A Literature Review on Fire Resistance Concrete Using Different Types of Fibres

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Abstract: Fire safety of any structure can be increased by considering the fire resistance of the construction material and the type of fire suppression system used in the structure. Structural integrity to a large extent depends on the load bearing capability of the materials by which structural elements are made under various fire conditions. Thus in order to maintain safety against fires suitable material selection is very decisive and it should be done in initial stages of the project with proper planning. Concrete being the most widely used construction material should be considered for improving the fire resistance of structures. In this paper various authors work has been studied and discussed in the form of literature review those who have used the polypropylene fibre in fire resistance concrete.

Keywords — Elevated Temperatures, Fire Resistance Concrete, Polypropylene Fibre.

I. INTRODUCTION

Fire in simple terms is the process of burning. Fire is an action of burning in which a chemical reaction takes place between the oxygen and substance which is triggered by the heat energy followed by energy emissions in various forms (heat, light and sound). Thus fire requires three elements i.e. oxygen (gas), combustible substance (fuel) and a heat source. If any of these three substances are absent it will result in fire extinguishing. It also leads to emission of gases like carbon dioxide and carbon monoxide which are extremely harmful for human beings.

Fires in buildings can result mainly from two types of errors

a) Human Errors: These types of errors include fires from rubbish burning, children playing with matchstick etc.

b) Appliance errors:

These types of errors include fires from electrical appliances, gas appliances, other fuel appliances etc.[1]

The fire accidents in buildings and other structures have always been a persistent problem in India and other parts of the world. The impact of fires on society i.e. human lives, environment and economy is great. The desire of minimizing the effects of fire have always been a matter of concern from past many years although the causes and type of fire accidents have changed but the risk of fire accidents has always been constant. So in order to minimize such conditions fire resistance of a structure should be given importance and should be considered in preliminary stages of building[2]. Fire accidents decrease structural stability so in order to maintain structural integrity concrete elements should be made with materials that are fire resistant. Concrete being the most widely used construction material although has good fire resisting properties also faces strength decrease at higher temperatures. The addition of fibres (PPL fibres, coir fibres etc.) has shown considerable improvements in strength of concrete even at higher temperatures [3].

The concept of using fibres in the concrete so as to improve its properties is not new and is being used from past 4500 years. The use of straw fibres in mud bricks in order to increase its toughness and reduce crack formation was seen in ancient civilizations. The use of FRC was less before 1960's but in early 1960's interests in using FRC increased. This period proved to be the turning point for using fibres and a number of new fibres with better properties were introduced in the market [4]. The researches for new fibres continue today also.

Polypropylene which is a thermoplastic polymer is used in polypropylene fibres. It is world's second widely produced synthetic plastic after polyethylene. PPL had a global market of 55 billion tones in 2013 [5].

II. FIRE IGNITION AND STAGES

From the point of ignition to the point when all combustible materials are burnt fires in buildings pass through a series of steps. Fire expansion in buildings depend on factors like the properties of combustible materials, quantity of combustible materials, geometry of structures, type of ventilation (natural or mechanical), fire location and the surrounding environment conditions like temperature, wind etc. Fire expansion in a building can be described in four stages:

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a) Ignition and temperature rise (incipient and growth stage):

It is the first stage where the reaction starts giving rise to a fully mature fire. It involves ignition at initial stage and then a fast reaction of developed fire. Ignition requires fuel (combustible material), heat and oxygen. After combustion the development of fire in a building depends on the characteristics and configuration of combustible material involved. The temperature starts rising rapidly although less material is consumed. This increasing heat warms the adjacent combustible material and continues the process due to which plume of hot flames and gases is produced. During this stage there is extreme devastation of exposed surface due to the smoke and heat produced also the obnoxious fumes and smoke vapors tend to further damage the contents of the structure. When the building has sufficient supply of oxygen more and more materials will get involved increasing the heat release.

Gases in structures due to fires are usually in two layers, a hotter layer continuously spreading down from the ceiling and a cooler layer near the floor. This transmission of radiant heat and hot particulates present in the smoke tend to increase the temperature of building linings and other components of the building. When gases present inside a structure or any building are heated they expand and when a structure is confined it tends to increase the pressure. This high pressure of hot gases create a push and moves out of the compartments through openings while the pressure of cooler gases is less which results in inward movement of air from the outer side of the buildings. At this point the pressure is neutral and the interface of two gases at the opening is referred as neutral plane. This stage depends on size, ventilation, fire load and the type of construction of a building or any structure.

b) Flash Over:

It is the conversion of fire from the growth stage to a fully mature stage. It is a rapid change where all the combustible materials present in the building are involved in combustion. Ceiling temperature reaches to about 500^0 C - 600^0 C [6]. Burning gases are pushed towards the openings such as doors at a large velocity towards the other rooms. It can occur in any type of building. The time fires take to reach the flashover stage depend on many factors such as fire load, ventilation and thermal properties of the combustible materials in the buildings.

The condition of flashover occurs occasionally. It requires sufficient fuel i.e. combustible material and oxygen to reach to this stage. If the object giving rise to a fire does not have sufficient energy and do not release the energy rapidly flashover will not occur e.g. small fire from thrash in the middle of a big room. Similarly flashover will not occur if the oxygen supply is depleting e.g. fires in small rooms with closed doors and windows.

c) Fully mature stage

This is the second and extremely dangerous stage of fire in which there can be temperature increase of about 900-1200^0 C. During this stage tremendous flame with lot of heat is produced as most of the flammable materials are consumed. Accumulation of unburned gases at ceiling level takes place which burn frequently while leaving the building resulting in flames that are visible from doors and windows. This is the most unsafe stage as structural elements oversee failure which can even lead to the collapse of the structure.

Fires can reach to fully mature stages without involving other buildings. Extending flames and gases from the building with fire transfer heat to other combustible materials resulting in fire spread. However the conditions of fire may vary from one building to the adjacent building i.e. it can be in fully mature stage in one building and at growth stage in another building and at incipient stage in other.

c) Extinction or Decay:

This is the final stage where everything is burnt producing toxic gases, heat and smoke. The conversion of fire from fully mature stage to extinction stage is very rapid and takes only few seconds. Any building fire will reach this stage when all the available combustible material is burnt or when oxygen supply ends. So a structure may reach to fully mature stage and then enter the decay stage as soon as the fuel (CM) ends [7].

These different stages of fire can be shown in following graph:

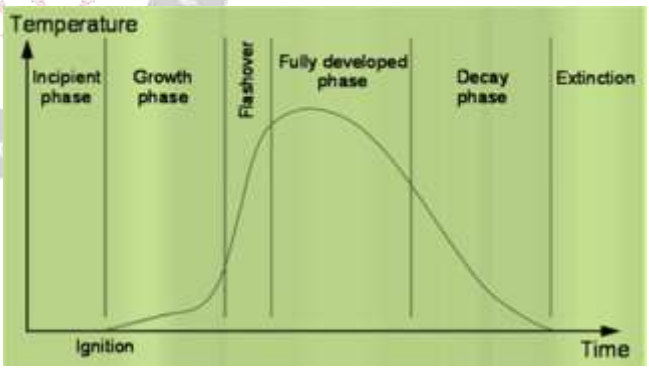

Figure 1. Different stages of fire

III. LITERATURE REVIEW

K.R. Kodur , T.C. Wang, F.P. Cheng predicted the fire resistance behavior of high strength Concrete columns. They used a numerical model in a computer program for studying High performance concrete column behavior after exposing with fires. This program also traced the performance of HPC columns from loading stage to collapse stage. It predicted the resistance of HPC columns after fires at various loads, columns lengths, aggregate lengths, fibre reinforcements etc [5]

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Saeed Ahmed, Imran A Bukhari, Javed Iqbal Siddiqui and Shahzad Ali Quresh (2006) studied the properties of polypropylene fibre reinforced concrete. He examined the properties of concrete at varying proportions of polypropylene fibres. The experimental investigations were carried on compressive strength, split tensile strength, flexural strength, shear strength and shrinkage. He concluded that there was a noticeable increase in flexural strength, tensile strength and shear strength but there was no change in compressive strength. It was also observed that shrinkage cracking was reduced by 83% -85% when fibres in the range of 0.35%- 0.50% were added [8].

.**Chul Hun Chung, Jungwhee Lee and Hyun Jun Kim** worked on the evaluation of Fire Performance of Polypropylene Fibre RC Slabs. They studied the effects of exposure of fires on five RC slabs and concluded that after heating no spalling was seen in PPL fibre reinforced concrete while spalling took place in slab made from conventional concrete. They also said that addition of polypropylene fibres improved the fire resistance of RC slabs. It was observed that after fire damages, in RC specimen without PPL fibre residual load-carrying capacity was decreased to 67.5% but in RC specimens with PP fibre load carrying capacity was 91.6-98.1% [9].

Anthony Nkem Ede and Adebodun Oluwaseyi Aina studied the effects of coconut husk fibre and polypropylene fibre on fire resistance of concrete. They stated that fires are one of the most commonly occurring disasters which result in loses of human lives, property and environment. In order to prevent such disasters fire safety should be considered in preliminary stages of any construction project. They further stated that concrete possess god thermal properties but at higher temperatures concrete also starts losing its strength and several damages like spalling may take place in concrete elements. They used coconut husk fibre and polypropylene fibres to improve the fire resistance of concrete. The samples were casted with 0.5% of coconut fibres and PPL fibres and then these samples were treated with temperatures of 200^oC, 400^oC, 600^oC, 800^oC and 1000^oC for 7, 14, 21, and 28 days. After performing fire tests compressive strengths of specimens were calculated. They concluded that the concrete samples made from coconut fibres showed increase in strength than the PPL fibre samples [10].

Jasira Bashir and Khushpreet Singh studied on fire resistance of concrete using Polypropylene fibre by using various percentages of PPF at different temperatures and found that the addition of PPF shows better result on the concrete than the conventional concrete. Author conducted mechanical property tests on the concrete [11].

Kodur VKR, Cheng FP, Wang TC studied stress-strain curves for high strength concrete at elevated temperatures and studied the performance of high strength concrete at 100, 200, 400, 600 and 800^0 C and concluded that HSC showed brittle properties below 600^0 C and ductility above 600^0 C. They also concluded that goes on decreasing with increasing temperatures [12].

Kodura V.K.R., Phanb L studied Critical factors governing the fire performance and stated that the use of HSC in structures where fire safety is to be considered. It also discusses fire, material and structural characteristics that influence the performance of HSC [13].

J.A. Larbi and R.B. Polder studied the effect of using polypropylene fibres in concrete. They considered explosive spalling as most dangerous damages of concrete which results due to fire accidents the damage was seen to be savior in restricted areas such as tunnels. The experimental investigations concluded that the effect of spalling can be reduced to a large extent by using polypropylene fibres in concrete. They concluded that the heated samples lost its properties as compared to unheated samples. The durability of concrete with polypropylene fibres under aggressive loading was found to be good and was confirmed to remain same at least for one year [14].

T.Ch.Madhavi, L.Swamy Raju, Deepak Mathur studied Polypropylene Fibre Reinforced Concrete. They studied the behavior of PPL fibre reinforced concrete, there properties, applications and performance. They concluded that PPL fibre reinforced concrete have less permeability, shrinkage. PPL fibres enhanced the strengths of concrete, problems of low tensile strengths can also be overcome by using these fibres [15].

Milind V. Mohod studied the Performance of Polypropylene Fibre Reinforced Concrete. He studied the effects on properties of high performance concrete i.e. M30 and M40 mixes. The experimental investigations were carried on compressive, flexural and split tensile strength at different curing periods. Polypropylene fibres at varying contents were used i.e. 0%, 0.5%, 1%, 1.5% & 2%. There was considerable increase in compressive strength, tensile and flexural strength of concrete. He also concluded that fibres in concrete decreased the workability of concrete. Compressive strength increase was seen up to the fibre content of 0.5% the CS starts decreasing. Similarly tensile strength and flexural strength increased up to 0.5% and then starts decreasing with increase in volume of fibres [16].

Lilly Grace Mural. P studied Fire Accidents with High Fire Spread in Buildings and stated that fire accidents are very dangerous and can lead to losses of life and property. She also stated the reasons which give rise to fires, life losses, and property losses and gave various solutions by which these losses can be minimized [17].

Kolli.Ramujee studied the strength properties of polypropylene fibre reinforced concrete. He stated that the use of fibres for reinforcement of concrete elements had increased over years. He studied the changes in

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compressive strength, split tensile strength and flexural strength of concrete with varying percentages of polypropylene fibres i.e. 0%, 0.5%, 1% 1.5% and 2.0%. the concrete specimens with 1.5% of polypropylene fibres added showed better results in compression as compared to other percentages. The experimental investigation of concrete samples for compressive strength and splitting tensile strength tests showed that strengths increased proportionally with the increase in Polypropylene Fibres volume ratios with reference to the conventional mix without fibres [18].

Alan Richardson studied the effect of polypropylene fibres within concrete with regard to fire manufactured concrete samples with medium strength with varying percentages of PPL fibres. He also manufactured without PPL Fibres. Further the samples were placed in furnace at the of 1000^0 C. He concluded that the explosive spalling of concrete reduced by the addition of polypropylene fibres but the strength of concrete as whole decrease with increasing temperatures [19].

A. P. Sathe, A. V. Pati worked on experimental investigation on polypropylene fibre reinforced concrete. In this study various types of fibres were used such as glass, carbon, steel, asbestos, polypropylene fibres were used. The effect of PPL fibres on various properties on concrete such as compressive, flexural, split tensile strength, workability was investigated at varying percentages of PPL fibres. They concluded that addition of fibres showed positive results and maximum strength increase was seen at 0.5% of PPL fibres [20].

Samir Shihada studied the effect of polypropylene fibres on concrete fire resistance. The experimental investigation was carried out by preparing concrete mixtures with polypropylene percentages of 0%, 0.5% and 1%. The samples are heated for 6 hours at temperatures of 200, 400 and 600 °C and then they are tested for compressive strength. He concluded that the concrete samples that were made by adding 0.5% of PPL fibres show a significant increase in residual compressive strength even after heating for 6 hours [21].

IV. CONCLUSION

Fire resistant properties of concrete can also be improved by using natural fibres like coir fibres in concrete. In order to improve fire resistance of concrete other fibres like glass fibres which have good fire resistant properties can be used in concrete. These papers gave a critical review on fire resistance of structures and discussed various modern fire resistant design methodologies for steel and concrete structures. The presence of fibres also increases the ductility of concrete and helps preventing collapse. Polypropylene reinforced concrete provides better fire resistance and strength than the conventionally used concrete.

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Table 1. Comparison chart for various fire stages.

Elements	Ignition & Temperature Rise Stage	Flash Over Stage	Fully Mature Stage
	Indications		
Smoke	• Hot Smoke Layers are produced. • The smoke is visible from exterior of building.	• Smoke indication may or may not be visible from the outer side of buildings. • Dark smoke is the indicator of flashover Stage.	• There will be an increase in volume and density of the smoke. • The height of hot air layer in a building depends on its ventilation.
Heat	• Temperature inside the building increases. • Condensation on windows will be visible due to pyrolysis of material. • Breaking of Window Panes due to heat.	• The increased heat cannot be felt from the outside of the building however heat indicators (HI) can show the increase in heat. • The increase in the velocity of smoke discharge also indicates flashover.	• Substantial heat is produced at this stage with many visual indicators such as blackened windows. • High temperature can be felt easily even by wearing fire fighting clothes.
Air Track	• When there is single opening in the building, air track will be bidirectional i.e. smoke at the top and bottom. • Velocity of air track will increase with increase in velocity of smoke discharge and air intake.	• Bi-directional air track is the indicator of this stage. if the air track shows more air movement toward the fire it is also an indication of flash over.	• This stage has strong air track as the velocity of smoke and air movement is very good.
Flame	• Fire extends to the ceiling height and begins to travel horizontally near the ceiling. • Fire can be seen from the exterior of the building if there is any opening in the building. • Isolated flames far from the main fire area can be seen later in the growth stage.	• These flames may or may not be visible by the naked eye without the use of any thermal imaging camera. • Isolated flames travel across the ceiling or in hot gas layers.	• Flames are visible from the exterior of building. It will involve the whole building.

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