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RESEARCH ARTICLE

A Study on Fire Resistance Property of HSC Using Silica fume and Metakaolin with Polypropylene fiber.

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Abstract

Concrete is a composite material made of cement, coarse aggregate, and fine aggregate and water. Recently High Strength Concrete (HSC) is being widely used in many applications. Concrete having compressive strength more than 60MPa is termed as HSC. It can be achieved by increasing the cement content and reducing water content by the addition of super plasticizers. HSC are brittle in nature and they are ready for plastic shrinkage in earlier stage. In order to reduce the brittleness and shrinkage effect fibers are used in HSC. Incorporation of polypropylene fiber in High Strength Concrete (HSC), reduced the spalling and cracking. This was achieved via melting and consequently, creating added escape routes for vapour pressure. In this work an attempt has been made to study the effect of exposure to elevated temperature upon high strength fiber reinforced concrete. The percentage of fiber considered for this investigations are 0.2%, 0.4% of volume of concrete mix at 100 ^{0}C, 200^{0} C, 300^{0} C, 400^{0} C for sustained duration of 24hrs of exposure. The tests have been carried out as per recommended procedures of relevant codes and previous investigations. The results are compared and conclusions are made.

Introduction:-

Concrete is a composite construction material composed primarily of cement, sand, coarse aggregate and water. Concrete is characterized as a brittle material with low tensile strength and strain capacity. Concrete is strong in compression, as the aggregate efficiently carries the compression load. However, it is weak in tension as the cement holding the aggregate in place can crack, allowing the structure to fail. This type of problems can be overcome by the addition of metallic and nonmetallic fibers. Such fibers improves the mechanical properties of concrete. Recently, the construction industry has shown more interest in the use of High Strength Concrete (HSC). This is due to the improvements in structural performance, such as high strength and durability, while comparing the HSC with normal strength concrete (NSC), the size of the members can be reduced in HSC and it will increase the working place. HSC is widely used in various applications such as high rise buildings, bridges, off-shore structures and infrastructure projects. One of the major use of HSC in buildings is for structural framing consisting of beams and columns, which are the primary load-bearing components, and hence, the provision of appropriate fire safety measures is a main safety requirement in building design. With the increased use of HSC, there is a special need to focus the behavior of HSC under fire exposure. The main advantage of FRC is to arrest the major and minor crack and to increase the ductility of concrete

A. High strength of concrete:-

In many countries, high strength concrete has become popular in recent years. High strength concrete is undergoing widespread use in civil engineering and construction processes today. A remarkable development in HSC is invention of two major admixtures (i.e.,) super plasticizer, silica fume, metakaolin. The benefits of HSC are increased strength, smaller dimensions and lower volumes which would see its immediate application into design. Same time it has some disadvantages like weak in fire resistance compared to NSC and suddenly failure under fire exposure conditions.

B. **Fire resistance of high strength concrete:-**

Concrete withstand fine up to certain level of temperature. When concrete is exposed to fire there is reduction in strength. NSC losses 10-20% of its strength when heated to 300^0C and 60-75% at 600^0C. For HSC, there is more reduction in strength up to 40% at 450^0C. In buildings, HSC structural members have to be designed to satisfy the requirements of safety and serviceability limit. One of the major safety requirements in building design is the provision of appropriate fire safety measures for structural members. The fire safety measures for structural members are measured by means of fire resistance. Generally, fire resistance is defined as the ability of a structural element to maintain its load bearing function under fire conditions. It is the time, during which a structural member exhibits resistance with respect to structural integrity, stability and temperature transmission.

C. **Effect of fibers in concrete:-**

Fiber has become a practical alternative construction material. It can be used internally to improve the flexural strength. Fibers are usually used in concrete to control cracking due to both plastic shrinkage and drying shrinkage. They also reduce the permeability of concrete and thus reduce seepage. Some types of fibers produce greater impact, abrasion resistance in concrete. Generally addition of fiber increase the flexural strength of concrete up to certain limit.

D. **Effect on silica fume in concrete:-**

Silica fume is a very effective pozzolanic material with extreme fineness and high silica content. Standard specifications for silica fume used in cementitious mixtures. Silica fume is added to Portland cement concrete to improve its properties, in particular its compressive strength, bond strength and abrasion resistance. It reduces the permeability of concrete, which products the reinforcing steel of concrete from corrosion. Silica fume is having greater fineness than cement, so the consistency increases.

E. **Effect on metakaolin in concrete:-**

Metakaolin can be used as highly effective Pozzolanic Admixture to provide high compressive strengths. Its Reduce permeability of Concrete, since the additional cementitious products formed increase the density of the cement paste, increases chemical resistance. Its Reduces efflorescence, drying shrinkage by allowing the use of less cement while developing improved properties.

Materials and Methods:-

Material used:-

Cement:-

Cement is the most important constituent of concrete, in that it forms the binding medium for the discrete ingredients made out of naturally occurring raw materials and sometimes blended with industrial wastes. The quantity required for this work was assessed and the entire quantity was purchased and stored properly in casting yard. The cement used in this experimental investigation is 53 grade OPC conforming to IS 12269: 1987.

Fine aggregate:-

Fine aggregate used in this investigation is clean river sand without impurities like clay, shell and organic matters. It is passing through 4.75mm sieve. The fine aggregate were tested, as per Indian Specifications IS 383-1970. The fine aggregate used in this investigation was clean river sand and conforming Zone II.

Coarse aggregate:-

The material retained on 4.75mm sieve is termed as coarse aggregate. Crushed stone and natural gravel are the common materials used as coarse aggregate for concrete. Well graded angular aggregate is use and the maximum size of aggregate is 20 mm. the coarse aggregate were tested as per Indian Specifications IS 383-1970.

Micro Silica:-

Cement was replaced partially by micro silica which is an artificial pozzolanic admixture. It is a by-product in the production of silicon and ferrosilicon alloys. Microsilica is very fine approximately 100 times smaller than the average cement particle and it has large surface area. The mean particle size is between 0.1 and 0.2 micron. Since it is very small in size it can easily fill up the voids in the concrete. Comparing to other admixtures like fly ash, micro silica is more reactive. The addition of silica fume act as a pozzolanic material of high strength concrete.

Table 1 properties of silica fume

Colour	Grey
pH	8
Fineness	Passing through 45microns 94%
Moisture content	Less than 1%
Specific surface	20sq.cm/gm
Bulk density	630kg/m3
Specific gravity	2.5

Metakaolin:-

The mineral admixture metakaolin a byproduct of clay mineral kaolinite. stone that are rich in kaolinite are known as china clay or kaolin. **Table 2 shows the properties of metakaolin.**

Table 2.properties of metakolin

Density	2.17
Colour	Off-white
Particle shape	Spherical
Specific gravity	2.1

Water:-

The water, as per IS 456:2000, was used for making concrete specimen. It was free from suspended matter and organic materials.

Super plasticizer:-

In order to improve the workability of concrete, super plasticizer (GLENIUM B233) in form of modified poly carboxylic ether was used. Super plasticizer of 1.0% of weight of cement was added with the concrete. Super plasticizer of glenium B233 is used in concrete to obtain.

Polypropylene fibre:-

Polypropylene Fibre used in this study has a tensile strength of 500 N/mm^2 and density is 0.91 g/cc. **The properties are tabulated in table 3.**

Fibre Properties	**Polypropylene**
Length (mm)	20
Shape	Straight
Size/Diameter(mm)	0.3
Aspect Ratio	67
Tensile strength (MPa)	500
Melting Point	465^{0}C

The mix design of M60 grade concrete is calculated using IS 456-2000 and IS 10262-2009. The material required as per design are given in Table:4

Table 4. Materials required as per is method of design

W/c ratio	**Quantity of Materials (kg/m^3)**		
	Cement	***Fine aggregate***	***Coarse aggregate***
0.3	618	473.6	1155.94

The properties of materials used are

- Specific gravity of cement = 3.15
- Specific gravity of fine aggregate = 2.62
- Specific gravity of coarse aggregate = 2.82

Experimental program:-

A. Ultrasonic pulse velocity (UPV) method:-

UPV method was used to establish the uniformity of the concrete. It involves the measurement of the time of travel of electrically generated mechanical pulses through the concrete.

Figure.1 Ultrasonic Non-destructive Digital-Indicating Test on concrete cubes

Ultrasonic Pulse Velocity method consists of measuring the time of travel of an ultrasonic pulse, passing through the concrete to be tested. The quality of concrete could be assessed by conducting UPV test, **as per IS 13311(Part 1):1992 as shown in table. 5**

Sl. No	Pulse Velocity (km/sec)	Concrete Quality
1	Above 4.0	Excellent
2	3.5 to 4.0	Good
3	3.0 to 3.5	Medium
4	Below 3.0	Doubtful

B. Compressive strength:-

Compressive strength test is the most common test conducted on hardened concrete. Cube specimens of size 150mm x 150mm x 150mm were cast for finding the compressive strength after curing for 28 days. Then the specimen was placed between the jaws of compression testing machine of 2000kN capacity. Compressive load was given till the specimen failed.

C. Split tensile strength:-

Split Tensile Strength was used to determine the tensile strength of concrete. Cylindrical specimens of size 150 mm diameter and 300 mm height were used in this test. For each mix 3 specimens were cast and cured for 28days. The failure load was recorded and the splitting tensile strength was computed.

D. Flexural strength:-

Prism specimens of size 100 mm x 100 mm x 500 mm were used in this test. The beam to be tested was placed in the loading frame of capacity 500 KN under two point loading at one third points and the test setup is shown in Fig2. The end condition of the beam was kept simply supported.

Figure 2. The Compressive strength, Split tensile strength and Flexural strength test set up

Results and discussion:-

The test results of ultrasonic pulse velocity, compressive strength, split tensile strength and flexural strength for control specimen and specimens of various fibre combinations under different temperatures are discussed as below.

A. Weight loss

Weight loss of the cube specimens were (150 x 150 x 150mm) determined before and after exposure **to tabulated in table 6**

Table 6. Weight of specimens (kg)

Specimen	Weight of specimens at normal and Elevated Temperatures (kg)				
	Normal temp (29^0 c)	100^0C	200^0C	300^0C	400^0C
Control specimen	8.70	8.61	8.50	8.37	8.30
Polypropylene-(0.2%)	8.70	8.65	8.61	8.55	8.52
Polypropylene-(0.4%)	8.75	8.70	8.63	8.54	8.42

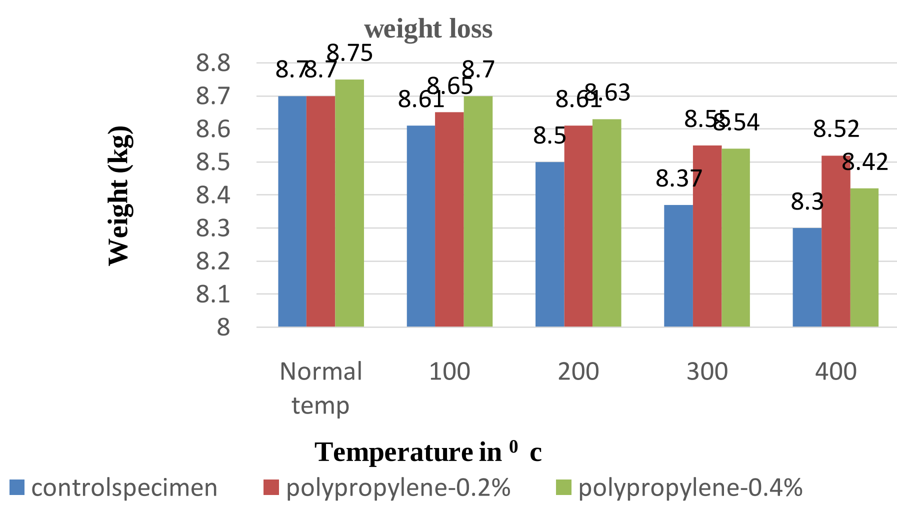
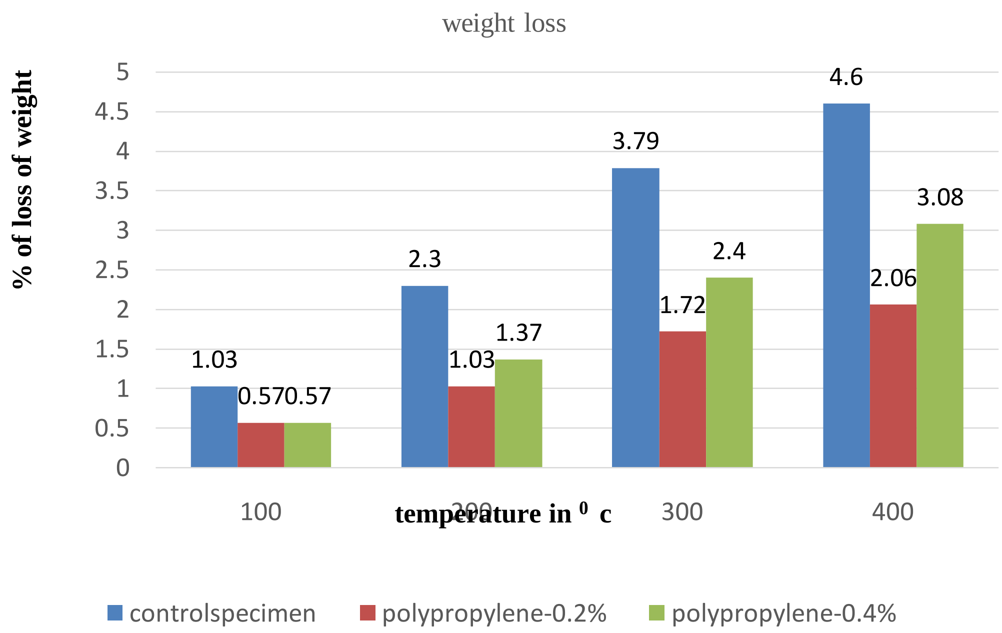


Table 7. Loss in weight (%)

Specimen	Loss in weight (%)			
	100^0C	**200^0C**	**300^0C**	**400^0C**
Control specimen	(1.03% loss)	(2.3% loss)	(3.79% loss)	(4.60% loss)
Polypropylene-(0.2%)	(0.57% loss)	(1.03% loss)	(1.72% loss)	(2.06% loss)
Polypropylene-(0.4%)	(0.57% loss)	(1.37% loss)	(2.4% loss)	(3.08% loss)

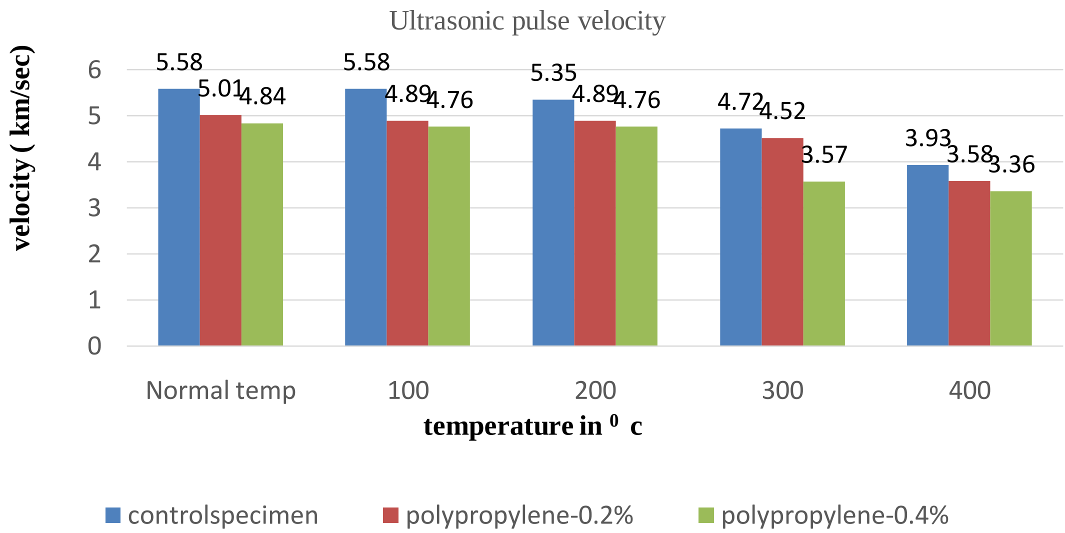


Ultrasonic pulse velocity:-

The homogeneity of the specimen was determined using Portable Ultrasonic Nondestructive Digital-Indicating Tester, **The various results observed are tabulated in table 8.**

Table 8.upv test reslts

Specimens	Velocity (km/s)	Quality
CN	5.58	Excellent
C100	5.58	Excellent
C200	5.35	Excellent
C300	4.72	Excellent
C400	3.93	Good
P_1N	5.01	Excellent
$P_1$100	4.89	Excellent
$P_1$200	4.89	Excellent
$P_1$300	4.52	Excellent
$P_1$400	3.58	Good
P_2N	4.84	Excellent
$P_2$100	4.76	Excellent
$P_2$200	4.76	Excellent
$P_2$300	3.57	Good
$P_2$400	3.36	Medium



Compressive Strength:-

Cube specimens of size 150mm x 150mm x 150mm were cast for finding the compressive strength after curing for 28 days. Then the specimen was placed between the jaws of compression testing machine of 2000kN capacity. Compressive load was given till the specimen failed. **The various results observed are tabulated in table 9.**

Table 9. Compressive strength result

Specimens	Split tensile strength at Elevated Temperature (MPa)				
	Normal temp(29^0 c)	100 ^{0}C	200^{0}C	300^{0}C	400^{0}C
Control specimen	4.7	4.2	3.9	3.8	3.5
Polypropylene- (0.2%)	5.3	5.2	5.1	4.7	4.5
Polypropylene- (0.4%)	5.4	5.1	5.0	4.9	4.6

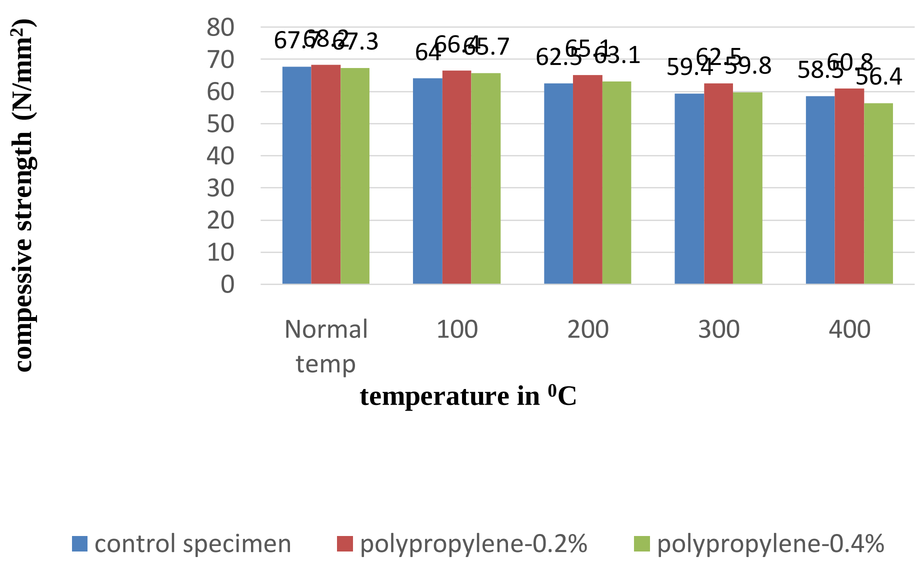
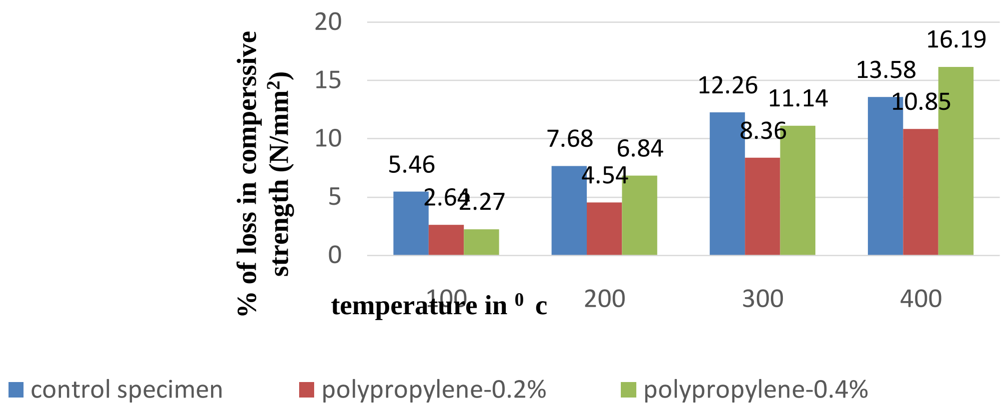


Table 10. Result showing the percentage loss in strength

Specimens	**% of loss in compressive strength(MPa)**			
	100^{0}C	**200^{0}C**	**300^{0}C**	**400^{0}C**
Control specimen	**(5.46% loss)**	**(7.68% loss)**	**(12.26% loss)**	**(13.58% loss)**
Polypropylene-(0.2%)	**(2.64% loss)**	**(4.54.% loss)**	**(8.36% loss)**	**(10.85% loss)**
Polypropylene-(0.4%)	**(2.27% loss)**	**(6.84% loss)**	**(11.14% loss)**	**(16.19% loss)**



D. Split tensile strength test:-

Cylindrical specimens of size 150 mm diameter and 300 mm height were used in this test. Tensile strength test was carried out in a 2000kN capacity of the compression testing machine in which the specimens were placed in such a way that its axis was horizontal to the platens of the testing machine, figure shows the testing of cylinder in compression testing.

Table.11 Split Tensile strength

Specimens	**Compressive strength at Elevated Temperature (Mpa)**				
	Normal temp (29^0 c)	**100^{0}C**	**200^{0}C**	**300^{0}C**	**400^{0}C**
Control specimen	67.70	64	62.5	59.4	58.5
Polypropylene- (0.2%)	68.2	66.4	65.1	62.5	60.8
Polypropylene-(0.4%)	67.3	65.70	63.1	59.8	56.4

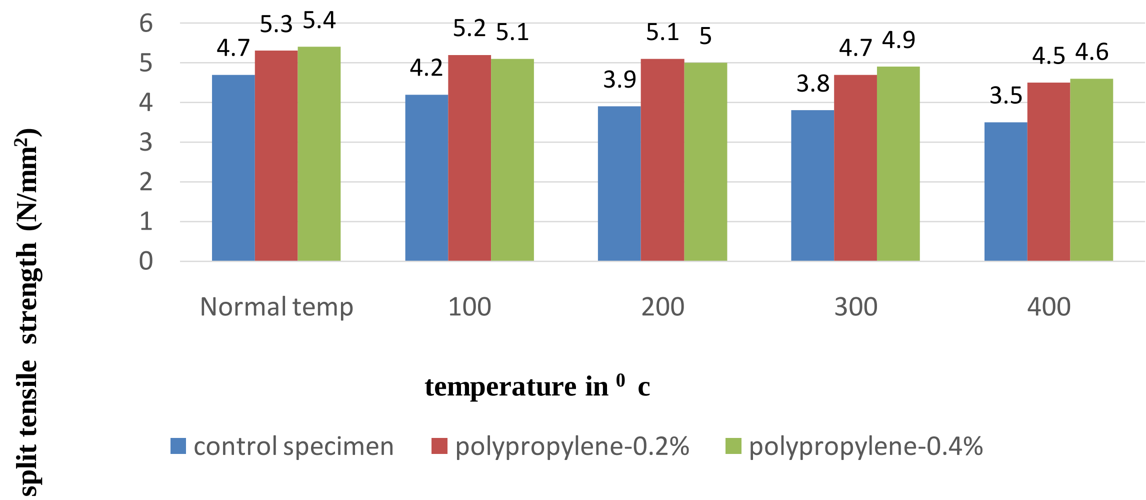
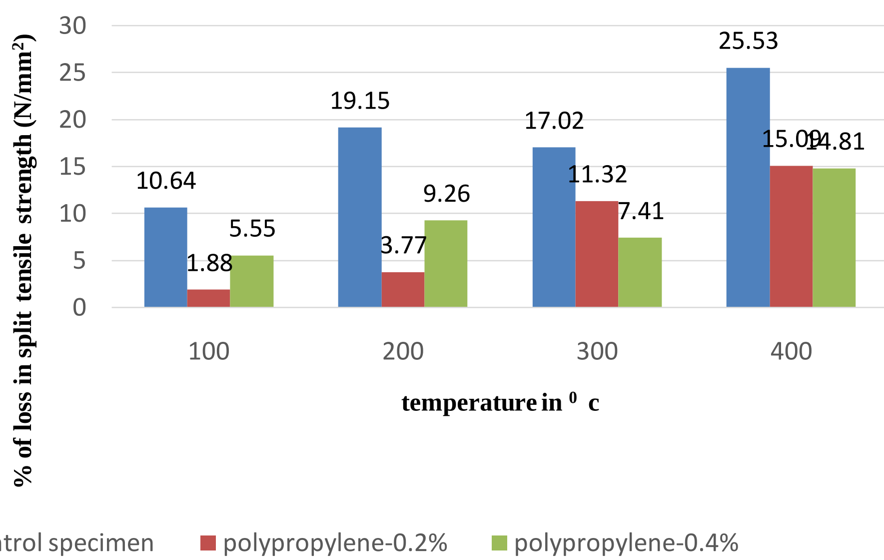


Table: 12 result showing the percentage loss in strength

Specimens	% of loss in tensile strength at elevated temperature (MPa)			
	100^0C	200^0C	300^0C	400^0C
Control specimen	(10.64% loss)	(19.15% loss)	(17.02% loss)	(25.53% loss)
Polypropylene-(0.2%)	(1.88% loss)	(3.77% loss)	(11.32% loss)	(15.09% loss)
Polypropylene-(0.4%)	(5.55% loss)	(9.26% loss)	(7.41% loss)	(14.81% loss)



E. Flexural strength test:-

Prism specimens of size 100 mm x 100 mm x 500 mm were used in this test. The beam to be tested was placed in the loading frame of capacity 500 KN under two point loading and the test setup is shown in figure. The specimen was placed perpendicular to normal axis on the platform of the flexural testing machine. The load was applied.

Table. 13 Flexural strength

Specimens	**Flexural strength at Elevated Temperature (MPa)**				
	Normal temp(29^0 c)	100^{0}C	**200^{0}C**	**300^{0}C**	**400^{0}C**
Control specimen	6.7	6.54	6.45	6.22	5.84
Polypropylene - (0.2%)	7.17	7.03	6.82	6.55	6.32
Polypropylene-(0.4%)	7.1	7.0	6.85	6.6	6.4

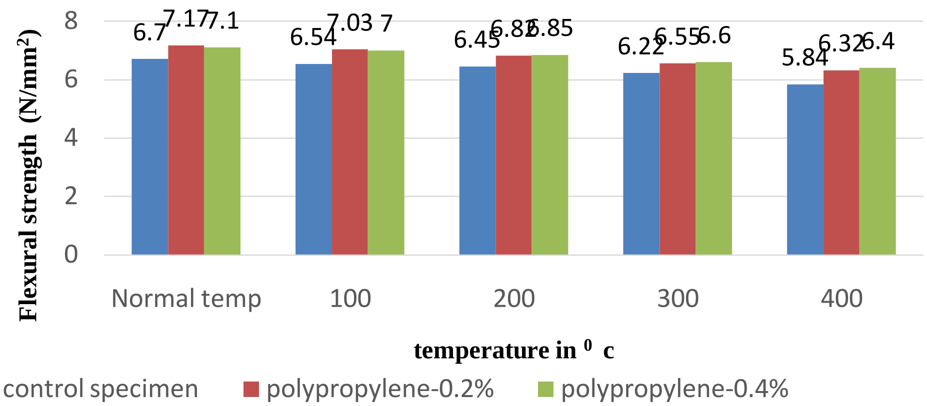
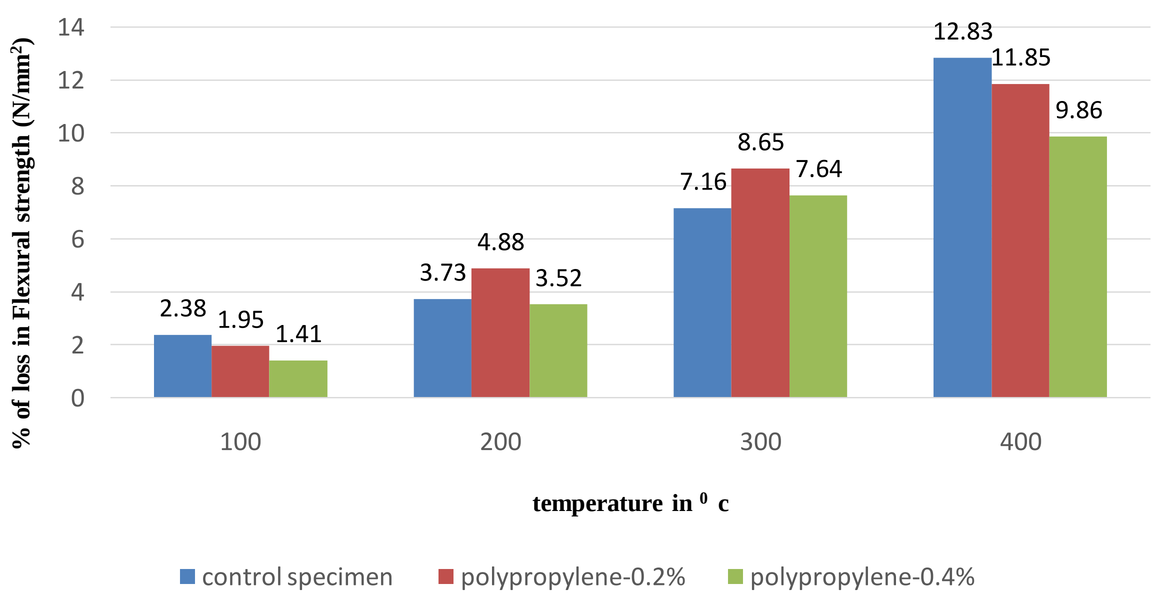


Table 14. Result showing the percentage loss in strength

Specimens	**% of loss in tensile strength at elevated temperatures (MPa)**			
	100^{0}C	**200^{0}C**	**300^{0}C**	**400^{0}C**
Control specimen	(2.38% loss)	(3.73% loss)	(7.16% loss)	(12.83% loss)
Polypropylene-(0.2%)	(1.95% loss)	(4.88% loss)	(8.65% loss)	(11.85% loss)
Polypropylene-(0.4%)	(1.41% loss)	(3.52% loss)	(7.64% loss)	(9.86% loss)



Conclusion:-

1. The results encourage the use of silica fume (10%), metakaolin (10%) as pozzolanic material for partial cement replacement in producing high strength concrete.
2. Addition of polypropylene fibre delay the formation of micro cracks and increases the strength of HSC.
3. The concrete used in this work are of excellent quality as the UPV result shows higher pulse velocity. So failure pattern of the cube, cylinder in general has dissipated that concrete with polypropylene fibre added, it improve the crack resistance
4. There is an appreciable increase in the compressive strength, split tensile strength and flexural strength in HSC when volume fraction of polypropylene increases from 0.2% to 0.4%.
5. It was found that there is a reduction in strength while exposing the concrete specimen at a temperature of 400^0C for 24 hour.
6. HSC has a weight loss than NSC in the temperature above 300^0 c

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