compared to the concrete produced with polypropylene fibre & C+FA+SF blend, slightly worse results were observed when concrete was produced with polypropylene fibre & C+FA+GGBFS blend, and drastic worst results were observed when concrete was produced with polypropylene fibre, and conventional concrete (C).

Addition of polypropylene fibre shows the boost in compressive strength, split tensile strength, and modulus of elasticity. Meanwhile, it also helps in the reduction of water absorption and sorptivity.

There is marginal variation in all the test results between two cooling regimes, gradual cooling shows better results compared to sudden cooling against all the temperatures and for all the combinations.

## REFERENCES


[1] K. Chandramouli, S. Rao P., N. Pannirselvam, T. S. Sekhar, and P. Sravana, "The effect of compressive strength on high strength concrete at different temperature and time," *J. of Emerging Trends in Eng. and Appl. Sciences*, vol. *2*, no. *4*, pp. 698–700, 2011.

[2] A. A. Yaligar and S. B. Vanakudre, "Effect of sudden & gradual cooling regimes on compressive strength of blended concretes subjected to sustained elevated temperatures," presented at the *4th Int. Conf. on Sci., Technol., and Manage. (ICSTM–2016)*, 15th May 2016, India Int. Centre.

[3] K. S. Rao, Raju M. P., and Raju P. S. N., "Effect of elevated temperatures on compressive strength of HSC made with OPC and PPC," *The Indian Concrete J.*, vol. *80*, no. *8*, pp. 43–48., 2006.

[4] D. A. Sinha, *An experimental investigation on the behaviour of steel fibre reinforced ternary blended concrete subjected to sustained elevated temperature*, Thesis submitted to BVM Eng. College, Sardar Patel University, Vallabh Vidyanagar, Gujrat for Ph. D., Sardar Patel University, 2013.

[5] S. Peter, *Resistance to high temperatures significance of tests and properties of concrete and concrete making*

*materials*, STP 169B ASTM Philadelphia 1978, pp. 388–417.
[6] J. Yu, W. Weng, and K. Yu, "Effect of different cooling regimes on the mech. properties of cementitious composite subjected to high temperatures," *The Scientific World J.*, pp. 1–7, 2014. doi: http://dx.doi.org/10.1155/2014/289213
[7] K. S. Kulkarni, S. C. Yaragal and K. S. B. Narayan, "An overview of high performance concrete at elevated temperatures," *Int. J. of Appl. Eng. and Technol.*, vol. *1*, no. *1*, pp. 48–60, 2011.
[8] A. A. Yaligar and S. B. Vanakudre, "Influence of sudden & gradual cooling regimes on split tensile strength of blended concretes subjected to sustained elevated temperatures," *Int. J. of Advanced Res. in Sci. and Eng.*, vol. *5*, Special Issue no. *1*, pp. 118–126, 2016.
[9] M. Heikal, "Effect of elevated temperature on the physico–mech. and micro structural properties of blended cement pastes," *Building Res. J.*, vol. *56*, pp. 157–172, 2008.
[10] K. Venkatesh and R. Nikhil, "Performance of concrete structures under fire hazards: Emerging trends," *The Indian Concrete J.*, April–June, pp. 7–18, 2010.
[11] *43 grade ordinary portland cement–specification*, IS 8112,1989.
[12] *Specification for coarse and fine aggregates from natural sources for concrete*, IS 383,1970.
[13] *Pulverized fuel ash (Part–1),* IS 3812, 2013.
[14]*Specification for granulated slag for the manufacture of portland slag cement,* IS 12089,1987.
[15] *Silica fume–specification,* IS 15388, 2003.
[16] *Concrete admixtures–specification,* IS 9103, 1999.
[17] *Concrete mix proportioning–guidelines*, IS 10262, 2009.
[18] D. A. Sinha, A. K. Verma and K. B. Prakash, "Influence of sustained elevated temperature on characteristic properties of ternary blended steel fibre reinforced concrete," *Indian J. of Appl. Res.*, vol. *4*, no. *8*, pp. 224–232, 2014.
[19] *Fire resistance tests–elements of building construction, part 2: guidance on measuring uniformity of furnace exposure on test samples,* ISO 834–2, 2014.
[20] A. N. S. A. Quadi, K. N. B. Mustapha, S. Naganathan and Q. N. S. Al–Kadi, "Effect of polypropylene fibres on fresh and hardened properties of self–compacting concrete at elevated temperatures," *Australian J. of Basic and Appl. Sciences*, vol. *5*, no. *10*, pp. 378–384, 2011.
[21] *Methods of tests for strength of concrete,* IS 516, 1959.
[22] *Splitting tensile strength of concrete–method of test,* IS 5816, 1999.
[23] A. A. Yaligar, S. Patil and K. B. Prakash, "An experimental investigation on the behaviour of re-tempered concrete," *Int. J. of Eng. Res.–Online*, vol. *1*, no. *2*, pp. 111–120, 2013.
[24] G. Peng, S. Bian, Z. Guo, Q., J. Zhao, X. Peng and Y. Jiang, "Effect of thermal shock due to rapid cooling on residual mech. properties of fiber concrete exposed to high temperatures," *Construction and Building Materials,* vol. *22*, no. *5*, pp. 948–955, 2008. doi: https://doi.org/10.1016/j.conbuildmat.2006.12.002
[24] M. Husem, "The effects of high temperature on compressive and flexural strengths of ordinary and high–performance concrete," *Fire Safety J.,* vol. *41*, no. *2*, pp. 155–163, 2006. doi: https://doi.org/10.1016/j.firesaf.2005.12.002

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