Effect of Elevated Temperature And Sudden Cooling on Strength Properties of Hybrid Fibre Reinforced Concrete

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Abstract- *Concrete is the most widely used man made construction material in the world. It is obtained by mixing cement materials, water and aggregates, and sometimes admixtures in required proportions. The mixture when placed informs and allowed to cure hardens in to a rock – like mass known as concrete. The hardening is caused by chemical reaction between water and cement and continues for a long time, and consequently the concrete grows stronger with age. Steel fiber is an alloy of iron and carbon. The most important properties of steel are great formability and durability, good tensile and yield strength and good thermal conductivity. As well as these important properties the most characteristic of the stainless steel properties is its resistance to corrosion. Because of its high tensile strength and low cost, it is a major component of structural and non-structural element. Steel fiber-reinforced concrete is basically a cheaper and easier to use form of rebar reinforced concrete. Polypropylene fibers are composed of crystalline and non-crystalline regions. The spherules developed from a nucleus can range in size from fractions of a micrometer to centimeters in diameter. The degree of crystalline of PP fiber is generally between 50-65%, depending on processing conditions. Crystallization occurs between glass transition temperature and the equilibrium melting point. The crystallization rate of polypropylene is fast at low temperature. 0.3% Polypropylene Fiber with 1.5% Steel Fiber (G3) gives 32% increase in compressive strength which is 55N/mm2 of this newly modified concrete in comparison with conventional concrete of M35 grade which is optimum amongst other combinations within 28 Days. 0.3% Polypropylene Fiber with 1.5%Steel Fiber (G3) gives increases in Tensile strengthwhichis5.45N/mm2 within28 Days alternatively. 0.3% Polypropylene Fiber with 1.5% Steel Fiber (G3) gives increases in Flexural strength which is 6.44N/mm^2 within 28 Days alternatively. Percentage increase in Steel Fiber results in decrease of strength parameters i.e .combination having 0.5%,1.0%,1.5%,2.0%and2.5%ofSteel Fiber gives less increase in results for this mix proportion.*

Keywords- Steel Fiber, Polypropylene Fiber, Compressive strength, Tensile Strength, Flexural Strength, Specific gravity, Concrete, Cement.

I. INTRODUCTION

Concrete, typically composed of gravel, sand, water and Portland cement, is an extremely versatile building material that is used extensively worldwide. Reinforced concrete is very strong and can be cast in nearly any desired shape. Unfortunately, significant environmental problem results from the manufacture of Portland cement. Worldwide, the manufacture of Portland cement accounts for 6-7% of the total carbon dioxide produced by humans. Cement is a very commonly used construction material. Concrete made with this cement has certain characteristics. It is relatively strong in compression but weak in tension and tends to be brittle. Because of the load and environmental changes, a micro crack appears in cement products. Therefore cement based materials have low tensile strength and cause brittle failure. Cement mortar and concrete made with cement is a kind of most commonly used construction material in the world. These materials have inherently brittle nature and have some dramatic disadvantages such as poor deformability and weak crack resistance in the practical usage. Also their tensile strength and flexural strength is relatively low compared to their compressive strength. The weakness in tension can be overcome by the use of sufficient volume fraction of certain fibers. In order to improve the mechanical properties of concrete it is good to mix cement with fiber which have good tensile strength. Adding fibers to concrete greatly increases the toughness of the material. The use of fibers also alters the behavior of the fiber matrix composite after it has cracked, thereby improving its toughness.

MATERIALS USED

Following materials are used for studying the mechanical properties of Concrete for this study use agricultural waste, eco-friendly material. Materials to be used are as follows:

Polypropylene Fiber

The most commonly used synthetic material Polypropylene fiber has been chosen due to its low cost and hydrophobic and chemically inert nature which does not absorb or react with soil moisture. The high melting point of 160^{o}C, low thermal and electrical conductivities, and high ignition point of 590^{o}C are other properties. Polypropylene fibers are composed of crystalline and non-crystalline regions. The spherules developed from a nucleus can range in size from fractions of a micrometer to centimeters in diameter. The degree of crystalline of PP fiber is generally between 50-65%, depending on processing conditions. Crystallization occurs between glass transition temperature and the equilibrium melting point. The crystallization rate of polypropylene is fast at low temperature. It is reported that the crystallization rate decreases with increasing crystallization temperatures and also decreases with the increase of molecular weight. The crystalline structure with only 45% crystalline resulting from immediate quenching after extrusion was observed. The higher crystalline of 62% was achieved when quenching further downstream of the die. Polypropylene fibers are composed of crystalline and non-crystalline regions. The spherules developed from a nucleus can range in size from fractions of a micrometer to centimeters in diameter. The degree of crystalline of PP fiber is generally between50-65%, depending on processing conditions. Crystallization occurs between glass transition temperature and the equilibrium melting point. The crystallization rate of polypropylene is fast at low temperature. It is reported that the crystallization rate decreases with increasing crystallization temperatures and also decreases with the increase of molecular weight. The crystalline structure with only 45% crystalline resulting from immediate quenching after extrusion was observed. The higher crystalline of 62% was achieved when quenching further downstream of the die.

Physical properties of Polypropylene fiber

S. No.	Physical parameter	Standard range
1	Tensile strength (gf/den)	3.5 to 5.5
2	Elongation (%)	40 to 100
3	Abrasion resistance	Good
4	Moisture absorption (%)	0 to 0.05
5	Softening point (ºC)	140
6	Melting point (ºC)	165
7	Chemical resistance	Generally excellent
8	Relative density	0.91
9	Thermal conductivity	6.0 (with air as 1.0)
10	Electric insulation	Excellent
11	Resistance to mildew, moth	Excellent
12	Specific gravity (gm/cm^3)	0.90 to 0.91
13	Water absorption (%)	0.3 After 24 hrs.

Steel Fibre

Steel fibre is an alloy of iron and carbon. The most important properties of steel are great formability and durability, good tensile and yield strength and good thermal conductivity. As well as these important properties the most characteristic of the stainless steel properties is its resistance to corrosion. Because of its high tensile strength and low cost, it is a major component of structural and non-structural element. Steel fiber-reinforced concrete is basically a cheaper and easier to use form of rebar reinforced concrete. Rebar reinforced concrete uses steel bars that are laid within the liquid cement, which requires a great deal of preparation work but make for a much stronger concrete. Steel fiber-reinforced concrete uses thin steel wires mixed in with the cement. This imparts the concrete with greater structural strength, reduces cracking and helps protect against extreme cold. Steel fiber is often used in conjunction with rebar or one of the other fiber types. Fibres are generally classified according to their length, diameter and aspect ratio. For reinforced concrete different types of steel fibres can be used like straight, hooked ended, corrugated, microfibres, twisted etc. Straight steel fibres are pieces of steel wire from 0.3 to 1.1 mm in diameter and 15 to 50 mm in length of straight cross section. Hooked end steel fibre is manufactured by quality base steel bar, which has excellent mechanical properties including high tensile strength as compare to conventional steel fibres. Corrugated steel fibres are zig-zag in shape which enhances interfacial bond strength due to corrugation. Crimped or twisted steel fibre are low carbon, cold drawn steel fibres designed to provide concrete with temperature and shrinkage crack control, enhanced flexural reinforcement, improved shear strength and increase the crack resistance of concrete

Properties of Steel Fibre Reinforced Concrete

Normal concrete is brittle and frangible, while fibre reinforced concrete has priority over the normal concrete because of its higher strength and its capacity to prevent frangibility. There are following properties of SFRC: -

- Good impact strength
- Good ductility
- High load bearing capacity after being cracked
- Good tensile, bending and shear strength

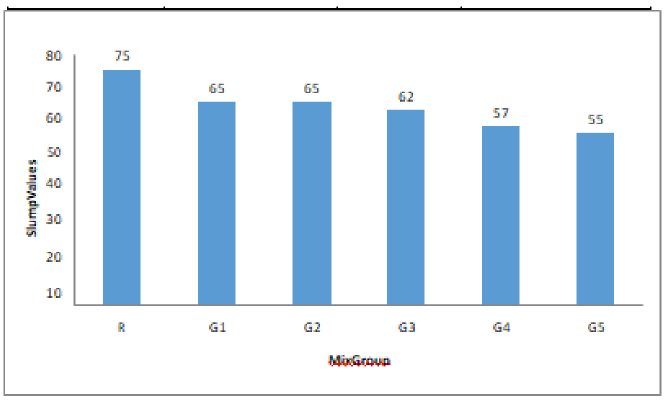
II. EXPERIMENTALRESULTS

Workability

The consistency of addition of polypropylene fibre and steel fibre in concrete mix group has been determined using the slump test (**IS: 1199-1959)**. For HFRC mix at addition percentage of 0.3% of polypropylene and 0.5%to2.5% of steel fibre and test were performed. It is observed that with the addition of fibre content into the concrete mix caused the decrease in the slump value. The workability will be increased with the decrease the slump value during mixing and casting. However, some difficulty will occure during finishing and casting of hybrid fibre reinforced concrete mix thus it was not easy to compact.

Slump Values of Concrete Mix

Mix Group	Addition percentage of polypropylene(%)	Replacementof RHA	Slump(mm)
R	0.0	0.0	75
G1	0.3	0.5	65
G2	0.3	1.0	65
G3	0.3	1.5	62
G4	0.3	2.0	57
G5	0.3	2.5	55



Variation of Slump Value

Compressive Strength (Optimization of Fibre Content)

The compressive strength of concrete is of greater importance as compared to other strength properties, as concrete can be considered as one of the strongest building material that is used more often in compression. The compressive strength testing was carried out for different mix group of hybrid fibre reinforced concrete at 28 days as per **IS: 516-1959**. Figure 21 represents the relation between the Concrete mixes and compressive strength. Mix R represents the reference mix. Mix G1 is the concrete reinforced with 0.3% PP and 0.5% SF, mixG2contains 0.3%PP and1.0 % SF, mixG3contains 0.3% PP and 1.5% SF, mix G4contains 0.3% PP and % SF and mix G5contains 0.3% PP and 2.5% SF.

Compressive Strength of Concrete Mix

Mixgroups	Polypropylene fibre(%)	Steel fibre(%)	Compressivestrengthat28days (n/mm2)
R	0	0	50
G1	0.3	0.5	50
G2	0.3	1.0	52
G3	0.3	1.5	55
G4	0.3	2.0	50
G5	0.3	2.5	45

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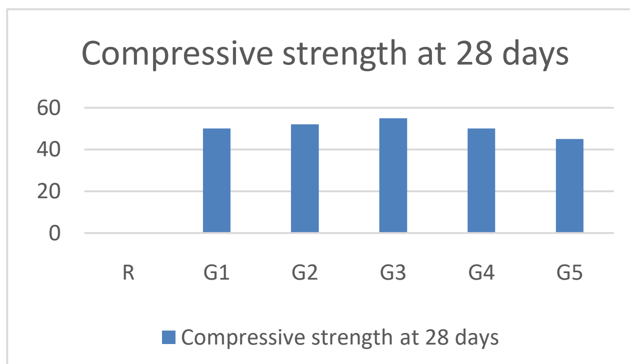


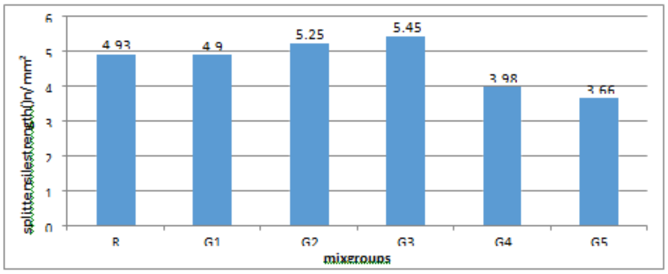
Split Tensile Strength

The split tensile strength of concrete is one of the basic and important properties. Splitting tensile strength test on concrete cylinder specimen (100×200mm) is a method to determine the tensile strength of concrete. Concrete being a weak material in tension due to its brittle nature does not resist the direct tension. Test results of split tensile strength test at the age of 28 days.

These values are graphically presented in Fig 22 , which shows the variation in split tensile strength of plain concrete and hybrid fibre reinforced concrete. Concrete made with 0.3% PP and 1.5% SF (i.e. mix G3) showed maximum split tensile strength among all other concrete samples.

Split Tensile Strength of HFRC

Mix groups	Polypropylene fibre(%)	Steel fibre(%)	Split tensile strength(n/mm 2)
R	0	0	4.93
G1	0.3	0.5	4.90
G2	0.3	1.0	5.25
G3	0.3	1.5	5.45
G4	0.3	2.0	3.98
G5	0.3	2.5	3.66



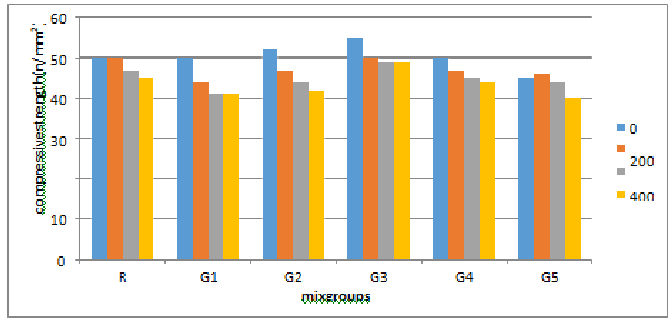
Compressive Strength

As mentioned before, the change of mechanical properties of concrete subjected to high temperature is influenced by many factors. Generally, an increase in exposed temperature causes concrete to gradually lose its mechanical strength. After the curing period of 28 days the specimens of size 100 mm×100mm were heated for 30 minutes and 1 hour at each temperature.

The residual compressive strengths of various HFRC mixes subjected to different elevated temperatures of 200, 400 and 600˚C and suddenly cooled by quenching in water are given below in table no 17 and18.

Residual Compressive Strength of Mixesafter30Minutes Exposure

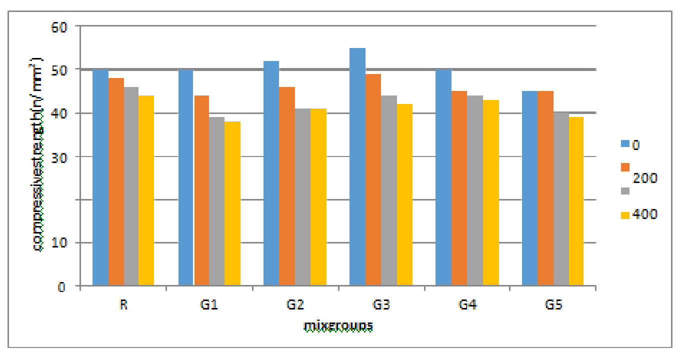
Mix group	Polypropylene(%)	Steel fibre (%)	Compressive strength before heating (n/mm^2)	Residual Compressive strengths of specimens for 30 min heating period		
				200˚ C	400˚ C	600˚ C
R	0	0	50	50	47	45
G1	0.3	0.5	50	44	41	41
G2	0.3	1.0	52	47	44	42
G3	0.3	1.5	55	50	49	49
G4	0.3	2.0	50	47	45	44
G5	0.3	2.5	45	46	44	40



Residual Compressive Strengths of Mixes after Heating Period of 30Minutes

Residual Compressive Strength of Mixes after 1 Hour Exposure

Mix group	Polypropylene(%)	Steel fibre (%)	Compressive strength before heating (n/mm^2)	Residual Compressive strengths of specimens for 1 hour heating period		
				200˚ C	400˚ C	600˚ C
R	0	0	50	48	46	44
G1	0.3	0.5	50	44	39	38
G2	0.3	1.0	52	46	41	41
G3	0.3	1.5	55	49	44	42
G4	0.3	2.0	50	45	44	43
G5	0.3	2.5	45	45	40	39



Residual Compressive Strengths of Mixes after Heating Period of1Hour

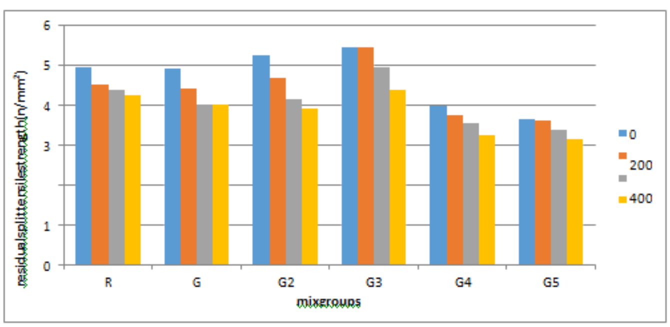
Residual Split Tensile Strength

The residual split tensile strengths of six types of concrete mixes subjected to different elevated temperatures of 200,400 and 600˚C and suddenly cooled by quenching in water are given below in table no 17. The specimens were heated in the furnaceat its maximum temperature level for30 minutes and1 hour separately.

it is observed that the result pattern obtained in residual split tensile strength is quite similar to the residual compressive strength. The residual split tensile strength of cubes exposed to ambient temperature is 4.93n/mm^2 and drops gradually to4.5, 4.38 and 4.25 at elevated temperatures of 200, 400 and 600˚C in the case of reference mix which was heated for 30 minutes at maximum temperature level and thermally shocked by water cooling. Similar pattern of residual split tensile strength is observed when fibres are reinforced in the concrete mix but as the fibre percent increases residual split tensile strength also increases up to mix G3 after then it decreases gradually.

Residual Split Tensile Strength of mixes after 30 minutes' exposure

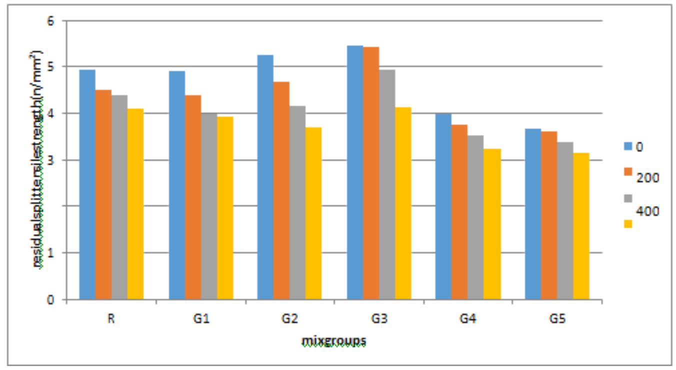
Mix group	Polypropylene(%)	Steel fibre (%)	Split tensile strength before heating (n/mm^2)	Residual split tensile strength of specimen after 30 min heating period (n/mm^2)		
				200˚C	400˚C	600˚C
R	0	0	4.93	4.5	4.38	4.25
G1	0.3	0.5	4.90	4.4	4	4
G2	0.3	1.0	5.25	4.68	4.16	3.9
G3	0.3	1.5	5.45	5.43	4.95	4.38
G4	0.3	2.0	3.98	3.75	3.54	3.25
G4	0.3	2.5	3.66	3.6	3.37	3.15



Residual Split Tensile Strengths after 30 Minutes Exposure

Residual Split Tensile Strength of Mixesafter1 Hour Exposure

Mix group	Polypropylene(%)	Steel fibre (%)	Split tensile strength before heating (n/mm^2)	Residual split tensile strength of specimen after 1-hour heating period (n/mm^2)		
				200˚C	400˚C	600˚C
R	0	0	4.93	4.5	4.38	4.10
G1	0.3	0.5	4.90	4.4	4	3.93
G2	0.3	1.0	5.25	4.68	4.16	3.7
G3	0.3	1.5	5.45	5.43	4.95	4.12
G4	0.3	2.0	3.98	3.75	3.54	3.25
G4	0.3	2.5	3.66	3.6	3.37	3.15

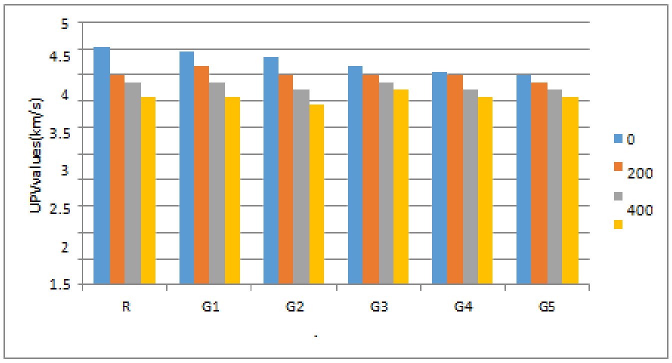


Residual Split Tensile Strengths of Mixes After Heating Period of 1Hour

Effect of Heating and Cooling Regime on Physical Conditions (NDT) UPV measurements were carried out before concrete cubes of size 100×100 mm were going to be heated and after cooling in water as per **IS 13311.1.1992**. The ultrasonic pulse is generated by an electro acoustical transducer. When the pulse is induced into the concrete from a transducer, it undergoes multiple reflections at the boundaries of different material phases within the concrete. A complex system of stress wave is developed which includes longitudinal (compressional), shear (transverse) and surface(Rayleigh) waves. The receiving transducer detects the onset of the longitudinal waves, which is the fastest.

NDT Results

Mix group	UPV(km/s) values at different Temperatures (˚C)			
	0˚C	200˚C	400˚C	600˚C
R	4.54	4.0	3.85	3.57
G1	4.46	4.16	3.85	3.57
G2	4.34	4.0	3.70	3.44
G3	4.16	4.0	3.85	3.70
G4	4.04	4.0	3.70	3.58
G5	4.00	3.86	3.70	3.57
Condition of concrete	excellent	good	good	good



UPV Measurements on Specimens

The result of ultrasonic pulse velocity test shown in table 21, Figure indicates that addition of polypropylene and steel fibre have negative effect on the ultrasonic pulse velocity of hybrid fibre reinforced sample. The reduction in ultrasonic pulse velocity could be due to the inclusion of a lower density ingredient polypropylene(910kg/m^3).

UPV measurements carried out on heated concrete cubes shows a reduction of velocity from 4.54 km/s to 3.44 km/s with the increase in temperature from 0˚C to 600˚C which shows an acceptable and consequent gradual degree of deterioration in the quality of concrete. This reduction in UPV could be due to the micro pathways which may be generated due to melting of polypropylene fibre.

II. CONCLUSIONS

1) Workability

- Test result shows that as the fibre content increases slump decreases, addition of PP fibre slightly increases internal particle friction which results in reduction of slump value. Rather the decrease of slump still lies in the range of 50-75mm.
- It can be concluded that HFRC require slightly more quantity of chemical admixture to make it workable enough.

2) Compressive Strength

- As the percentage of fibre content increases, the compressive strength of specimens also increases upto some extent. Mix reinforced with 0.3%PP and 1.5% SF has the optimum value of compressive strength. Afterward the compressive strength decreases gradually.

3) Split Tensile Strength

- As the percentage of fibre content increases the split tensile strength of specimens also increases upto some extent. Mix reinforced with 0.3%PP and 1.5% SF has the optimum value of split tensile strength. Afterward the compressive strength decreases gradually.

Residual Compressive Strength

4) For Heating Period of 30Minutes

- As the temperature level increases the residual compressive strength decreases.
- Addition of fiber has the positive effect on residual compressive strength. Mix G_3 reinforced with (0.3% PP+ 1.5% SF) show the optimum value.
- There is no significant difference between the residual compressive strength of the specimens heated in the temperature range of 400˚C and600˚C.
- Explosive spalling doesn't occur in any specimen at any temperature level.

5) For The Heating Period of 1Hour

- Heating duration of 1 hour also reflects almost similar results as compared to 30 minutes heating.
- Some hair line cracks and edge spalling were observed when the specimens are heated at maximum temperature level of 600˚C for 1hour.

6) Residual Split Tensile Strength

- As the temperature increases the residual compressive strength decreases for both the heating period of 30 minutes and 1hour.
- HFRC mix G_3 reinforced with 0.3% PP and 1.5% SF shows the maximum value of residual split tensile strength.

7) Non Destructive Testing

- UPV measurements carried out on heated concrete cubes show reduction of velocity from 4.54 km/s to 3.44 km/s with the increase in temperature from 0˚C to600˚C.
- The reduction in the pulse velocity in HFRC mixes that contained PP and FF was significantly

higher than normal concrete mix for all additional ratios.

8) Weight Analysis

- As per the prediction, the total percentage of weight loss of the specimen increases as the exposure temperature increases.
- The average range of variation is 0.3% to 4.3% for the temperature range from 200 to 600˚C when the specimens are heated for 30 minutes and 2.1% to 5% when the specimens are heated for 1hour.
- From the figure 31 and 32 it is clear that duration of heating has a significant impact on weight of concrete.

9) Surface Characteristics

- The visual inspection of the surface of specimens after subjecting to high temperature and thermally shocked cooling regime show no visible cracking or spalling on the samples in the 200-400˚C temperature range. Only a small amount of spalling and hair line cracks at 600˚C were observed on some specimens.
- A light pinkish color was observed when the specimens were heated at 600˚C at its maximum temperature level for 30 minutes and 1hour.

REFERENCES

[1] Bingol A. Farhat and GulRustem, "Effect of elevated temperatures and cooling regimes on normal strength concrete", Journal of fire and materials, Vol. 33, Issue 2, March2009, pp. 79-88.

[2] LuaXin, Sun Wei, Chan Yin Nin Sammy, "Effect of heating and cooling regimes on residual strength and microstructure of normal strength and high performance concrete", Journal of cement and concrete research, Vol. 30, Issue 3, march2000,pp.379-383.

[3] UsyalMucteba, YilmazKemalettin, IpekMetin, "Properties and behaviour of self- compacting concrete produced with GBFS and FA additives subjected to high temperatures", construction and building materials, Vol. 28, Issue 1, march2012, pp.321-326.

[4] S. DeepaShri, Thenmozhi R., Anitha M., "Mechanical properties of SCC with polypropylene fibres", international journal of advanced scientific research and technology, Vol. 3, Issue 2, june2012, pp.2249-9954.

[5] MashhadbanHadi, KutanaeiSamanSoleimani, Sayarinejad Ali Mohammad, "Prediction and modelling of mechanical properties in fibre reinforced concrete using particle swarm optimization algorithm and artificial neural network", journal of construction and building materials, Vol. 119, Issue 30, august2016, pp.277-287.

[6] Tao Jin, Youn Yong, Taerwe Luc, "Compressive strength of self-compacting concrete during high temperature exposure", journal of materials in civil engineering Vol. 22, Issue 10, March2016,pp.1005-1011.

[7] PengGai-Fei , Song-HuaBian,Zhan-QiGuo, Zhao Jie, Xin-LaiPeng, Yu-ChuangJiang, "Effect of thermal shock due to rapid cooling on residual mechanical properties of fibre concrete exposed to high temperatures", journal of materials in civil engineering Vol. 22, Issue 5, may2008,pp.948-955.

[8] Yao Wu,JieLi,WuKeru, "Mechanical properties of hybrid fibre-reinforced concrete at low fibre volume fraction", journal of cement concrete and research, Vol. 33, Issue 1, Jan2003, pp. 27-30.

[9] Handoo S.K., Agarwal S., Agarwal S.K., "Physicochemical, mineralogical, and morphological characteristics of concrete exposed to elevated temperature",journal of cement and concrete research, Vol. 32, Issue 7, july2012, pp.1009-1018.

[10] Yaragal C. Subhash, Babu Narayan S K and Adari S, "Strength Characteristics of Concrete Exposed to Elevated Temperatures and Cooled Under Different Regimes", journal of structural fire engineering Vol. 3, Issue 4, 2012, pp.301-310.

[11] Khoury Alexander Gabriel, "Effect of fire on concrete and concrete structure", Jhonswiley library, Vol. 2, Issue 4, december2000, pp.429-447.

[12] Qian C.X. and Stroeven P., "Development of hybrid polypropylene-steel fibre-reinforced concrete" Cement and concrete research" Vol. 23, Issue 1, january2000, pp.63-69.

[13] Lie T.T. and Kodur V.K.R., "Thermal and mechanical properties of steel fibre reinforced concrete at elevated temperature", Canadian journal of civil engineering, Vol. 23, Issue 3, april1996, pp.511-517.

[14] Song P.S. and Hwang S., "Mechanical properties of high strength steel fibre reinforced concrete", Construction and building materials, Vol. 18, Issue 9, november2004, pp.669-673.

[15] YuzurNabi, AkozFevziye, LeylaDokuzerOzturk, "Compressive strength–color change relation in mortars at high temperature", Cement and concrete research, Vol. 34, Issue 10, october2004, pp.1803-1807.