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Exposure to elevated temperatures and cooled under different regimes–a study on polypropylene concrete

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Abstract. Fire is one of the most destructive powers to which a building structure can be subjected, often exposing concrete elements to elevated temperatures. The relative properties of concrete after such an exposure are of significant importance in terms of the serviceability of buildings. Unraveling the heating history of concrete and different cooling regimes is important for forensic research or to determine whether a fire-exposed concrete structure and its components are still structurally sound or not. Assessment of fire-damaged concrete structures usually starts with visual observation of colour change, cracking and spalling. Thus, it is important to know the effect of elevated temperatures on strength retention properties of concrete. This study reports the effect of elevated temperature on the mechanical properties of the concrete specimen with polypropylene fibres and cooled differently under various regimes. In the heating cycle, the specimen were subjected to elevated temperatures ranging from 200°C to 800°C, in steps of 200°C with a retention period of 1 hour. Then they were cooled to room temperature differently. The cooling regimes studied include, furnace cooling, air cooling and sudden cooling. After exposure to elevated temperatures and cooled differently, the weight loss, residual compressive and split tensile strengths retention characteristics were studied. Test results indicated that weight and both compressive and tensile strengths significantly reduce, with an increase in temperature and are strongly dependent on cooling regimes adopted.

Keywords: concrete; performance; heating; cooling regimes; polypropylene; strength loss

1. Introduction

Concrete is the most widely used construction material in the world. It is used in many different structures such as dams, pavements, buildings, bridges etc. Its appealing characteristics such as mould ability and high compressive strength have made it a popular building material. Concrete offers good resistance to heat because of its low thermal conductivity, is incombustible, and favourably, no toxic fumes are emitted from concrete surface, when it is heated. Concrete is subjected to high temperatures, during accidental events of fire, natural disasters, and sabotages. Even though concrete is the most desired material for construction, it has some limitations like loss

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in strength, loss of weight, shrinkage, expansion, etc. when exposed to elevated temperatures.

Concrete at elevated temperatures is sensitive to the temperature level, heating rate, thermal cycling and temperature duration (as long as chemical and physical transformations occur). Its mechanical properties such as strength, modulus of elasticity decreases remarkably and this results in structural quality deterioration of concrete. Unless large temperature differentials develop (as in rapid heating), the compressive strength of concrete at elevated temperatures is usually maintained up to 300°C. However, above this temperature, significant decrease in strength can be anticipated. The magnitude of the decrease depends on the nature of the aggregate and the initial moisture content of the specimen. The changes in strength have been attributed to a combination of decomposition of the hydrated pastes, deterioration of the aggregates and the thermal incompatibilities between paste and aggregate leading to stress concentrations and micro cracking.

When exposed to high temperature, the chemical composition and physical structure of the concrete change considerably. The dehydration, such as the release of chemically bound water from the Calcium Silicate Hydrate (CSH), becomes significant above about 110°C. The dehydration of the hydrated calcium silicate and the thermal expansion of the aggregate increase internal stresses and from 300°C micro cracks are induced through the material, Hertz (2003). Calcium hydroxide, which is one of the most important compounds in cement paste, dissociates at around 530°C resulting in the shrinkage of concrete, Janotka and Nurnbergerov. (2005).

Studies have shown that concrete loses strength with increase in temperature. The reason attributed is due to the decomposition of structure of the C-S H gel that starts at about 550°C. Yaragal *et al*. (2010), have proposed strength prediction equations for normal strength concretes (M20, M25, M30, M40, and M45) at elevated temperatures. Bingol and Gul (2008), have investigated on the compressive strength characteristics of normal strength concrete at elevated temperatures up to 700°C and the effect of cooling regimes. To increase residual compressive strength of concrete at elevated temperatures, several studies have been performed worldwide for the development of concrete compositions of enhanced fire behaviour. Concretes with polypropylene fibres showed good behaviour at elevated temperatures and controlling spalling of concrete on the basis that, as the concrete is heated by fire, the Polypropylene fibres melt at about 160°C-170°C thus creating channels for vapour to escape and thereby release pore pressures. Polypropylene fibres have some unique properties that make them suitable as reinforcement in concrete. The fibres have a low density, are chemically inert and non corrosive. The residual strength of concrete depends on heating rate, retention time, and most importantly the way it gets cooled to room temperature.

Al Qadi and Al-Zaidyeen (2014) have investigated the effect of specimen shape on residual mechanical properties of polypropylene (PP) fibre Self Compacting Concrete (SCC) exposed to elevated temperatures from 200°C to 600°C. Various shaping regimes were used including cylindrical and cubical shapes for a series of durations of 2 and 4 h, and air cooling to the room temperature before testing. The temperature determination results prove that the shaping regimes caused an action of “thermal shock” to SCC under elevated temperatures, characterized by a high temperature at fixed time of exposure. The experimental results indicate that, compared cylindrical specimen with cubical one, thermal shock induced by cylindrical shape air cooling caused more severe damage to concrete in terms of greater losses in compressive strength than those with cubical shapes. The presence of PP fibres in cubical specimens and at different dosages cannot affect the relative residual compressive strength at 200°C, and 400°C, while they considerably increase the residual compressive strength of concretes after exposure to 600°C. Whereas, 0.10% PP fibres prove to be optimum for cubical shape.

Ramujee (2013) has investigated the effect of polypropylene fibres (dosage of 0%, 0.5%, 1%, 1.5% and 2%) on compressive and split tensile strengths of concrete (M20 grade) at room temperature. Maximum compressive and split tensile strengths of concrete were observed at 1.5% dosage of polypropylene, those values were 45.25 MPa and 3.52 MPa respectively. Compressive and split tensile strengths of concrete at 1% dosage of polypropylene were 44.12 MPa and 3.4 MPa respectively, these values are approximately equal to those values which were observed at 1.5% dosage of polypropylene.

Yaragal *et al*. (2012), have reported that loss in strength is highly dependent on the type of cooling regimes, say at 550°C, the loss is 35% and 55% for the cooling regimes of furnace and sudden cooling in water respectively.

Monal *et al*. (2012) have reported the effect of elevated temperature on the mechanical properties of the concrete specimen obtained by replacing 30% OPC by GGBS and cooled differently under various regimes.

Shihada (2011) has investigated the effect of Polypropylene fibres on fire resistance of concrete. In order to achieve this, three concrete mixes were prepared using different percentages of Polypropylene; 0%, 0.5% and 1%, by volume. Out of these mixes, cubes (100×100×100 mm) in dimension were cast and cured for 28 days. The cubes were then soaked at 200°C, 400°C and 600°C, for 2, 4 and 6 hours for each of the three temperatures, and tested for compressive strength. Based on the results of the experimental program, it is concluded that when Polypropylene fibres are used in certain amounts they improve fire resistance of concrete. Furthermore, it is observed that concrete mixes prepared using 0.5%, by volume retain more than 84% of the initial compressive strength when heated to 600°C for 6 hours. On the other hand, samples prepared using 0% Polypropylene retains about 50% of their initial strength under the same temperature and duration.

Abdelalim, Abdel-Aziz, El-Mohr and Salama (2009) have studied the effect of elevated fire temperature and cooling regime on the fire resistance of Self Compacting Concrete (SCC) and Normal Concrete (NC). Both concretes were exposed to elevated degrees of fire temperatures of 200, 400, 600 and 800°C. In addition, the temperature was maintained at 800°C while the exposure durations have been increased to 15, 30, 60 and 120 minutes. After that the samples were cooled to room temperature using three different cooling regimes namely; air cooling, CO_2 powder cooling and water cooling. Reductions in both compressive and tensile strength results along with the extent of spalling were examined. Results concluded that, for same time duration, cooling regime plays an important role in the obtained percentages of the residual compressive strength for both NC and SCC. Water cooling regime provided the least percentage of the residual compressive strength while CO_2 cooling regime (chemical) provided the highest percentage of residual compressive strength because of CO_2 powder cooling regime provided the least damage to the concrete after exposure to fire while water cooling regime was the worst of the studied cooling regimes due to the thermal shock experienced during the cooling process.

Jianzhuang and Falkner (2006) have conducted experiments on cubes and cylindrical specimen with C50, C80 and C100 High Performance Concrete (HPC) mixed with and without Poly Propylene (PP) fibres. These specimen were heated in an electric furnace, approximately following the curve of ISO-834, with a series of target temperatures ranging from 20 to 900°C. No explosive spalling was observed during the fire test on HPC specimen with PP fibres, whereas some spalling occurred for HPC specimen without PP fibres. The relationship between the mass loss and the exposure temperature was investigated. In addition, the heated and cooled cubes and prisms were tested under monotonic compressive loading and four-point bending loading, respectively. The degradation of both the residual compressive strength and the residual flexural strength was analysed. Furthermore, the effects of PP fibres on the residual mechanical strength of HPC specimen at elevated temperatures were also investigated. Finally, a fire-resistance design curve relating the residual compressive strength to temperature, as well as a design curve relating the residual flexural strength to temperature, was proposed based on the statistical analysis of the test data.

Mendes, Sanjayan, and Collins (2000) have studied the effect of Ordinary Portland Cement (OPC) and OPC/slag concretes when exposed to elevated temperatures, 400°C and 800°C, and based on these studies the following conclusions were made. The critical temperature of 400°C has been reported for OPC paste. Above 400°C, the paste hydrate $Ca(OH)_2$ dehydrates into CaO causing the OPC paste to shrink and crack. After cooling and in the presence of air moisture, CaO rehydrates into $Ca(OH)_2$, resulting in disintegration due to re-expansion of OPC paste. Therefore, their work assessed whether this also applies to OPC concretes. Two cooling methods were used: furnace and water cooling. Following the heat treatment/cooling method, compressive tests and Infrared (IR) spectroscopic studies were conducted. Results showed that after 400°C, water cooling caused all concrete, regardless of the type of blended cement binder, a further 20% loss in the residual strength. After 800°C, water cooling caused OPC concrete a further 14% loss while slag blends presented around 5% loss. IR indicated that the further loss observed in the OPC concrete is due to the accelerated CaO rehydration into $Ca(OH)_2$. Afterwards, the non-wetted furnace cooled specimen were exposed to air moisture for one week, resulting in further strength loss of 13%. IR results suggested that slow rehydration of CaO occur with exposure to air moisture. In conclusion, water cooling caused more damage in OPC concrete, while the concrete that has not been wetted undergoes progressive deterioration. This indicates a need to monitor the non-wetted concrete after a fire event has occurred for potential further deterioration.

In this study the performance of concrete mixes with polypropylene fibres (length = 15 mm, diameter = 45 μm, aspect ratio = 333) subjected to various levels of elevated temperatures and cooled under various regimes (Furnace cooled, Air cooled, Water cooled) is discussed and reported.

2. Materials and methods

2.1 Materials

Table 1 Properties of fine aggregates

Property	Result
Specific gravity	2.65
Bulk density	Loose: 1463 Kg/m^3 Compact: 1661 Kg/m^3
Moisture content	Nil

Table 2 Properties of coarse aggregates

Property	Result
Specific gravity	2.71
Bulk density	Loose: 1360 kg/m^3 Compact: 1527 kg/m^3
Moisture content	Nil

Table 3 Physical properties of Ordinary Portland Cement

<table>
<tr><th>Sl. No.</th><th>Property</th><th colspan="3">Result obtained</th><th colspan="3">Requirements as per IS code</th><th>Remarks</th></tr>
<tr><td>1</td><td>Specific gravity</td><td colspan="3">3.10</td><td colspan="3">--</td><td>ACC cement 43 Grade</td></tr>
<tr><td>2</td><td>Normal consistency</td><td colspan="3">31%</td><td colspan="3">--</td><td rowspan="6">Satisfies IS code requirements.</td></tr>
<tr><td>3</td><td>Setting times, minutes</td><td colspan="3">Initial 65
Final 270</td><td colspan="3">Not less than 30
Not more than 600</td></tr>
<tr><td>4</td><td>Fineness, m2/Kg</td><td colspan="3">330</td><td colspan="3">Not less than 300</td></tr>
<tr><td>5</td><td>Soundness, mm</td><td colspan="3">2.50</td><td colspan="3">Not more than 10 mm</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">Compressive strength, Mpa</td><td>3 Days</td><td>7 Days</td><td>28 Days</td><td>3 Days</td><td>7 Days</td><td>28 Days</td></tr>
<tr><td>34</td><td>51</td><td>61</td><td>22</td><td>33</td><td>43</td></tr>
</table>

Table 4 Properties of Polypropylene fibers

Property	Result
Unit weight (kg/m³)	0.9 - 0.91
Tensile strength (MPa)	400
Fibre Length (mm)	15
Fibre diameter (µm)	45
Melting point (C°)	170-160
Thermal conductivity (w/m/k)	0.12
Density: (g/cm³)	0.91

Coarse aggregate was crushed stone with a maximum size of 20 mm. Locally available natural river sand conforming to zone II (IS 383-1970 grading requirements) was used as fine aggregate. Physical properties of fine and coarse aggregates are presented in Tables 1 and 2 respectively. Ordinary Portland Cement (OPC) 43 grade was used and its properties are tabulated in Table 3. Potable quality water is used. Properties of polypropylene fibres are presented in Table 4.

2.2 Mix proportion

Table 5 Weight of ingredients per cubic meter of concrete

Materials	Weight (kg)	
	Mix 1	Mix 2
Cement	318	318
Water	175	175
Coarse aggregate	1272	1272
Fine aggregate	636	636
Polypropylene	0	0.9

The concrete ingredients have their different individual properties. Strength, workability and durability of the concrete depend on the concrete mix proportion of the individual ingredients. Since the process of concrete formation is a unidirectional chemical reaction, concrete gets its different properties all together. Here, nominal concrete mix 1:2:4 with (0.9 kg/m³ Polypropylene) and without Polypropylene are studied. Table 5 presents various quantities for both concrete mixes per cubic meter of concrete.

Chemical admixture dosage of 8 ml/Kg of cement is adopted for Mix 2, to obtain comparable slump values equal to that of Mix 1.

2.3 Test matrix

Table 6 Test matrix for compressive strength

Cubes without polypropylene			
Temperature (°C)	Furnace cooling	Sudden quenching	Air Cooling
Room temperature	3	3	3
200	3	3	3
400	3	3	3
600	3	3	3
800	3	3	3
Cubes with polypropylene			
Room temperature	3	3	3
200	3	3	3
400	3	3	3
600	3	3	3
800	3	3	3
Total number of specimen = 90			

Experiments were conducted on 100 mm cubes. Table 6 presents the details of number of specimen required for compressive strength determination.

A similar test matrix consisting of 90 specimens was adopted for determination of split tensile strengths.

2.4 Heating and cooling processes

Fig. 1 shows a programmable electric furnace. Target temperature is set using the knob and temperature increase is noted for convenient time intervals till it reached the target temperature. Fig. 2 shows time temperature build up curves for various test temperatures.

The specimen were subjected to exposure tests in an electrical furnace for temperatures of (200°C, 400°C, 600°C and 800°C) with a retention period 1 hour. Three types of cooling regimes studied here are, furnace cooling, air cooling and water cooling. By furnace cooling, it is meant that, after completion of 1 hour retention period at designated temperature, the furnace power supply is cut off and the door of the furnace shall not be opened till the specimen inside attain room temperature. The interior of the furnace temperature can be monitored digitally from outside display panel. It is a function of the temperature exposed to, for example, it takes nearly one day for specimen subjected to 800°C, to reach room temperature. By air cooling, it is meant that, after

Fig. 1 Programmable electric furnace

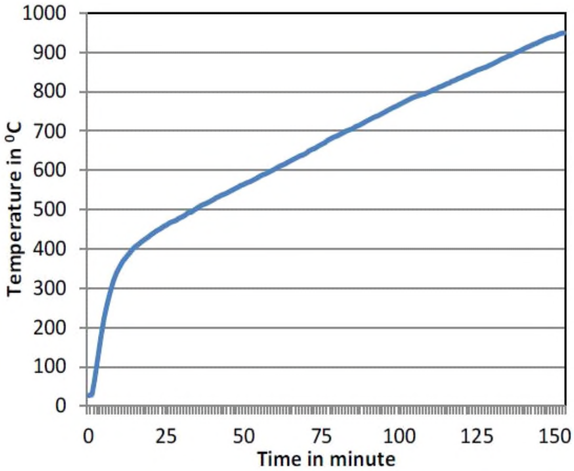

Fig. 2 Time Vs. Temperature build up curve for the furnace

retention period, that furnace door is opened and specimen are removed and allowed to cool in ambient/ room temperature. By water cooling it is meant that, after completion of retention period at designated temperature, the door of the furnace shall be opened and the specimen shall be immediately quenched in water at room temperature.

3. Results and discussions

3.1 Weight loss

Initial specimen weights were taken after 28 days of water curing. After exposure to various elevated temperatures and cooled under different cooling regimes (furnace, air and sudden) the weights of the normal concrete specimen were recorded to determine the percentage loss in weight. Table 7, presents the test results of weight loss with temperature for concretes with and without PP fibers. The effect of elevated temperatures on the weight loss of the concrete specimen is shown in Fig. 3. It is observed to increase with increase in temperature.

Table 7 Weight loss variation with temperature for concretes with and without PP fibers

Temperature exposed to (°C)	Furnace cooling		Air cooling		Water cooling	
	without pp	with pp	without pp	with pp	without pp	with pp
200	4.8	4.5	4.3	4.1	3.7	3.5
400	5.8	5.4	5.1	4.7	4.4	4.1
600	7.1	6.2	6.4	5.6	5.5	4.8
800	8.2	7.4	7.3	6.5	5.8	5.2

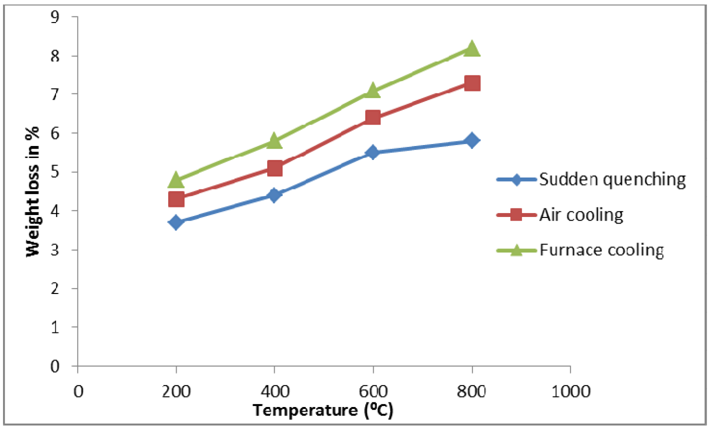

Fig. 3 Variation of loss in weight with temperature

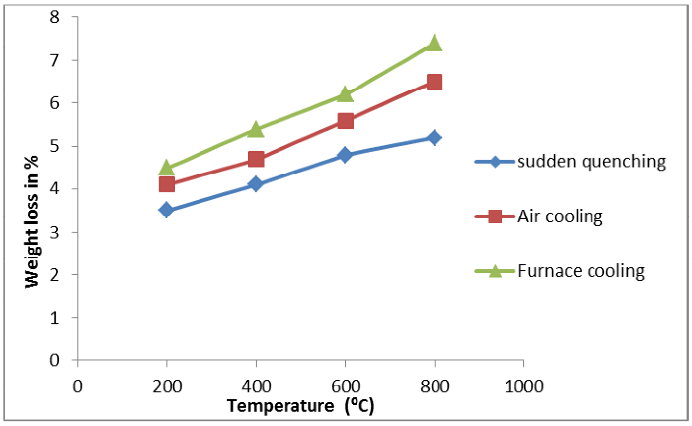

Fig. 4 Weight loss of concrete with polypropylene fibres

From Fig. 3, it is observed that average percentage of weight losses were 3.7%, 4.3% and 4.8% at 200°C, 4.4%, 5.1%and 5.8%, at 400°C, 5.5%, 6.4% and 7.1% at 600°C and 5.8%, 7.3% and 8.2% at 800°C for cases of sudden quenching, air cooling and furnace cooling respectively. It is to be noted that water cooling regime provided least average percentage of weight loss while furnace cooling regime provided the highest average percentage of weight loss and air cooling regime provided medium average percentage of weight loss.

It is observed from Fig. 4 that, the weight loss of concrete with polypropylene fibres is also following same manner like normal concrete regarding to cooling regimes, water cooling regime provided least average percentage of weight loss while furnace cooling regime provided the highest average percentage of weight loss and air cooling regime provided medium average percentage of weight loss. Concrete with PP fibers, has shown lower loss in weight for all elevated temperatures and also for all the three cooling regimes when compared with concrete having no PP fibers.

3.2 Compressive strength

Residual compressive strengths of both concrete cubes (i.e., with and without polypropylene fibres) were measured at different temperatures (200°C, 400°C, 600°C and 800°C), for heating

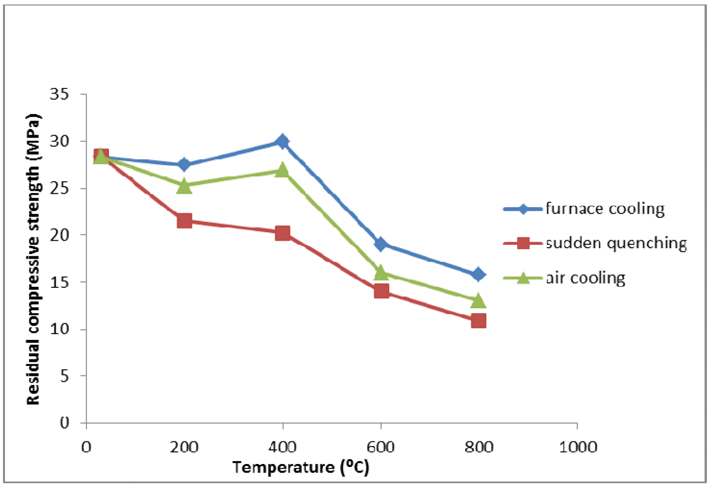

Fig. 5 Residual compressive strength of normal concrete

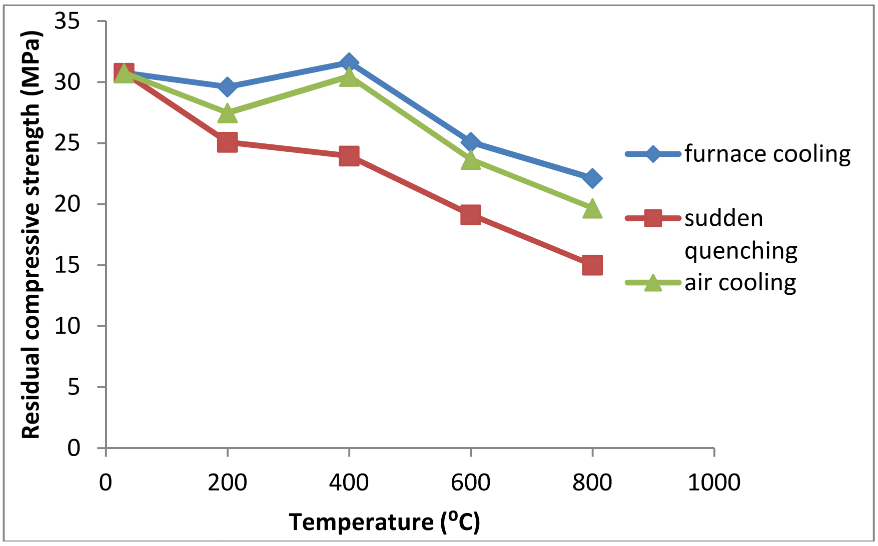

Fig. 6 Residual compressive strength of concrete with PP fibers

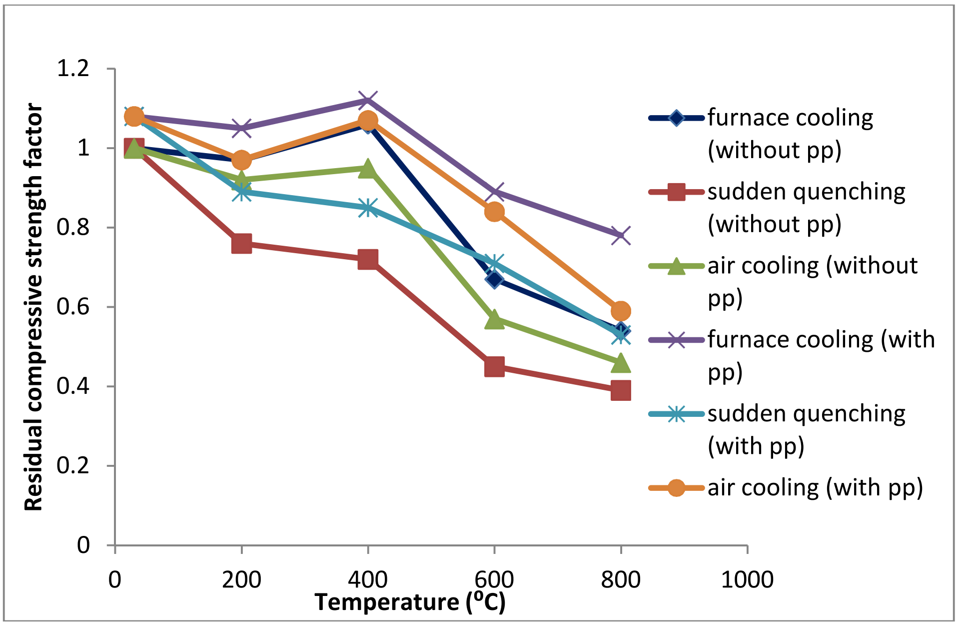

Fig. 7 Variation in residual strengths of concretes, with temperature under different cooling regimes

Table 8 Consolidated compression test results

Temperature exposed to (^{0}C)	Furnace cooling		Air cooling		Water cooling	
	without pp	with pp	without pp	with pp	without pp	with pp
Ambient	1.00	1.00	1.00	1.00	1.00	1.00
200	0.97	0.96	0.92	0.89	0.76	0.82
400	1.06	1.03	0.95	0.99	0.72	0.78
600	0.67	0.82	0.57	0.77	0.45	0.66
800	0.54	0.61	0.46	0.54	0.39	0.49

duration of 1 hour for three different cooling regimes (Furnace cooling, Air cooling, Sudden quenching). Table 8 presents the consolidated residual compression test results. The results are presented in the graphical form in Fig. 5, Fig. 6 and Fig. 7.

From Table 8, it is observed for the case of concrete without PP fibres, and furnace cooling, that is at low temperature, i.e. at 200°C the compressive strength decreased by about 3 to 4% compared with the original compressive strength at room temperature. While increasing the exposure temperature from 200°C to 400°C, caused a slight increase in the compressive strength of normal concrete. This could be attributed to the general stiffening of the cement gel or the increase in surface forces between gel particles as a result of removal of the adsorbed moisture which in turn depends on the porosity of concrete. Increasing the exposure temperature from 400°C to 600 °C, caused a dramatic reduction in the compressive strength values by about 30%, because of chemical structure of the concrete starts to break down between 225°C and 450°C where first capillary cracks were observed. These cracks do not have significant effect on the compressive strength of the material, but above 500°C the amount of the cracks develop corresponding to the increase of temperature and the material becomes weaker. By increasing temperature from 600°C to 800°C, the values of compressive strength have been reduced by about 46 % for normal concrete. Although not much variation is seen at 200°C and 400°C for concrete with and without PP fibres, however at 600°C and 800°C, concrete with PP fibres has exhibited superior strength retention characteristics. This is true for all the three cooling regimes.

Relative residual strength is defined as the ratio of residual compressive strength of specimen exposed to elevated temperature to its initial compressive strength at ambient temperature. In both concretes (normal concrete, concrete with polypropylene) it was observed that at temperatures up to 400°C the relative residual compressive strength of furnace cooled and air cooled specimens does not change significantly. On the other hand, in the same temperature range, the strength of sudden quenched specimen witnesses severe deterioration due to the thermal shock experienced during cooling process. At 600°C residual compressive strengths of normal concrete specimen are 67%, 57% and 45% for furnace cooling, air cooling and sudden quenching respectively and similarly at 800°C residual compressive strengths of normal concrete specimen are 54%, 46% and 39%. On the other hand, at 600°C residual compressive strengths of normal concrete specimen are 82%, 77% and 66% for furnace cooling, air cooling and sudden quenching respectively and at 800°C residual compressive strengths of normal concrete specimen are 61%, 54% and 49% for furnace cooling, air cooling and sudden quenching respectively. However for the same time duration, cooling regime plays an important in obtaining percentage of residual compressive strength for both normal concrete and concrete with polypropylene fibres. Water cooling regime provided least percentage of residual compressive strength while furnace cooling regime provided the highest percentage of residual compressive strength and air cooling regime provided medium percentage of residual compressive strength. In the view of above, it can be concluded that concrete with polypropylene fibre has better fire endurance characteristics up to 800°C when compared with normal concrete.

3.3 Split tensile strength

Residual split tensile strengths of both types of concrete cubes (i.e., with and without polypropylene fibres) were measured after exposing them to designated elevated temperatures, soaking them at the rated temperature for one hour and subjecting them to different cooling regimes. Table 9 presents the consolidated residual split tensile strength test results. These results are presented in the graphical form in Fig. 8. The decrease in split tensile strength of normal concrete with increasing temperature can be attributed to weak microstructure of normal concrete allowing initiation of micro cracks.

At temperature range 20°C-400°C the split tensile strength of concrete was observed to decrease gradually, it was observed that the relative residual split tensile strength of furnace cooled and air cooled specimen does not change significantly. On the other hand, in the same temperature range, the strength of quenched specimen loses about 40% of its initial strength due to the thermal shock experienced during cooling process. Above 400°C, the split tensile strength of normal concrete decreases at a rapid rate due to a more pronounced thermal damage in the form of micro cracks. At 600°C residual split tensile strengths of normal concrete specimen are 36%, 33% and 19% of its initial strength (2.18 MPa) for furnace cooling, air cooling and sudden quenching respectively and at 800°C residual split tensile strengths of normal concrete specimen are 20%, 16% and 06% of its initial strength for furnace cooling, air cooling and sudden quenching respectively. On the other

Table 9 Consolidated split tensile test results

Temperature exposed to (°C)	Furnace cooling		Air cooling		Water cooling	
	without pp	with pp	without pp	with pp	without pp	with pp
Ambient	1.00	1.00	1.00	1.00	1.00	1.00
200	0.99	0.91	0.94	0.83	0.76	0.63
400	0.95	0.87	0.89	0.76	0.61	0.52
600	0.36	0.47	0.33	0.33	0.19	0.22
800	0.20	0.22	0.16	0.18	0.06	0.12

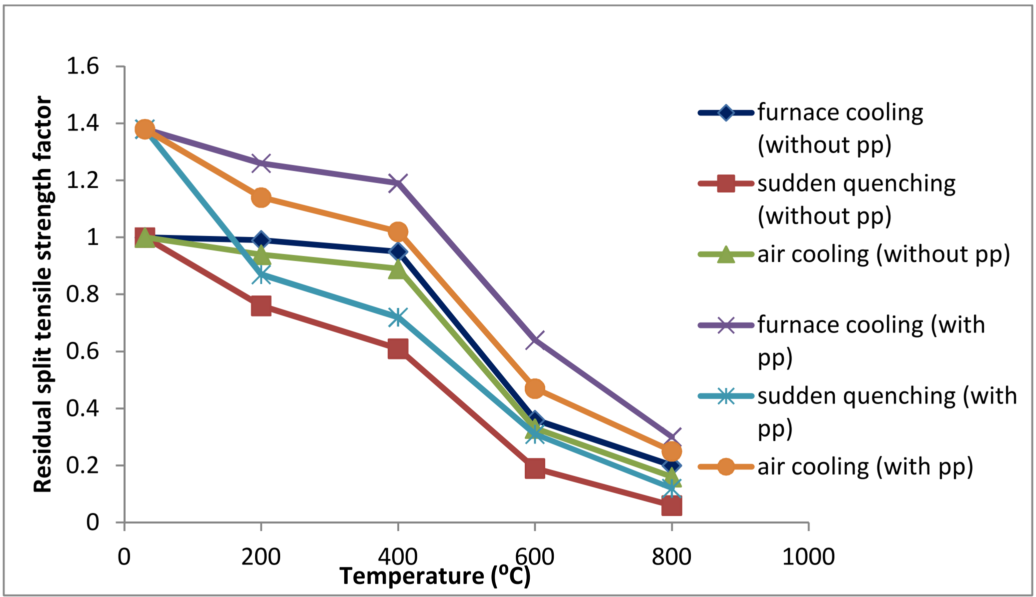

Fig. 8 Residual split tensile strength factor of concrete with and without polypropylene fibres

hand, at 600°C residual split tensile strengths of concrete with polypropylene fibres specimen are 47%, 33% and 22% of its initial strength (3.02 MPa) for furnace cooling, air cooling and sudden quenching respectively and at 800°C residual split tensile strengths of concrete specimen with polypropylene fibres are 22%, 18% and 14% for furnace cooling, air cooling and sudden quenching respectively. Water cooling regime provided least percentage of residual split tensile strength while furnace cooling regime provided the highest percentage of residual split tensile strength and air cooling regime provided medium percentage of residual split tensile strength.

4. Conclusions

(1) Weight loss of concrete increases with increase in temperature, water cooling regime gave least percentage of weight loss while furnace cooling regime gave the highest percentage of weight loss.

(2) Relative residual compressive strengths of normal concrete and concrete with polypropylene fibres have not shown significant loss in strength up to 400°C.

(3) However, at high temperatures (600°C and 800°C), there is a very steep drop in compressive strength for both types of concretes.

(4) Furnace cooling regime provided the least damage to the concrete after exposure to elevated temperatures while water cooling regime was the worst of the studied cooling regimes, as far as strength retention was considered.

(5) Residual compressive strength of concrete with polypropylene fibres is 82% of initial strength of concrete at 600°C for one hour retention period in furnace cooling. On other hand at same temperature and retention period, residual compressive strength of normal concrete is 67% of initial strength of concrete in furnace cooling, i.e., concrete with polypropylene fibers have shown better temperature endurance results.

(6) Residual split tensile strength of concrete with polypropylene fibres is 47% of initial strength of concrete at 600°C for one hour retention period in furnace cooling. On other hand at same temperature and retention period, residual split tensile strength of normal concrete is 36% of initial strength of concrete in furnace cooling.

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