International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 7 Issue 1, January-February 2023 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Fire-Resistant Concrete using Sustainable Fibers

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ABSTRACT

Fire accidents are one of the frequently occurring disasters which can take place anywhere at any time without any warning. They can be fatal and inflict higher risks on human lives, properties and environment. In order to improve the resistance of structures against fire, fire safety should be considered from the preliminary stages of design and material selection. Concrete and structural steel are primary construction materials in world. Concrete is known to have good thermal resistance when compared to steel. If concrete is subject to elevated temperatures, the separation of concrete masses occur, giving rise to a phenomenon known as "spalling" which further leads to weakening of the cross sectional area of the concrete members thereby decreasing their resistance to service loads. In the present scenario where the pace of urbanization is at its peak, fire accidents in building is a crucial factor of consideration. During fire, safety of inhabitants and structural integrity are equally important and is ought to go hand-in-hand.. In such a situation use of fire resistant concrete can prove to be fruitful. This project investigates the effect of fire on polypropylene fiber and coconut husk fiber reinforced concrete. In the present era the use of fiber reinforced concrete is no more an innovation. But this project explores the effectiveness of sustainable fibers such as polypropylene fiber and natural coconut husk fiber on the fire resistance on concrete. The aim is to improve the problems of concrete spalling and deterioration by the addition of polypropylene fibers and natural coconut husk fibers in concrete. Several samples of fiber reinforced concrete cubes are casted by partial replacement of fine aggregate with these fibers and are tested for fire resistance and strength yield. These test results are compared with conventional concrete samples and inferences formed.

How to cite this paper: Rinisha PK | Bilsha Babu P | Basima Parveen TP "Fire-Resistant Concrete using Sustainable Fibers" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-7 | Issue-1, February 2023, pp.178-193, URL: www.ijtsrd.com/papers/ijtsrd52660.pdf

IJTSRD52660

KEYWORDS: *Polypropylene Fibers, Fire Resistance, Compressive Strength, Workability, Exposure*

1. INTRODUCTION

1.1. GENERAL

Concrete is known to have good thermal resistance when compared to steel. If concrete is subject to elevated temperatures, the separation of concrete masses occur, giving rise to a phenomenon known as "spalling" which further leads to weakening of the cross sectional area of the concrete members thereby decreasing their resistance to service loads. Reports from National Crime Records Bureau (NCRB) of the Union home ministry shows that over 1.13 lakhs of people have been killed across the country in the past three years(2013-2016). The cause-wise analysis of these accidents reveals that the maximum, 25% of these total accidents were reported in residential/dwelling units. The primary aim of this experiment is to reduce the failure of concrete structures by spalling during fire. Reinforced concrete structure tends to deteriorate by spalling at temperatures of 400ºC when subjected to a direct fire exposure for 1-2 hours. As much as the time delayed for the expansive collapse by the resistance of concrete structures against fire helps the occupants to safely vacate the dwellings. Several innovative fiber reinforced concrete designs are prevailing in the field of concrete technology using steel fibers, glass fibers etc. each of which exposes certain disadvantages, for example steel fibers, being heavy are ought to increase the dead weight of the structure. Similarly glass fibers have availability issues along with safety issues while handling. Burying all these disadvantages, this project presents a sustainable form of fiber reinforced concrete design using Polypropylene fibers and Coconut husk fibers.

1.2. SPALLING OF CONCRETE

The fire resistance of concrete is well appreciable, whether it is in material form or in structural form. This is due to the inherent properties in built in concrete. When concrete made of ordinary Portland cement is subjected to fire greater than 300 degrees Celsius, it will lose most of its important properties. This concrete will lose its structural performance for a temperature greater than 600 degrees Celsius. At elevated temperatures, concrete is subjected to spalling. Concrete spalling can be described as the breaking off of layers or pieces of concrete from the surface of a structural element when exposed to the high and rapidly increasing temperatures experienced in fire. Three different kinds of concrete spalling are:

➢ **Surfaces palling**

Small pieces of concrete, up to 20mm in size, are gradually and nonviolently dislodged from the surface during the early part of the fire. This is usually caused by the fracture of pieces of aggregate due to physical or chemical change at high temperatures. In the case of surface spalling (shown in fig.1.1), the degradation of the concrete is relatively slow and involves the dehydration of the cement matrix followed by the loss of bond between aggregate and matrix.

➢ **Corner break-off**

Also known as sloughing off, corner break-off occurs at the edges and corners of concrete elements during the latter stages of the fire when the concrete has cracked and weakened.

➢ **Explosive spalling**

Unquestionably the most serious and dangerous form of spalling that occurs during the first 20–30 minutes of a fire when the temperature in the concrete is in the range of 150-250°C. Explosive spalling (fig.2) occurs when there is a rapid temperature rise, such as in hydrocarbon fuelled fires following a traffic incident, where very large pieces of concrete can be violently ejected for several metres. After several decades of research, it is known that there is a complex combination of chemical, physical and thermodynamic factors that influence explosive spalling.

1.2.1. HOW FIBERS INHIBIT EXPLOSIVE SPALLING

➢ As the temperature in the microfiber reinforced concrete rises the Polypropylene fiber softens and begins to melt due to a progressive change of phase which starts at approximately 150°C when the crystallinity begins to break down into an amorphous polymer. It peaks at 160°C (the commonly quoted melting point), and is complete at approximately 165°C. It is this melting that is believed to facilitate the reduction in the internal stresses in the concrete that cause the explosive spalling. The fig.1.1shows the flowing out of vapour pressure through the melted Polypropylene fibers in case of fire.

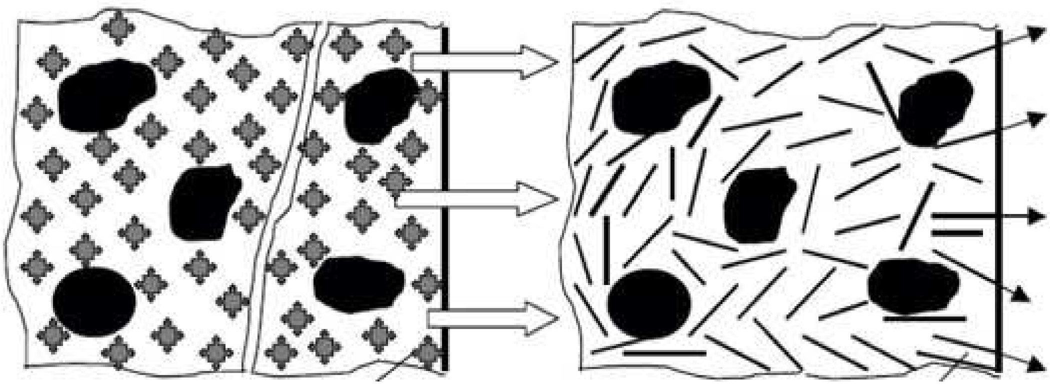

fig.1.1 Flowing out of vapour pressure

Heat penetrates the concrete resulting in desorption of moisture in outer layer. Moisture vapors flow back towards the cold interior and are reabsorbed into voids. Water and vapor accumulate in the interior thereby increasing the vapor pressure rapidly causing cracks and spallingin the concrete. In case of Polypropylene fiber reinforce concrete, the fibers melt at 160ºC creating voids in the concrete. The vapour pressure is released in newly formed voids and explosive spalling is significantly reduced. This prevents sudden collapse of the structure enabling the occupants to safely escape. The concrete samples reinforced with polypropylene fibers when subjected to fire shows considerable differences when compared with plain concrete samples is picturised in fig 1.2

Fig1.2 Comparison of plain concrete with fiber reinforced concrete

1.3. SUSTAINABLE FIBERS

Fiber-reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers – each of which lend varying properties to the concrete. In addition, the character of fiber-reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation, and densities. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers. Within these different fibers that character of fiber reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation and densities. Two important fibers which is widely used in fiber reinforced concrete design are steel fibers and glass fibers. Steel fiber reinforced concrete consist of Steel fiber technology which actually transforms a brittle material into a more ductile one. Catastrophic failure of concrete is virtually eliminated because the fibers continue supporting the load after cracking occurs. And while measured rates of improvement vary, Steel fiber reinforced concrete exhibits higher post-crack flexural strength, better crack resistance, improved fatigue strength, higher resistance to spalling, and higher first crack strength. But steel fibers tend to increase the unit weight of concrete by increasing the specific gravity of concrete. This means that the concrete will be heavier than normal concrete. Higher cost because of its control issues (production issues) as well as the cost of raw material is

Polypropylene fibers and coconut husk fibers exhibit sustainable solution for fiber reinforced concrete design. To be sustainable, a material must satisfy three aspects; economical, environmental and social as depicted in fig.1.3.1. Sustainability is achieved when projects achieve balance between environmental, social & economic issues. It creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations

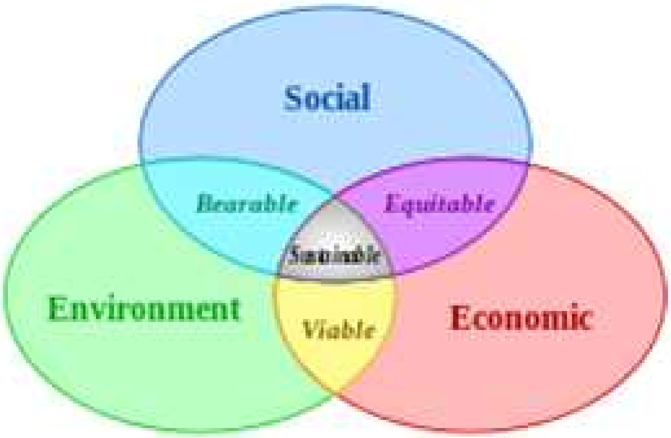

Fig.1.3.1 Concept of sustainability

For a fiber reinforced concrete design to be sustainable, the fibers employed should satisfy sustainability aspects. Polypropylene and coconut husk fibers provide cheap and best alternatives for glass fibers and steel fibers in fiber reinforced concrete design. Having a melting point of 160-165℃ polypropylene fibers are having negligible environmental impacts with no harmful fume emissions during burning. Having wide applications including packaging, textile industry, construction industry, medical applications etc. polypropylene is the world's second widely manufactured synthetic plastic after polyethylene. In Kerala the availability of coconut husk fiber is not at all a matter of consideration due to the abundance of coconut trees. Hence the use of polypropylene fibers as well as coconut husk fibers enable a sustainable means of fiber reinforced concrete design.

2. LITERATURE REVIEW

2.1 Dr. Jasira Bashir et al (2017) reported that fibers in the cementitious matrix tend to reinforce the composite under all modes of loading and the interaction between the fiber and matrix affects the performance of cement based fiber composite material in resisting fire. Polypropylene fiber reinforced concrete is made by replacing 0.5% fine aggregate by polypropylene fiber. Then these concrete elements are heated at different temperatures i.e. 300° and 800° by using annealing furnace. Then these concrete elements are tested for strength i.e. compressive strength, split tensile strength and flexural strength test are conducted on these samples. Polypropylene fiber reinforced concrete showed better fire resistance and have properties of handling severe temperatures. They offer better resistance towards spalling, thermal expansions and creep.

2.2 Dr. Anthony Nkem Ede et al(2015) experimented the use of coconut husk fiber in fiber reinforced concrete design. They were from Nigeria, hence they used coconut fiber since it was abundantly available in their country. They studied the effect of fire on coconut husk fiber reinforced concrete mix and found that, the coconut fiber reinforced specimen showed increased percentage of strength gain during strength tests than conventional concrete specimen. The coconut fibers tend to increase the bond between concrete masses retreating it from separating off and undergoing deterioration due to the process of "spalling".

2.3 AmitRai and Ramcharantheja (2014) reported that the weakness in tension of concrete can be overcome to some extent by mixing a sufficient volume of certain fibers. He also reported that the plain concrete fails suddenly when deflection corresponding to ultimate flexural strength is exceeded, but fiber reinforced concrete continue to sustain considerable loads. He used steel fiber reinforced concrete, glass fiber reinforced concrete, polymer fiber reinforced concrete and natural fiber reinforced concrete. Some examples of natural fibers are coir, jute etc. The specification for concrete aggregates were that water should be clean and of good quality. The length of fibers may vary from 1 to 2 inch. Typical values of diameter for unprocessed natural fibers may vary from 0.004inch to 0.03 inch. He also used some synthetic fibers like polyesters, polypropylene etc. Polypropylene is the most widely used in ready mix concrete. They are hydrophobic, so don't absorb water and have no effect on concrete mixing water requirements. Results obtained shows increased compressive strength for polypropylene.

2.4 Dr. Bhupendra Kumar (2015) studied the effects of coconut fiber and fly ash on the compressive strength properties of concrete. It was reported that addition of coconut fiber enhanced the compressive strength of concrete. As per their investigations and reports, compressive strength of concrete significantly increased at 20% fly ash with 1.5% coconut fiber and at 10% fly ash and 2% coconut fiber. The methodology adopted by them includes mix design as per IS1062-2009. The experiments like slump test for concrete and compressive strength tests were performed. Results obtained for M40 grade of concrete shows increased compressive strength and workability for fly ash and coconut fiber added concrete other than conventional concrete.

2.5 Dr. CH Madhavi and Priti A Patel (2014) analyzed the effect of polypropylene fiber in the properties of concrete. It is reported that with the addition of these fibers the entrapped air voids increases, and also it has greater impact on the compressive strength of concrete. Test results showed that the compressive strength increased by the addition and polypropylene fiber. The fibers embedded in concrete affect the stress and strain enhancing the stress redistribution and reducing strain localization. The addition of polypropylene fibers to plain concrete reduces the crack width to an extend of 21% to 74%.

2.6 DR Darshan et al (2015) studied the concrete fire resistance improvement techniques by means of fiber addition. Concrete itself gives comprehensive fire protection for that the better one is the Portland cement which is better than most alternative materials. The concrete is non-combustible and a reasonable insulator in which it protect the embedded steel for as long as possible against a rise in temperature. The paper investigates conventional and new requirements of fire resistant buildings, the suitable materials to be used and the precautions in building construction, providing fire alarm system and fire extinguishers. It also gives us the design considerations of the fire resistant buildings, the load and design equations etc.

2.7 Dr. Rossi and Dr. James Thomas (1987) studied the application of different types of fibers together in a concrete mixture where each fiber type would have a different function in the control of crack growth. They investigated the mechanical action of steel fibers during the micro and macro cracking stages of concrete and recommended use of steel fibers. Fiber reinforced concrete containing several volume fractions of polypropylene and steel fiber were tested under different fire loads and the authors observed that the fracture and impact energy during fire was less in polypropylene fiber reinforced concrete other than conventional concrete samples.

3. METHODOLOGY

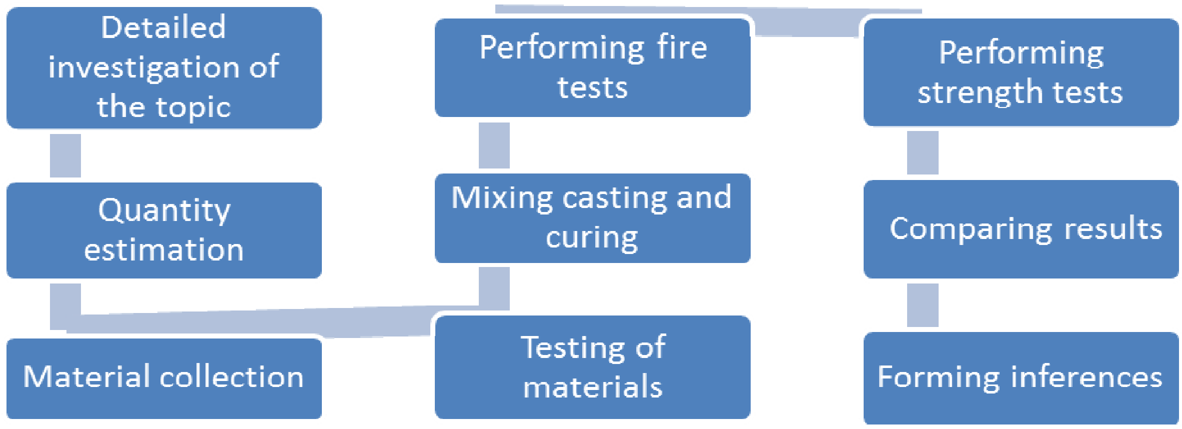

Fig.3.1 Methodology of the experiment

4. PRELIMINARY TESTS AND RESULTS

Material that are used for making concrete for this study were tested before casting the specimens. The preliminary tests were conducted for the following materials.

4.1. Cement

A. Fineness

The fineness is of cement is measured by sieving it through a standard sieve. The proportion of cement, the grain sizes of which, is larger than the specified mesh size is thus determined.

Aim:
Determination of fineness of cement

Apparatus:
IS sieve 90 micron, weighing balance, trowel, tray, bristle brush etc…

Procedure:
1. Weigh accurately 100g of cement and place it in standard IS 90 micron sieve
2. Breakdown the lumps with fingers, but do not rub on the sieve
3. Sieve the sample continuously for 15 min by holding the sieve in both hands and giving a gentle wrist motion. Mechanical sieve shaker may also be used
4. Weigh the residue left after 15 min sieving. This residue shall not exceed the specific limit.

Observations and Calculations:

Observation	1	2	3
Weight of cement (w)g	100	100	100
Weight of cement retained in size (w1)g	2	1	0
% weight retained (w1/w)*100	2	1	0

Table.4.1 Fineness of Cement

Mean = (2+1)/2 =1.5%

Result:
Fineness of cement by dry sieving =1.5%

Inference:
Since the fineness of cement is less than 10%, it is good quality ordinary Portland cement.

B. Consistency

The standard consistency of a cement paste is defined as that consistency which will permit the Vicat plunger to penetrate to a point 5 to 7 mm from the bottom of the Vicatmould. The consistency test is generally carried out using a Vicat apparatus (fig.7). The Initial and Final Setting time of cement can also be determined using vicat apparatus.

Vicat Apparatus comes complete with:
- Initial-set needle, 1.0 mm dia
- Consistency plunger 10 mm dia
- Vicatmould 60/70 dia. X 40mm

Determination of consistency of cement

Aim:

To find out the percentage of water required to produce a cement paste of standard consistency.

Apparatus:

Vicat apparatus with plunger, Vicat needle, mould, measuring jar, weighing balance, stop watch, glass plate

Procedure:
1. Take about 300g of cement and break air set lumps of cement, if any by hand.
2. Add about 28% of clean water by weight of cement and mix it thoroughly.
3. Start stop watch when water is added to the dry cement and prepare a cement paste such that the gauging time is not less than 3 minute and not greater than 5 minutes.
4. Place the mould up on the glass plate and fill the mould with prepared paste
5. After filling, level the surface of the mould with trowel. Shake the mould slightly to expel air
6. Place the mould with glass plate under the plunger
7. Lower the plunger gently to touch the surface of the test block and quickly release it. Note the settlement of plunger
8. Prepare the paste with varying percentage of water until the penetration is between 5-7 mm from the bottom of the mould
9. Express this amount of water as a percentage by weight of dry cement

Observation and calculations:

SL. No	Percentage weight of water	Quantity of water (ml)	Plunger reading from bottom
1	28	84	24
2	30	90	14
3	32	96	7

Table.4.2 consistency of cement

Result:

Percentage of water for standard consistency = 32%

C. Specific Gravity of cement

In concrete technology, specific gravity of cement is made use of in design calculations of concrete mixes,and it also used to calculate its specific surface. The specific gravity is defined as the ratio between the weight of given volume of cement to the weight of an equal volume of water. The most popular method of determining specific gravity of cement is by the use of kerosene which doesn't react with cement.

Apparatus:

Specific gravity bottle, balance

Procedure:
1. Weigh a clean dry specific gravity bottle with its stopper (W1)
2. Place the sample of cement up to half of the flask and weigh with its stopper(W2)
3. Add kerosene to cement in the flask till it is about half fill
4. Mix thoroughly with glass rod to remove entrapper air. Continue stirring and add more kerosenetill it is flush with the graduated mark
5. Dry the outside and weigh (W3)
6. Empty the flask, clean it and refill with clean kerosene till it flush with the graduated mark
7. Dry the outside and weigh (W4)
8. Empty the flask, clean it and refill with water flush with the graduated mark
9. Dry outside and weigh (W5)

Calculations:
Specific gravity of cement with respect to kerosene
=(W2-W1)/[(W4-W1)-(W3-W2)]
(56-24.4)/[(44.6-24.4)/(67.4-56.6)]

Specific gravity of kerosene =W4/W5
= 44.6/50.2 =0.889……………….2

Specific gravity of cement= 1*2
= 3.54*0.889
= 3.15

Result:
Specific gravity of cement: 3.15

D. Initial and Final Setting Time of Cement

As soon as water is added to cement, hydration of cement starts which results in changing the water cement mix from fluid to solid. Initial setting time is that time period between the times at which water is added to cement paste, placed in the Vicatmould 5mm to 7mm from the bottom of mould. Final setting time is that time period between the time water is added to cement and the time at which needle with plunger with annular collar attachment fails to make an impression on the surface of cement paste.

Aim:
To determine initial and final setting time of cement

Apparatus:
Vicats apparatus with plunger, needle and mould, measuring jar, weighing balance, stop watch, glass plate etc

Procedure:
1. Weigh 300g of cement and place it in a bowl
2. Add 0.85 times the water required for standard consistency and mix it thou roughly
3. Start the stopwatch at the instant when water is added to the cement
4. Fill the vicat'smould with cement paste prepared. Gauging time should not be less than 3 minutes and more than 5 minutes
5. Place the mould on the glass under the needle of apparatus
6. Lower the needle gently till it comes contact with the surface of the test block and quickly release, allowing it to penetrate the test block and note penetration after every 2 minutes
7. Repeat the procedure until the needle fails to pierce the sample for 5 mm, measured from the bottom of mould. Stop the stopwatch and note the time, which is the initial setting time of cement.
8. Replace the needle by the needle with annular attatchment
9. Bring the needle attatchment near the surface of cement and replace it
10. Repeat the process until the needle makes an impression on surface while attatchment fails to do so
11. Note the time and is reffered as final setting time

Result:
Initial setting time: 2 hours 31 minutes
Final setting time: 4 hours 13 minutes

4.2. Fine Aggregates

A. Water Content determination

Weight Of Container	22g	23g	23g
Weight Of Container +Wet Sand	52g	42g	40g
Weight Of Container + Dry Sand	51g	41g	39g
Water	1g	1g	1g
Water Content	3%	5%	6.2%
Average			4.73%

Table.4.3 water content

B. Water Absorption

Weight Of Container	20g	20g	20g
Container + Wet Sand	60g	60g	60g
Container + Dry Sand	57.5g	58.5g	51.7g
Water	2.5g	1.5g	8.3g
Water Content	6.6%	3.8%	26.18%
Average			12.19%

Table 4.4 water absorption

C. Sieve Analysis

Total weight offine aggregates: 2kg

Fineness modulus=Σcumulative % retained/100 =275.5/100=2.75

IS Sieve	Weight Retained(G)	Percentage Weight Retained	Cumulative Percentage Retained	Cumulative Percentage Passing
4.75mm	60	3	3	97
2.36mm	80	4	7	93
1.18mm	330	16.5	23.5	76.5
600 Micron	470	23.5	47	53
300 Micron	970	48.5	95.5	4.5
150 Micron	80	4	99.5	.5
			∑=275.5	
Grading Zone Of Fine Aggregate Is-Zone III				

Table.4.5 sieve analysis of fine aggregate

Effective size D10=.28

Uniformity coefficient=D60/D10=. 55/.28 =1.964

Sand is in zone III

D. Physical Properties of Aggregates

Sl. No.	Particulars	Loose (Kg)	Compact (Kg)
1	Weight Of Container W1 (Kg)	3.49	3.49
2	Weight Of Container +Compacted Aggregate W2(Kg)		8.450
3	Weight Of Container +Compacted Aggregate +Water W3(Kg)		9.450
4	Weight Of Container +Loose Aggregate W4(Kg)	8.280	
5	Weight Of Container+ Loose Aggregate + Water W5 (Kg)	9.460	
6	Weight Of Container + Water W6 (Kg)	6.440	6.440
7	Bulk Density For Loose = W4-W1/W6-W1 For Compact = W2-W1/W6-W1	1.601	1.653
8	Void Ratio For Loose= W5-W4/(W6-W1)-(W5-W4) For Compact= W3-W2/(W6-W1)-(W3-W2)	0.666	0.5128
9	Porosity For Loose= W5-W4/W6-W1 For Compact= W3-W2/W6-W1	0.4	0.3389
10	Specific Gravity For Loose = W4-W1/(W6-W1)-(W5-W4) For Compact = W2-W1/(W6-W1)-(W3-W2)	2.7062	2.5435 2.543

Table.4.6 Test For Physical Properties Of Fine Aggregates

E. Bulking Of Sand

Volume of dry sand = 200 ml
Weight of sand= 300g
Submerged Volume =V0=200 ml

Sl. No	Water Content (%)	Volume Of Water Added	Sand Volume(V)	Percentage Bulking (V-V0/V0)*100
1	2%	6	253	26.5
2	4%	12	252	26
3	6%	18	251	25.5
4	8%	24	248	24
5	10%	30	245	22.5
6	12%	36	240	20

Table 4.7 bulking of sand

Water content = 4.2%

4.3. Coarse Aggregates

A. Moisture Content

Weight of container	14g
Weight of container + wet aggregate	64g
Weight of aggregate + dry aggregate	64g
Water	0
Water content	0

Table.4.8 water content

B. Water Absorption

Weight of container	27g
Weight of container + wet aggregate	77g
Weight of container + dry aggregate	77g
Water content	0

Table.4.9 water absorption

C. Impact Value

Weight of container=0.778 kg
Weight of container + coarse aggregate = 1.098 kg
Weight of container + weight retained on 2.36 mm sieve =1.018 kg

Observation	Sample
Total Weight Of Dry Sample W1 G	320
Weight Of Portion Passing 2.36 Mm Sieve W2 G	80
Aggregate Impact Value =(W2/W1)*100	25

Table.4.10 Impact test

D. Sieve Analysis of Coarse Aggregate

Fineness modulus of coarse aggregate represent average size of particles in coarse aggregate calculated by performing sieve analysis with standard sieves. Fineness modulus is the number at which the average size of particle is known when we count from low order sieve size to high order sieve size.

IS sieve	Weight retained(kg)	Percentage weight retained	Cumulative percentage retained	Cumulative percentage passing
80 mm	0	0	0	100
40mm	0	0	0	100
20 mm	1.67	55.67	55.67	44.33
10 mm	1.320	44	99.67	0.33
4.75mm	0	0	99.67	0.33
2.36mm	0	0	99.67	0.33
1.18mm	0	0	99.67	0.33
600 micron	0	0	99.67	0.33
300 micron	0.004	0.133	99.803	0.197
150 micron	0.006	0.2	100	0

Table.4.11 sieve analysis of coarse aggregates

Total weight of coarse aggregates = 3 kg

Sieve analysis of coarse aggregate

Fineness modulus= Σ cumulative % retained /100

= ∑w /100=753.823/100 = 7.53

Effective size D10 = 15 mm

Uniformity coefficient = D60/D10 =23/15=1.533

E. Physical Properties of Coarse Aggregates

Sl. No.	Particulars	Loose (Kg)	Compact (Kg)
1	Weight Of Container W1 (Kg)	3.490	3.490
2	Weight Of Container +Compacted Aggregate W2(Kg)		8.4
3	Weight Of Container +Compacted Aggregate +Water W3(Kg)		8.460
4	Weight Of Container +Loose Aggregate W4(Kg)	7.770	
5	Weight Of Container+ Loose Aggregate + Water W5 (Kg)	9.250	
6	Weight Of Container + Water W6 (Kg)	6.440	6.440
7	Bulk Density For Loose = W4-W1/W6-W1 For Compact = W2-W1/W6-W1	1.451	1.664
8	Void Ratio For Loose= W5-W4/(W6-W1)-(W5-W4) For Compact= W3-W2/(W6-W1)-(W3-W2)	1.007	0.021
9	Porosity For Loose= W5-W4/W6-W1 For Compact= W3-W2/W6-W1	0.502	0.0203
10	Specific Gravity For Loose = W4-W1/(W6-W1)-(W5-W4) For Compact = W2-W1/(W6-W1)-(W3-W2)	2.912	1.698

Table.4.12 Test For Physical Properties Of Coarse Aggregates

5. MIX DESIGN

Mix design is the process of selecting suitable ingredient of concrete and determines their relative proportions with the objective of certain minimum strength and durability as economical as possible. The procedure for mix design of M25 concrete is as follows:

➢ **Step 1: Determination of target strength**

Ftarget = fck+1.55 X S

= 25+1.65 X 4 = 31.6 N/mm²

➢ **Step 2: Selection of water/cement ratio**

From table IS: 456, maximum water cement ratio for mild exposure condition =0.55

(w/c ratio adopted =0.5 ; 0.5,0.55, hence OK

➢ **Step 3:Select of water content**

From Table 2 of IS 10262:2009, maximum water content=186 L

Estimated water content for 100 mm slump= 186+(3/100)186=191.58L

➢ **Step 4: Selection of cement content**

w/c ratio=0.5 and cement content=191.58/0.5=383.16 kg/m³

From Table 5 of S 10262-2009,for nominal mix, maximum size of aggregate =20mm & w/c ratio=0.5

Volume of coarse aggregate per unit volume of total aggregate =0.6

Volume of fine aggregate content per unit volume of total aggregate=0.4

➢ **Step 5:Estimation of the mix ingredients**

- Volume of concrete = 1m³
- Volume of cement =(mass of cement/specific gravity of cement) x (1/1000) = 0.12163m³
- Volume of water= (mass of water/specific gravity of water) x (1/1000) = 0.19158m³
- Volume of total aggregate = 1-(0.1216+0.19158) = 0.6868 m³
- Mass of coarse aggregate= volume of total aggregate(0.6868 m³) x volume of coarse aggregate x specific gravity of coarse aggregate x 1000
- =0.6868 x 0.6 x 2.65 x 1000 = 1092.012 kg
- Mass of fine aggregate= volume of total aggregate x volume of fine aggregate x specific gravity of fine aggregate x 1000 = 728.008 kg

Hence total mass of ingredients required for casting 45 cubes assuming a wastage of 25% is as follows;

- Size of each cube = 150x150x150 mm
- Total volume of concrete required = (150x150x150)x45
- **= 0.151875 m³**
- Total quantity of cement = 383.16 x 0.02109 = **8.08 kg**
- Total quantity of water= 191.58 x 0.02109 = **4.04 kg**
- Total quantity of coarse aggregate = 1092.012 x 0.0210 =**22.93 kg**
- Total quantity of fine aggregate=728.008 x 0.0210=**15.288 kg**
- Polypropylene fibers= 0.5% of fine aggregate = **0.0764 kg**
- Coconut husk fiber = 0.5% of fine aggregate = **0.0764 kg**

6. MATERIAL CHARACTERISATION

6.1. Cement

Cement is fine, granular material that forms a paste when water is added to them. This paste hardens and encapsulates aggregates and reinforcement steel. Immediately water is added, cement paste begins to harden through a chemical process called hydration. Hydration takes place at different rates according to the different properties of binders and admixtures that are used, the water to cement ratio and the environmental condition under which the concrete is placed. The way in which the binder affect the concrete, mortar and similar product can vary with the chemical and physical properties of the source materials, the mix design, and to lesser extent, the variation in the cement manufacturing process**.** There are different types of cement but Portland cement is the binder used most widely. Although Portland cement is named after an area in England where its use was originated, today it is manufactured all over the world. ASTM international defines Portland cement as hydraulic cement (cement that forms as water resistant products) produced by pulverizing clinkers consisting of hydraulic calcium silicates usually containing one or more of the form of calciumsulphates as an inter ground addition

6.2. Fine aggregates

"Fine aggregates" is defined as material that will pass through 4.75mm IS sieve and will, be retained on 75 micron IS sieve. For increased workability and economy as reflected by the use of less cement, the fine aggregate should have a rounded shape. The purpose of the fine aggregate is to fill the voids in the coarse aggregate and to act as a workability agent. Usually sand or stone dust and its size limited to 4.75 mm gauge. i.e., passing through 4.75 mm IS sieve but retained on 75 micron sieve. Fineness modulus and gradation of sand places an important part in deciding the segregation, and bleed characteristics. Absorption values determine the amount of water needed for adjustment after deciding free water content. Saw dust obtained from industry which is passing through 2.36 mm sieve is using in this work.

6.3. Coarse aggregates

"Coarse aggregates" is a material that will pass the 3-inch screen and will be retained on 4.75mm IS sieve. As with fine aggregates, for increased workability and economy as reflected by the use of less cement, the coarse aggregate should have a rounded shape. Broken stone and its size is 4.75 mm guage plus. Coarse aggregate can have round, angular, irregular shape. Rounded aggregates because of lower surface area will have lowest water demand and also have lowest mortar or paste requirement. Hence they will resulting most economical mixes for concrete grades up to M35.

6.4. Polypropylene Fiber

Polypropylene is a synthetic thermoplastic polymer. It is worlds second widely manufactured synthetic plastic after polyethylene. It has wide applications including packaging, textile industry, construction industry, medical applications etc. One of the most commonly used fibers in concrete matrix is the polypropylene fiber. These fibers are hydrophobic and do not absorb water. There modulus of elasticity is also low (3-5 Giga Pascal). It is the lightest fiber available and is ever lighter than water, polyester (34%) and nylon (20%). Thus, it provides bulk with less weight. The polypropylene fibers available in market are usually shorter in length and have small diameters. During fires in concrete polypropylene fiber melt and help in releasing the vapor pressure thereby decreasing the explosive impulse of concrete at high temperatures. The inclusion of polypropylene fibers in concrete show significant improvement in fire resistance, strengths i.e. compressive, flexural and tensile strength, shrinkage and crack reduction, some important properties of polypropylene fibers are:

- ➢ These fibers posses low thermal conductivity. They can retain heat for a longer time and have good insulating properties.
- ➢ These fibers are hydrophobic which keeps them dry and warm. They are even warmer than wool.
- ➢ These fibers are resistant to bacteria against mold growth and are rot proof and moth proof.
- ➢ These fibers are environment friendly and are recyclable. When incinerated they form ash leaving no hazardous volatiles.

- They are flexible even at lower temperatures of 55°
- These fibers have a softening point of 140° and a melting point of 165° also the extended exposure to heat can even degrade the fibers.
- It is the lightest fiber with density of 0.91 gm/cm
- It is less expensive than other synthetic fibers and can be easily processed.
- It has excellent resistance against acids and alkalis.
- It is highly flammable and burns like wax.

6.5. Coconut Husk Fiber

- Coconut fiber is obtained from the fibrous husk (mesocarp) of the coconut (Cocosnucifera) from the coconut palm, which belongs to the palm family (Palmae).Coconut fiber has a high lignin content and thus a low cellulose content, as a result of which it is resilient, strong and highly durable. The remarkable lightness of the fibers is due to the cavities arising from the dried out sieve cells.
- Coconut fiber is the only fruit fiber usable in the textile industry. Coir is obtained by wetting for up to 10 months in water followed by sun-drying. Once dry, the fiber is graded into "bristle" fiber (combed, approx. 20 - 40 cm long) and "imattress" fiber (random fibers, approx. 2 - 10 cm long).Coconut fiber is used to produce hawsers, ropes, cords, runners, mats, brooms, brushes, paint brushes and as stuffing for mattresses and upholstered furniture.
- Coconut fiber is transported in bales (compressed and uncompressed), in hanks and in rolls. The fibers are sometimes wrapped in jute or bamboo mats or are also shipped unpackaged. Steel strapping and coir cordage are used to ensure that packages hold together better. Coconut fiber requires particular temperature, humidity/moisture and possibly ventilation conditions for storage. Coconut fiber is strongly hygroscopic. It must be protected from sea, rain and condensation water and also from high levels of relative humidity, if decay, staining, self-heating, mold, attack by microorganisms and rusting of the steel strapping are to be avoided.

6.6. Water

- Water is mixed with the dry composites, which produces a semiliquid that workers can shape. The concrete solidifies and hardens through a chemical process called hydration. The reaction with cement, which bonds other components creates a robust stone like material.

7. MIXING AND CASTING

7.1. Conventional Concrete

The calculated quantities of cement, fine aggregate and coarse aggregate are mixed uniformly at required water content calculated as per the water cement ratio. The mixing should be carried out in a uniform manner so as to ensure a homogenous mass of concrete.

7.2. Polypropylene Fiber Reinforced Concrete

The mixing of polypropylene fiber reinforced concrete is same as conventional concrete mixing except that the fine aggregate is partially replaced with polypropylene fiber. The calculated quantities of cement and coarse aggregate along with the polypropylene fiber replacing 1% by weight of total quantity of fine aggregate is mixed uniformly with required quantity of water to form a homogenous mass of polypropylene fiber reinforced concrete.

7.3. Coconut Husk Fiber Reinforced Concrete

Coconut husk fiber reinforced concrete is prepared in similar way by mixing cement, coarse aggregate and coconut husk fiber replacing 1% by weight of total quantity of fine aggregate along with required quantity of water uniformly. The concrete cubes to be casted are of size 150X150X150mm. The required moulds are well cleaned and oiled before pouring the concrete. The moulds are then filled with the prepared concrete samples in three equal layers and tamped properly to ensure effective compaction and to prevent segregation. A day after casting the concrete, samples are de-moulded and immersed completely in water for curing. Effective curing is essential for controlling the rate and extend of moisture loss from concrete during cement hydration. Also curing plays an important role on strength development and durability of concrete. As per IS 456-2000 the recommended curing duration is at least 7 days for Ordinary Portland Cement. Samples are bought out of water a day before the tests are conducted.

8. TEST PROCEDURE

8.1. Fire Test

The experiment involves fire tests to assess the fire resistance of casted concrete cubes. The fire tests were conducted on a annealing gas furnace (fig9.1).

Fig 8.1 Annealing gas furnace

One day after the curing process is over, samples are heated in a furnace for one hour at different temperature ranges i.e. 200˚C, 400˚C, 600˚C and 800˚C. After performing the fire tests, samples are allowed to cool and are then tested for strength value (fig 9.2)

Fig8.2 Annealing gas furnace with burning specimen

8.2. Compressive strength of concrete cubes

The compressive strength of any material is defined as the resistance to failure under the action of compressive forces. Especially for concrete, compressive strength is an important parameter to determine the performance of the material during service conditions. Concrete mix can be designed or proportioned to obtain the required engineering and durability properties as required by the design engineer. The compressive strength of concrete is determined in batching plant laboratories for every batch in order to maintain the desired quality of concrete during casting. The strength of concrete is required to calculate the strength of the members. Concrete specimens are a cast and tested under the action of compressive loads to determine the strength of concrete.

In very simple words, compressive strength is calculated by dividing the failure load with the area of application of load, usually after 28 days of curing. The strength of concrete is controlled by the proportioning of cement, coarse and fine aggregates, water, and various admixtures. The ratio of the water to cement is the chief factor for determining concrete strength. The lower the water-cement ratio, the higher is the compressive strength.

Compressive test on concrete cubes was done according to IS 516-1959.

Fig 8.3 Compression Testing Machine with cube specimen

In brief, The experimental program consisted of fire endurance tests and compressive tests to assess the performance of Coconut fiber and Polypropylene fiber reinforced concrete. After finishing the curing process for the samples, the heating process were executed for the samples in an electrical oven, for temperatures of 200 Cº, 400 Cº, 600 Cº, 800Cº, 1000 Cº. After all the concrete samples were exposed to temperatures of various degrees, the samples are tested for their compressive strength capacity. Two samples of the each concrete cube type were prepared and tested it in order to obtain average value and then the results are taken, analyzed and compared to the results of the un-burnt cubes.

9. RESULTS AND DISCUSSION

Here, the results got from the fire tests and compression tests performed on normal concrete, coconut fiber reinforced concrete and polypropylene fiber reinforced concrete cube samples are discussed. The compressive tests on concrete cube samples were conducted according to standards. Control samples of 150mm x 150mm x150mm dimension were cured and tested to determine their 7, 14, and 28 days compressive strength using a compression testing machine. The concrete samples were heated at various temperatures of 200ºC, 400ºC, 600ºCand 800ºC on their 7, 14and 28 days of curing and tested to determine their compressive strength.

Conventional Concrete

	0ºC	200°C	400°C	600°C	800°C
7days curing	32	26.22	24.44	8.44	3.95
14 days curing	33.42	32.88	26.66	12.88	4.44
28 days curing	33.86	32.4	31.02	20.08	5.33

Table 9.1

The casted concrete cube specimen were kept for curing periods of 7,14 and 28 days after which they were subjected to compression test in a standard compression testing machine. The compressive test results for conventional concrete samples are shown in the table above. At 0°C, the concrete samples after 7 days and 28 days curing periods show an increment of 0.42%.But after subjected to a fire of 800°C, the compressive strength drastically changes froma value of 762N/mm² to 210N/mm². This drastical decrement of the compressive strength in concrete samples can be seen soon after when the temperature rises after 400°C.The findings are plotted as graph below;

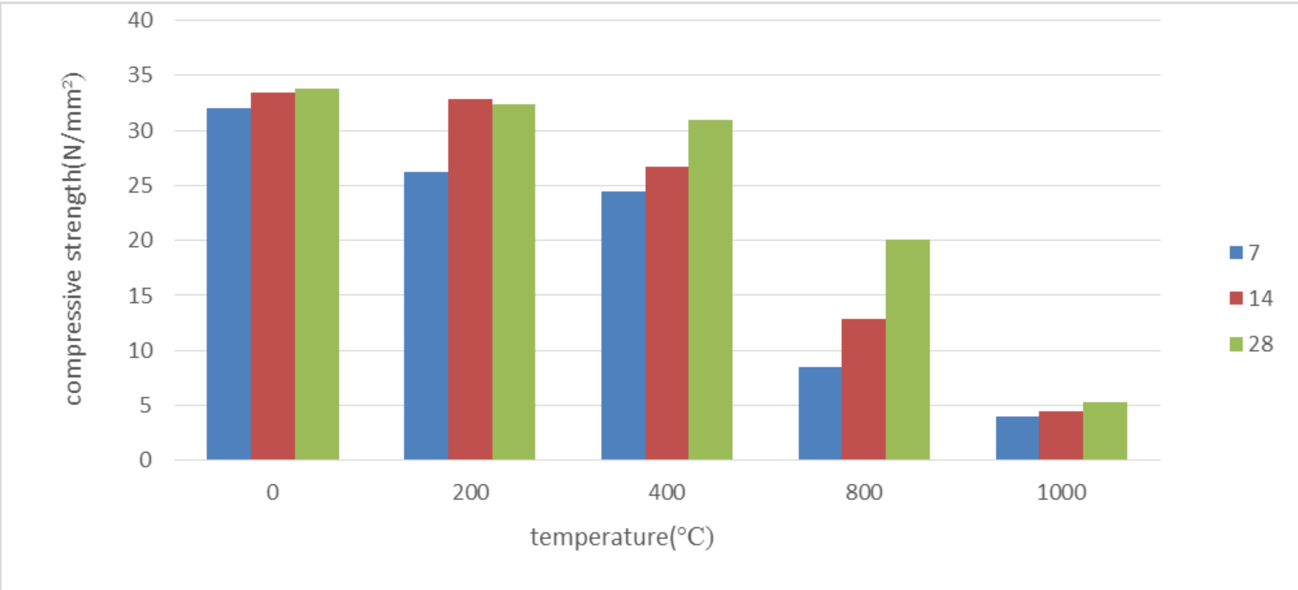

Fig.9.1Compressive strength Vs Temperature (forconventional concrete specimen)

The major cause of the decrement of the compressive strength of concrete cubes are the fire induced spalling. The vapour pressure developed in the concrete specimen during fires exerts pressure on the concrete mass from its interior resulting in mass outbreak. This leads to the loss of compressive strength of concrete. This project investigates the use of fiber reinforced concrete is adopted to tackle this issue. During fires the sudden melting of these fibers paves way for the escape of the vapour pressure build inside the concrete mass.

With this object in mind, polypropylene fibers and cocnut husk fibers were bought and added by partial replacement of fine aggregate by 0.5%.The results obtained after compression test for polypropylene fiber reinforced concrete cubes subjected to fire tests after a curing period of 7,14 and 28 days are as follows.

Polypropylene fiber reinforced Concrete

	0ºC	200°C	400°C	600°C	800°C
7days curing	39.55	31.11	28.88	26.22	12.44
14 days curing	40.44	38.75	35.28	30.22	18.66
28 days curing	45.77	44.44	36.88	35.55	22.22

Table9.2

In polypropylene fiber reinforced concrete specimen, the concrete cubes subjected to 0° temperature after a curing period of 7 and 28 days shows an increment of 1.4 % in compressive strength. At 800°C, the increasein compressive strength is 2.2% which is far better than conventional concrete samples which showed 1.21% increase. The graph plotting the resultant values are as follows;

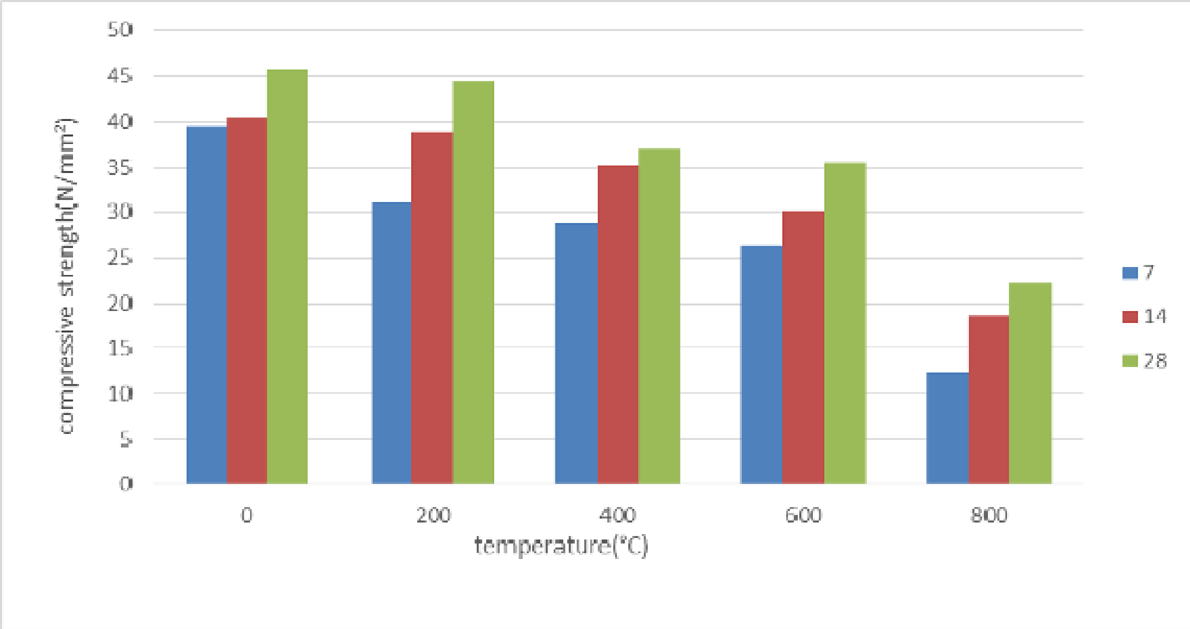

Fig 9.2

Polypropylene fiber reinforced concrete showed much improvements in the compressive strength values of concrete specimen. The search for a more sustainable fiber for reducing the fire induced spalling in concrete stated the use of coconut husk fiber which is comparatively cheap, more available and environmental friendly.

The concrete cubes were casted using partial replacement offineggregate using 0.5% of coconut fiber. The test results are as follows

Coconut fiber reinforced Concrete

	0ºC	200°C	400°C	600°C	800°C	
7 days curing	48	35.55	31.11	28	17.77	
14 days curing	48.44	40.44	36.44	29.33	19.11	
28 days curing	62.22	55.64	48.88	44	35.55	

Table 9.3

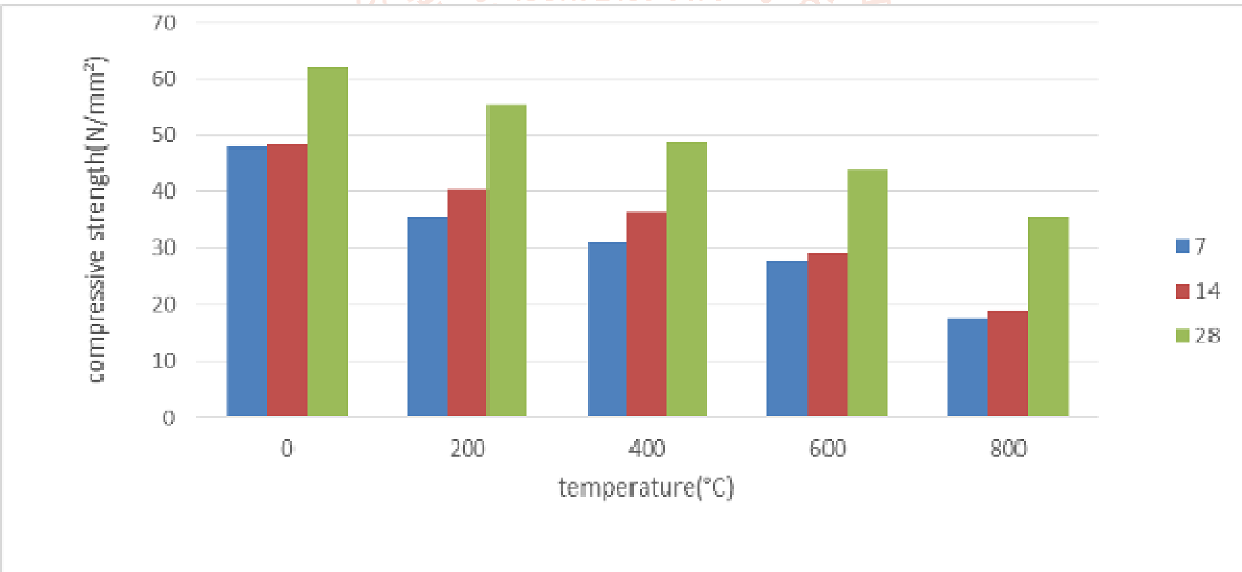

Fig 9.3 Compressive strength Vs Temperature (for cocunut fiber reinforced concrete samples)

Coconut husk fiber reinforced concrete samples showed best results against fire induced spalling. They exhibited an increase of 4% in the value of compressive strength when subjected to a temperature of 800°C after a curing period of 28 days. In brief, it can be concluded that polypropylene and coconut fiber reinforced concrete cubed inhibit better compression strength even after subjected to a continuous fire of 800ºC or more for one hour. The graph below(fig 10.4) shows the variation in compressive loads taken by concrete samples of different variety when subjected to varying degrees of temperatures after 28 days of curing. It can be clearly stated that fiber reinforcement considerably increases the fire resistance of concrete by improved compressive strength. At elevated temperatures of 800 ºC or more cocnut fibers are ought to show better performance. The analysis of the test results shows that the fiber reinforced concrete specimen shows considerable improvement in fire sresistance and stability conditions by possessing improved compressive strength values. At a temperature range of 300-400 ºC and above normal concrete samples fail due to spallng. But polypropylene and coconut fiber reinforced concrete specimen shows considerable gain in compressive strength values after 28 days of curing. The results are depicted n graph as follows:

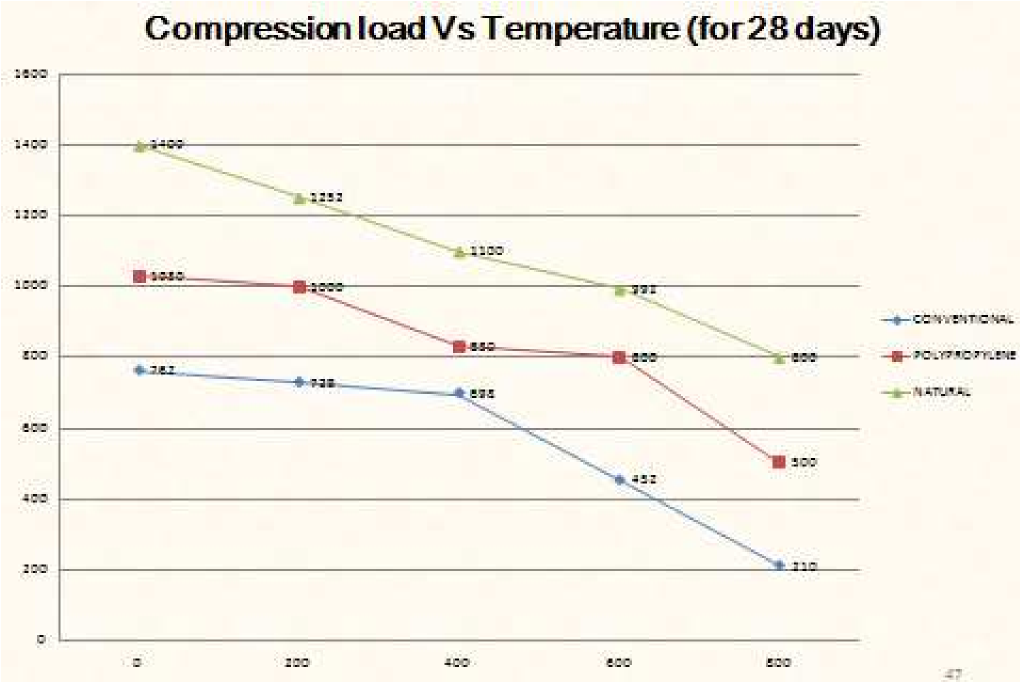

Fig 9.4 compression load vs temperature

10. CONCLUSION

This research tried to provide an understanding of the effect of coconut and polypropylene fiber on the fire resistance property of concrete. Based on laboratory test results obtained, it can be easily concluded that the presences of either of the two types of fibers increases the compressive strength of concrete. The addition of both fibers did not just increase the compressive strength, but test results have proven that they also increase the fire resistance property of the concrete. Coconut fibers can therefore not only improve strength for concrete but also improve the fire resistance of concrete more than polypropylene fibers. The presence of coconut fiber confers greater ductility on concrete as it prevents fragile collapse. In light of the results obtained, these fibers are recommended because of their good influence in improving the compressive strength of concrete even at elevated temperatures. Hence the study investigated the improvement of the fire resisting capacity of concrete by addition of natural fibers, although suggesting sustainable means of improving fire resistance of concrete structures.

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