Behavior of Reinforced Concrete Subjected to High Temperatures- A Review

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Abstract
This paper reviews the research carried on effects of fire on the mechanical and thermal properties on concrete. Fire in the structure causes higher temperature at the concrete surface, which causes a reduction in compressive strength, modulus of elasticity of concrete. Though concrete is a poorer conductor than steel, sustained high temperature at the surface leads to progressive heating of the inner layers of concrete. This leads to exposing reinforcing bars to higher temperature; which causes a reduction in the yield stress, ductility and tensile strength of steel. This paper also focuses on the concrete cover, the reinforcement bars in a concrete structure are protected against fire only by the concrete cover layer thus higher is the cover more is the resistance and vice a versa. Effects of temperature on the thermal conductivity of concrete is also discussed in detail.

Keywords: Fire resistant concrete, Thermal conductivity, High temperature.

1. INTRODUCTION

High temperature is the most important physical deterioration processes which reduces the durability of concrete structures. Concrete deteriorates when exposed to fire and the mechanical properties such as strength, elastic modulus and volume deformation reduces considerably. (S. Aydın, 2008). Concrete has relatively high compressive strength, but significantly lower tensile strength. Tensile stresses within the concrete can cause cracks and brittle failure. Thus steel reinforcement is generally used with concrete in the areas of tensile stresses in the structural members. Besides actions such as abrasion, durability of concrete on account of penetration of harmful substances such as chlorides through cover is a major concern. In certain cases, the thickness of concrete cover is to be determined from the consideration of fire. This is important considering the fact that the reinforcement steel cannot be expected to retain its structural integrity at elevated temperatures.

Reinforced concrete (RC) structures lose their load carrying capacity when reinforcement becomes hot (Wickstrom & Hadziselimovic, 1996). The subsequent sections discuss briefly the issues involved in study of fire resistance of RC structures. For the sake of convenience separate sections deal with issues related to concrete and steel separately.

This paper presents the effects of fire on concrete and reinforcing steel taking into account the following factors,

- Moisture content of concrete
- Fire duration
- Compressive Strength
- Spalling
- Thermal conductivity
- Concrete Cover

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2. EFFECTS OF FIRE ON CONCRETE PROPERTIES

Concrete is incombustible and has insulating properties. The main disadvantage of concrete is that, its material properties changes with temperature. Properties of concrete depend on the properties of its constituents. Mainly the constituents can be subdivided into two parts, one is cement paste and other is aggregate.

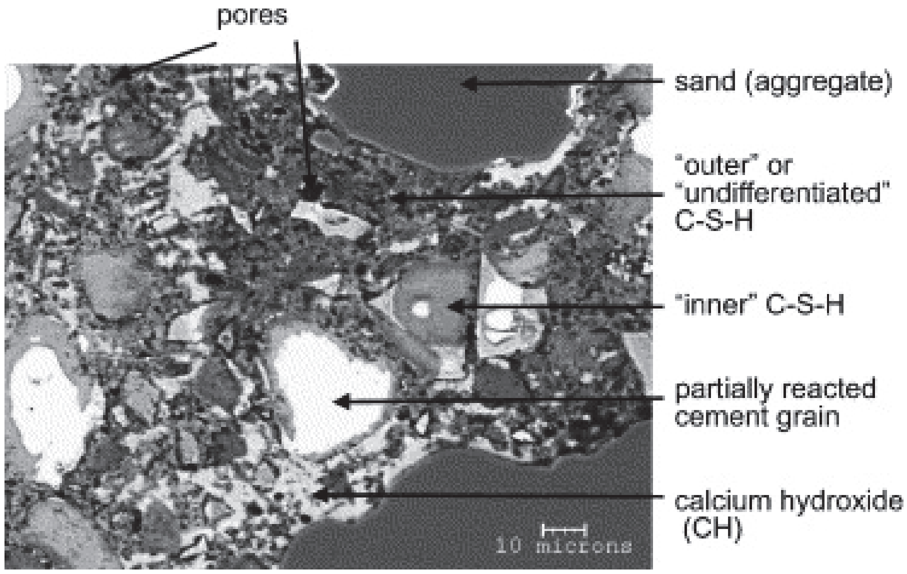

Figure 1. Portland cement mortar with the micro structural constituents distinguished (*Source: Karen L. Scrivener, 2004*)

Figure 1 shows a typical Backscattered electron image of a Portland cement mortar (200 days old, w/c=0.4), with the micro structural constituents distinguished and Figure 2 shows the SEM images of heated Portland cement paste at different temperatures after cooling.

The main factors affecting the performance of concrete in fire are (V.K.R. Kodur et al. 2007).

- Type and relative proportions of aggregate used and cement,
- Highest temperature and duration of fire,
- Size and shape of member, and
- Moisture content of concrete.

Many researchers have shown the effect of these factors on the performance of concrete in fire.

Effect of fire on concrete has been described in two parts;

- Effect on mechanical properties and
- Effect on thermal properties.

Above 110^0 C dehydration and release of chemically bound water from calcium silicate hydrate, becomes significant (K.D. Hertz, 2005). Above 500^0C temperature, compressive strength of concrete decreases rapidly. In 570^0C -600^0 C, then α-β inversion of quartz takes place and quartz crystals in the aggregate get converted to other silica products and calcium hydroxide and other cement hydration products begin to dehydrate (Lin, W.-M, 1996, Timo G. Nijland & Joe A. Larbi, 2001). At about 900^0C calcium carbonate also decomposes through the loss of CO2 (Harmathy, T.Z, 1993). The phenomenon that occurs in concrete as it is exposed to elevated temperatures is schematically shown in Table 1.

Loss of hydration water and decomposition of calcium carbonate causes large loss in weight and also very less strength. 1150 °C feldspar melts and the other minerals of the cement paste turn into a glass phase, this is called as melting phase of concrete (Timo G. Nijland & Joe A. Larbi, 2001).

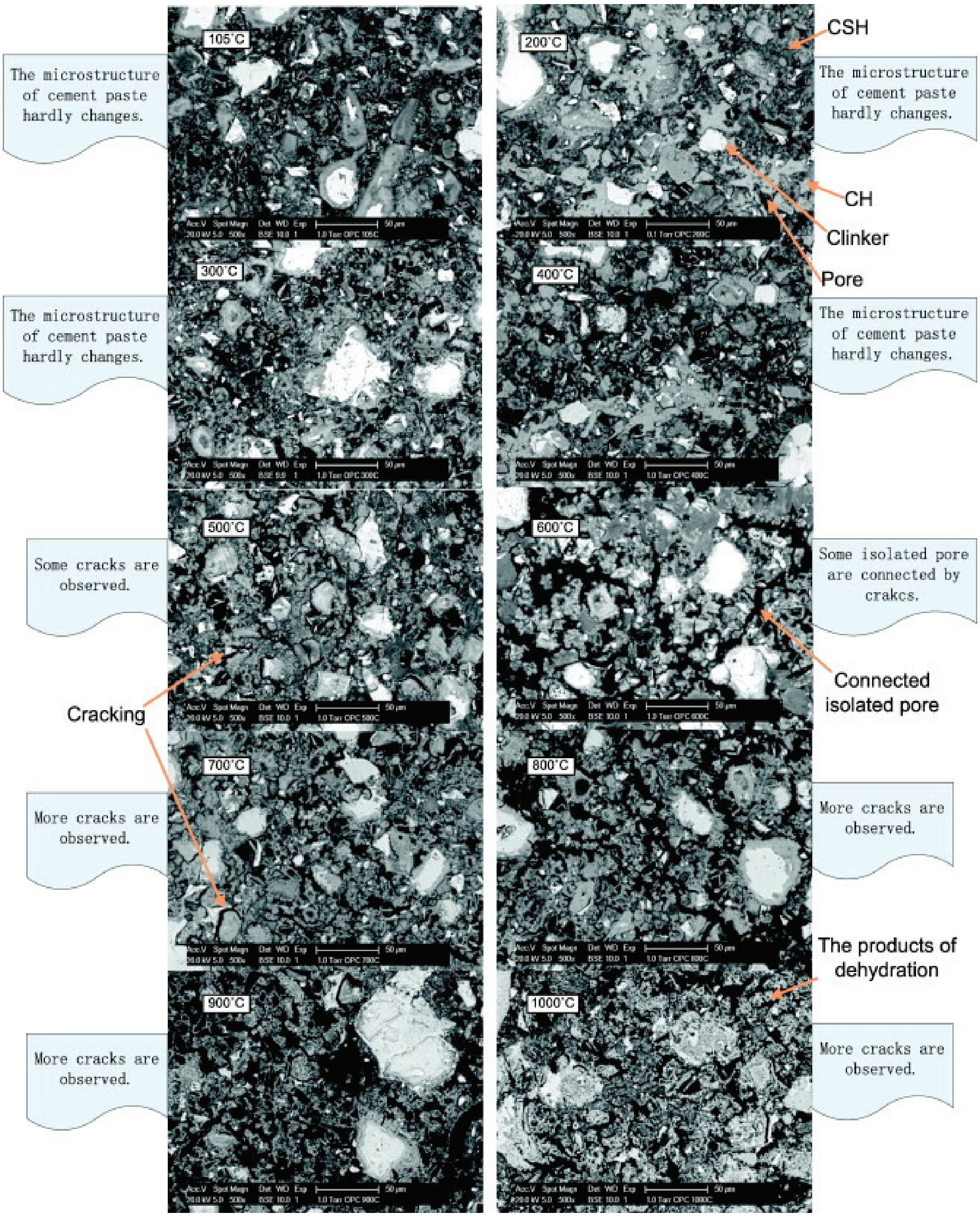

Figure 2. The SEM images of heated Portland cement paste after cooling.
(*Source- Qi Zhang* (*2012*))

Table 1. Effect of rising temperature on concrete

Temperature in ^{0}C	Effect
20	Normal temperature
80	Reversible strength loss
100	Starts loosing chemically bound water
250	Spalling generally starts range (250-420^{0}C) (B.B.G. Lottman, 2007)
300	Permanent Reduction in strength
500	Rapid loss in strength in concrete
800	Total loss of Hydration water (Timo G. Nijland & Joe A. Larbi, 2001).
1200	Conversion to glass phase and Melting of concrete starts

High temperature reduces thermal conductivity and strength of concrete. Weight loss and modulus value also show a reduction with higher temperature. This reduction is rapid above 400^0 C. Specific heat value shows an increase in temperature and density of concrete shows little variation with higher temperature (B.B.G. Lottman, 2007).

The following sections give more details of the effect of fire on the mechanical as well as thermal properties of concrete.

Mechanical properties includes compressive strength, splitting tensile strength, modulus of elasticity and weight loss whereas thermal properties of concrete can be listed as thermal conductivity, specific heat, thermal diffusivity, density etc. Temperature distributions and heat transfer in concrete members is dependent on thermal properties of concrete.

2.1 Mechanical properties of concrete

Mechanical properties of concrete deteriorate at higher temperature, due to photochemical changes in the cement paste and aggregate and the incompatibility between these two (Khoury, 2000). The behavior of concrete material in a fire depends very much on the specific concrete mix proportions and constituents used. At lower temperatures the mechanical property deterioration can be reduced through proper mix design and choice of aggregate (V.K.R. Kodur et al. 2007).

Compressive strength: Compressive strength of concrete reduces with increasing temperature. Most concretes experience a strength reduction above 300^{0}C (Ulrich Schneider, 1988), but this depends upon the type of aggregate and cement blend used in the mix. According to the author, aggregate-cement ratio, type of cement, maximum size of aggregate and different types of aggregates influence the strength-temperature characteristics. Beyond 400^{0}C there is a sharp decrease in compressive strength. However the proper mix design could help to protect the structure up to a certain temperature, but above 550-600^{0}C Portland cement concrete loses their load bearing capacity (Khoury, 2000).

Figure 2 shows the variation in the relative strength of concrete with respect to elevated temperature. The effect of w/c ratio and aggregate type on the concrete compressive strength has been also shown in the same graph. It can be seen that for strength after 500^{0}C-600^{0}C is more than 80% but after that it falls rapidly and after 800^{0}C only 20% strength remains.

Takeuchi et al. (1993) carried out the experimental program. The tests were carried out to calculate the temperature effect on thermal properties as well as mechanical properties of concrete. Thermal conductivity and compressive strength reduces with higher temperatures where as specific heat and density showed a little variation in his study.

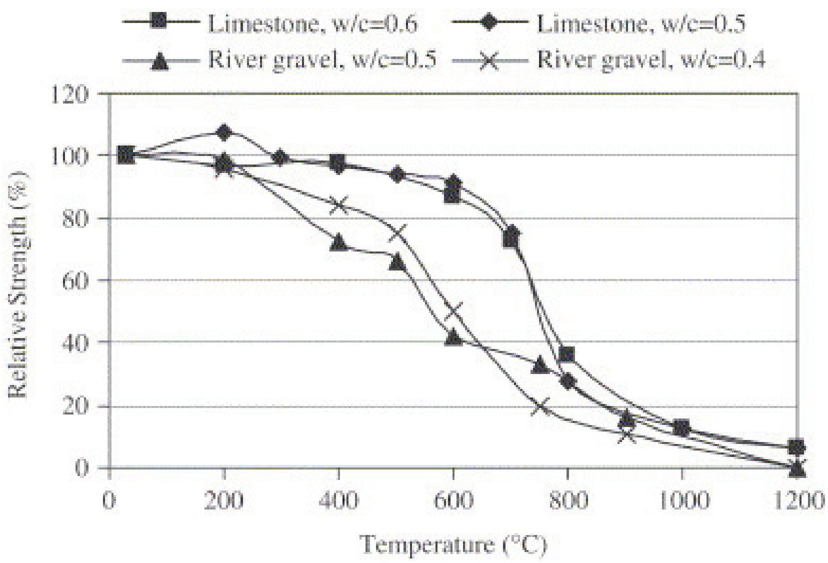

Figure 2. Relative strength of concrete subjected to elevated temperatures after cooling (*Omer Arioz, 2006*)

M. Li et al. (2004) tested the mechanical properties of High strength concrete (HSC) after exposure to the higher temperatures. The influence of temperature, water content, specimen size, strength grade, and temperature profiles on mechanical properties of HSC was discussed. Metin Husem(2006) examined the compressive and flexural strength of concrete exposed to high temperature. In this study, effect of cooling method on the residual strength of concrete was also examined. Strength loss in water cooled samples was observed to be more than the air cooled samples. Results show the loss the strength after 400^0C was rapid.

Omer Arioz (2006) has shown the influence of different types on aggregate on the physical and mechanical properties of concrete. The experiments were carried out to study effect of w/c ratio on these properties. Weight loss and compressive strength after the exposure to higher temperature was studied. It was found that the effects of w/c ratio and aggregate type on the weight loss were not significant. It was concluded that w/c ratio did not affect the relative strength of concrete but the type of aggregate used has the pronounced effect on the strength of concrete.

2.2 Spalling

The spalling is breaking of a layer of concrete or pieces of concrete because of rapid heat exposure to concrete such as in a fire situation. Spalling is of different nature depending on the temperature it exposed to. The influencing factors can be said as aggregate properties, heating rate, concrete properties such as strength and permeability, moisture content etc. Khoury (2000) has discussed about spelling nature and causes.

2.3 Thermal properties of concrete

An accurate understanding of the variation of thermal properties, including thermal conductivity, specific heat, thermal diffusivity and density, enables a more accurate determination of the temperature variation within concrete. From these, the thermal conductivity and specific heat are discussed in details below.

Thermal conductivity: Thermal conductivity of concrete can be defined as the quantity of heat transfer through the unit thickness of material, in the direction normal to surface of unit area under unit temperature gradient. Thermal conductivity of concrete depends on the properties of its constituents.

Aggregates are generally more conductive than the cement paste (Harmathy, 1970). The influencing parameters on thermal conductivity are the moisture content, type of aggregate and porosity of concrete. In general the thermal conductivity of concrete can be from 1.91 to 2.94 W/m^{0}K, depending on the type of aggregate (Kim et al, 2003). The thermal conductivity of rocks can vary from 1.163 to 8.6 W/m^{0}K depending on the type of rocks (Khan, 2001).

Kook-Han Kim et al. (2003) carried out experimental studies on thermal conductivity of concrete. In the experiment the effect on thermal conductivity on concrete and cement paste was studied. The results showed that the thermal conductivity of cement paste is nearly half that of the concrete. The volume of aggregate, w/c ratio, age of specimen, fine aggregate fraction, admixture and moisture content were varied and their effects on thermal conductivity were determined. A numerical equation to calculate thermal conductivity was also developed using the results obtained from the experiments. Figure 3 shows the experimental results for thermal conductivity with age, aggregate content, W/C ratio of paste and the type of cementitious materials.

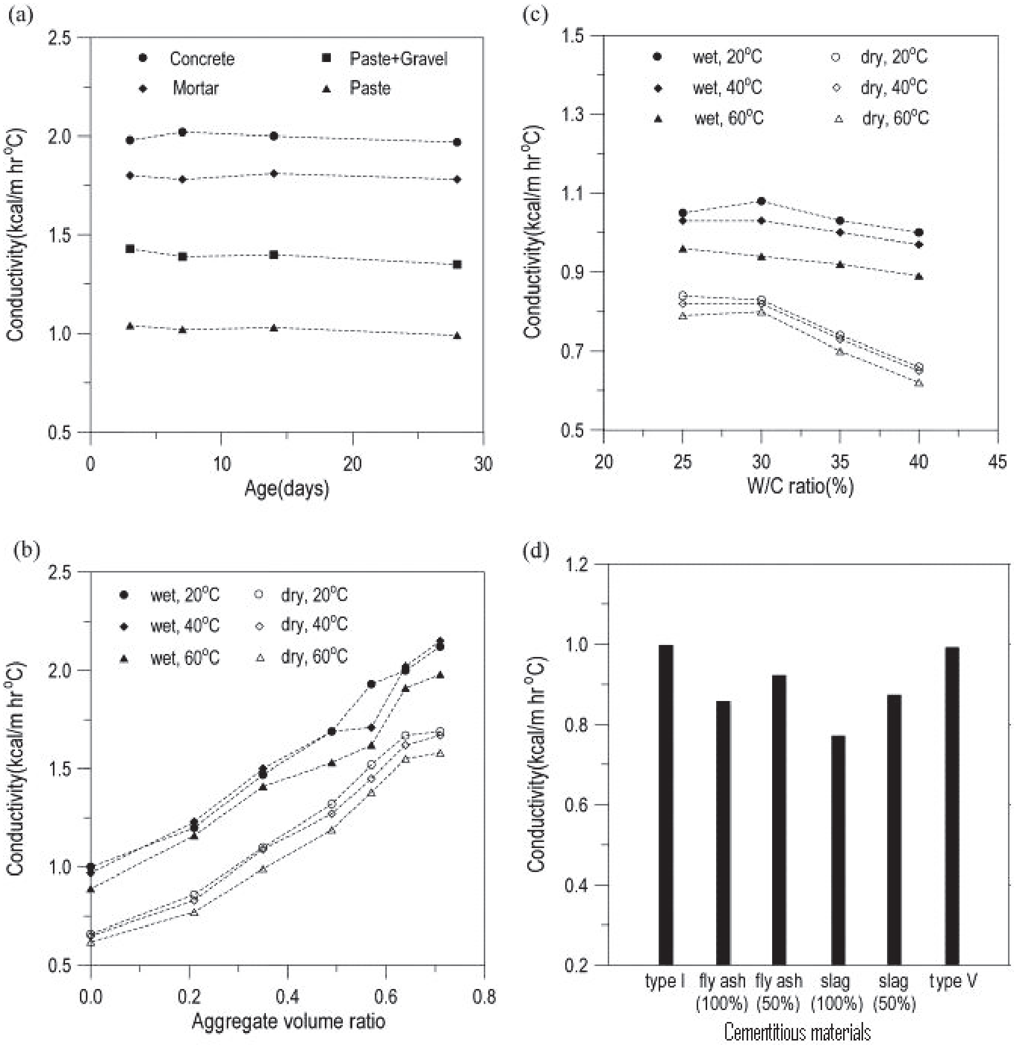

Figure 3. Experimental results for thermal conductivity. (a) Age; (b) Aggregate content; (c) W/C ratio of paste; (d) Type of cementitious materials.
(*Source- Kook-Han Kim et al.* (*2003*)).

The thermal conductivity can be determined by using the models developed by various research groups. Some of these models are discussed by Khan (2001). Various models reviews were taken and some models were validated with the experimental results. The experiments were performed to evaluate thermal conductivity of cement paste, aggregates and concrete. The effect of moisture content and type of aggregate was also examined. The prediction of thermal conductivity was done using the values obtained from experiments for aggregate and cement paste. The results then compared with the experimental data of thermal conductivity of concrete.

Thermal conductivity of concrete varies with temperature. In general, thermal conductivity of concrete decreases with increase in temperature. Harmathy (1970) had shown this kind of variation. The aggregate type is one of the influencing factors of thermal conductivity at higher temperature. The thermal conductivity at normal temperature was shown to be 2.7 W/m^0K and reduces to 1.25 W/m^0K when the temperature reached to 1000^0C. Kodur and Sultan (2003) studied the effect of temperature on thermal properties of HSC along with the effect of different type on aggregate in their experimental work. Properties included the thermal conductivity, specific heat, thermal expansion, and mass loss. Summary of the experimental work showed that the type of aggregate had a significant influence on the specific heat and thermal conductivity. Temperature dependent numerical relationships to calculate thermal properties of concrete were given depending on the experimental data.

Thermal properties of concrete have been also discussed in detail by Ulrich Schneider (1988). According to study the density of concrete shows very little effect of higher temperatures. Thermal conductivity of concrete depends on the thermal conductivity of its constituents. The author in his paper explained the role of constituents on thermal conductivity. The major factors are the moisture content, type of aggregate and the mix proportions. As per the experimental results up to 100 °C, the conductivity seems to increase with temperature. Thereafter a loss of conductivity is observed. The conductivity of any given concrete varies approximately linearly with the moisture content. With lightweight concretes the conductivity may be nearly constant or slightly increasing up to temperatures of 1000°C which indicates that the density of aggregates plays an important role. Figure 4 shows some typical data for normal and lightweight concretes. The types of aggregate have an influence on thermal conductivity but little influence on specific heat. The specific heat value of concrete shows increase with higher temperature. Moisture content and mix proportion both have an influence on both thermal conductivity as well as specific heat.

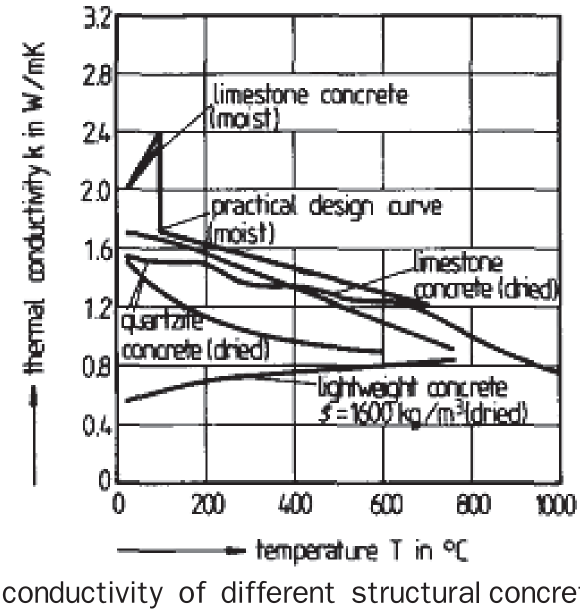

Figure 4. Thermal conductivity of different structural concretes.
(*Source- Ulrich Schneider* (*1988*))

Specific heat: Specific heat is the amount of heat energy required to raise the temperature of a unit quantity substance by a certain temperature interval. Harmathy (1970) showed the variation in the specific heat of cement paste, aggregate and concrete as a function of temperature. The specific heat value shows increase with rising temperature.

The extra heat is required in a certain temperature range and specific heat value shows some peaks as water in concrete at different phase get released. This nature was observed in the experiments conducted by Kodur and Sultan (2003). Specific heat was expressed in terms of thermal capacity, which is a product of specific heat and density.

The Eurocode 2 Part 1-2 (1996) also provides some relations to calculate thermal conductivity and specific heat as a function of temperature.

2.4 Effect of High Temperature on Steel

Steel is one of the widely used materials in the construction industry. Many structures are now a day built with the steel as the main structural material. Steel is also a common material used in reinforced concrete structures as reinforcement.

Load bearing capacity of RC structure reduces as steel reinforcement exposes to higher temperatures. Thus in the study of fire effects it is important to know the properties of steel at higher temperatures. Critical temperature for the steel reinforcement is generally known to be above 500^0 C. After this temperature steel starts loosing it strength rapidly.

Effect of higher temperature on steel has been widely studied.

Takeuchi et al. (1993) carried out experiments to see the effect of high temperature on properties of reinforcing steel. For temperature up to 300^0C, there was very little variation in strength of steel but above this value strength decreases with increasing temperature. The Young's modulus also decreases with increasing temperature.

Fletcher at el. (2007) reviewed relevant research on the concrete and concrete structures, including performance of reinforcing steel. It may be noted that reinforcement steel and concrete shows same expansion up to 400^0C. After that steel expands faster than concrete. At temperatures near to 700^0C load bearing capacity reduces to 20% of the designed value.

The mechanical properties of structural reinforcement steel have been investigated by Unluoglu et al. (2007). The study was carried out to know the concrete cover effect on reinforced concrete bars exposed to high temperatures. An experiment was carried onto the steel, embedded in mortar with the cover of 25 mm. Then the residual strength was verified with plain steel exposed to higher temperature. It was observed that cover provides protection to reinforcement in the case of higher temperatures. Up to 500^0C temperatures, reinforcement with cover has shown very little variation in yield and tensile strength. He had also shown the variation in strength in steel exposed to high temperature. According to his results strength reduction after exposure to 600^0C was higher.

According to Eurocode 2, part 1-2, the yield strength of reinforcing steel is assumed to be same for temperature up to 400^0C but there is a decrease in yield strength beyond 400^0C and yield strength reduces to 50% at temperature about 590^0C. According to ASTM E119 standards, the temperature in the reinforcing bar used as tension reinforcement shall not exceed 593^0C.

Thus it can be said that the critical temperature for the reinforcing bars is between 500^0C and 600^0C. The purpose of the concrete cover is to protect the reinforcement from this high temperature for the design duration of the fire.

3. MODELING RISING SURFACE TEMPERATURE IN RC STRUCTURE

The surface temperature depends on the fire temperature. Thus calculating the fire temperature helps in determining the surface temperature of concrete in RC structures.

Mathematical modeling for compartment fire temperature has been done by several research groups. The primary objective of compartment fire modeling is to determine the gas temperature for the design purpose. The final purpose of any theoretical study of compartment fires is to develop purposeful design procedures by means of which the destructive effect of building fires can be kept at a low level.

The physical basis for the theoretical simulation of compartment fires is the heat balance equation. Thus the mathematical formulation has been developed to calculate the gas temperature within the compartment using the heat balance equation. The highest values of the effective heat flux occur at the critical values of the ventilation parameter. To achieve the protection against the high temperature in a compartment large ventilation openings were recommended. In the case of high fire loads, selecting low compartment heights is also an effective way of reducing the severity of fire.

Use of fire-resistant elements for compartment boundaries may not be required to avoid possible structural damages. By proper design much more protection can be achieved.

Takeyoshi Tanaka et al. (1993) have carried out a study for ventilation controlled fire temperatures using the simple formulation. The pre-flashover room temperature equations developed earlier was extended to obtain simple equations for ventilation controlled fire temperature for the room of assumed dimensions and corridor connected to the room. The time temperature curve was obtained for the room as well as for the corridor.

Andrew Buchanan (2001) in his book described the compartment fire in details. The pre and post flashover fires has discussed in chapter number 4. In the post flashover fires the ventilation as well as fuel controlled fires was discussed. The ventilation parameter has been discussed along with the issue addressing the multiple openings in the compartment.

Gas temperature within the compartment depends upon the heat release rate as well as the losses through the compartment by the means of radiation, convection through an opening and conduction through the concrete walls. The time-temperature curves depending upon the ventilation factor and fuel load has been provided from the different referred material, which are necessary for designing purpose.

3.1 Modelling for Temperature within Concrete

Temperature distribution within the concrete wall or slab/floor needs to be calculated to design a nominal cover value for the reinforcement. In order to calculate the performance of a building element, the temperature distribution within it need to be evaluated, which requires the relevant material properties and their temperature dependence.

Finite difference method is very common and simple method for the one dimensional heat analysis purpose. Lie (1978) used the finite difference method to calculate the temperature history of the slab. The composite slab was assumed to be of concrete having different thermal properties and thickness. The slab was divided into a number of small segments of the same size except the boundaries where half the thickness of the element was assumed. The one dimensional heat conduction was assumed. The temperature atone boundary was increasing because of the fire. This fire temperature was calculated by the ASTM E119 standard fire equation. For each boundary the boundary condition was applied and then finally all the equations were derived to calculate the temperature at each point for time‘t’ using the temperature at time ‘t-dt.’ Here ‘dt’ was an assumed time step.

The temperature dependent material properties were used. The results were generated until the critical temperature at the reinforcing level (assumed as1100^{0}F) or the temperature at unexposed face (assumed as 250^{0}F) exceeded the decided value. The results from modelling were compared with the available experimental data. Using this method the simple approximate formulas are developed to calculate the fire resistance and concrete cover for the composite type of slabs.

Wickstrom and Hadziselimovic (1996) used the finite element computer program called TASEF to calculate the temperature variation within the concrete. The study was one dimensional analysis with the ISO 834 fire curve being used to calculate the fire temperature. The critical temperature was assumed to be 500^{0}C for the reinforcement.

Specific heat and density were assumed to be constant during the temperature variation whereas thermal conductivity was assumed to vary with temperature. The temperature at different depths as function of time was plotted in the graphs.

Jonas Palm (1994) did the temperature analysis for circular enclosure, beam and a slab using the software ABAQUS. The results are verified with the obtained one by TASEF and SUPER-TASEF. The analysis was two dimensional with temperature dependent material properties as described in the paper.

The structures were exposed to the standard ISO 834 fire.

Kodur et al. (2005) applied a one dimensional numerical model to analyze FRP- reinforced slabs. The results of the model validated with the experimental data. Parametric studies were also carried out to investigate the effect of a range of parameters on the fire performance of FRP slabs. The model developed by lie (1992) for simple composite slabs was used for one dimensional numerical analysis. The slab was divided into number of layer of small uniform thickness with boundary layer of half the thickness. The temperature dependent material properties were used which are available in the program for 4 different types of materials. The limiting criteria were used as per the ASTM E119 standards. After the results from the analysis were validated with the experimental parametric study was performed. In parametric study effect of slab thickness, cover thickness, aggregate type, reinforcement type etc. were discussed.

4. STANDARDIZATION FOR FIRE RESISTANCE

Standard fire test are sometimes performed to determine the fire resistance of elements of buildings to determine the time for which the specimen satisfies the standard failure criteria. Fire resistance of structural elements depends on the load bearing criteria, insulation criteria and integrity criteria. In load bearing criteria, structural member should carry the loads during the entire fire duration. Integrity means the member should not form cracks, holes or any passage to the hot gasses or flames from one side to another. An insulation criterion is achieved when the temperature at the unexposed face should not increase beyond a certain limit. For different members of structures combinations of these criteria are used to determine its fire resistance rating. (ASTM E119, IS 3809).

The temperature at different level within the wall can also be monitored and data can be used for designing the structure for fire. These fire tests are reliable if performed properly but are not easy to perform and they are expensive too.

4.1 Fire Curves

ASTM and ISO fire curves: The time temperature curve used in the fire resistance test is standard fire curve. The most excepted standard fire curves are provided by ASTM standard E119 and ISO 834. Mostly other country codes are based on these two curves (Buchannan, Structural design of fire safety, 2001). ISO 834 gives the fire time temperature relationship by the equation,

$$T = T_0 345 Log_{10}(8t+1)$$

where T_0 is ambient temperature in ^{0}C and t is time in minutes. ASTM E119 standard has gives the standard fire curve and also the points of curves that determine its character. The equations approximating the ASTM curve are developed and one of them is as follows, (Buchanan, 2001)

$$T = T_0 + 750 = \left[1 - e^{-3.79533\sqrt{t}}\right] + 170.41\sqrt{t}$$

where t is time in hours.

The Indian standard fire curve given in IS 3809 is based on the ISO 834 standard fire curve. The equation to calculate the fire temperature at any time is same as ISO 834 standard fire equation.

Euro code parametric fires: A fire temperature in a typical compartment fire is a function of fuel amount, openings and the thermal properties of the boundaries of compartment. The drawback of standard fire curves provided by ISO 834 and ASTM E119, are not realistic as temperature of the standard fire continues to increase with time and geometry and properties of the compartment are not considered (Lewis, 2000). The decaying phase has also been included in Eurocode as fuel in the compartment is going to end at some time.

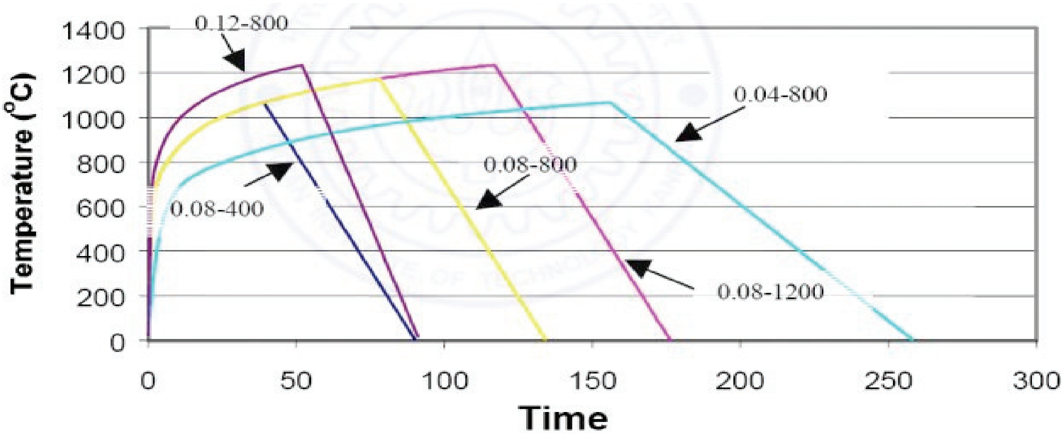

Figure 5. Eurocode fires with varying ventilation factors and fuel loads (*Lewis, 2000*)

Figure 5 shows the standard fire curves generated, for different ventilation factors and fuel loads considering material properties to be constant (with respect to temperature) by using equations given by Eurocode. These curves are for ventilation controlled fire without considering the effect of fuel load on the fire temperatures.

The widely referred standard fire curves are those generated by Magnusson and Thelandersson (1974) and generally known as Swedish fire curves. They are derived from heat balance calculations, using Kawagoe's equation for the burning rate of ventilation controlled fires. The curves are calculated for fixed values of thermal properties of material (K, C and ρ). The rising branch of the curve for an opening factor of 0.04 is very similar to the ISO 834 standard time–temperature curve (Feasey & Buchanan, 2002). These curves for opening factor of 0.04 and for different fuel load in MJ/m^2 given below in Figure 6.

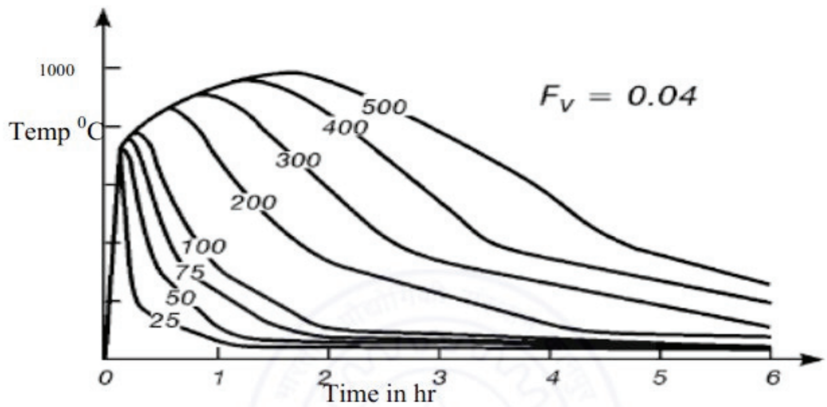

Figure 6. Time–temperature curves for different opening factors and fuel loads (*Feasey & Buchanan, 2002*).

Therefore using either the compartment fire theory or the Standard fire curves, fire temperature can be calculated.

4.2 Requirements of Concrete Cover

The reinforcement bars in a concrete structure are protected against fire only by the concrete cover layer. These structures lose their load bearing capacity when reinforcement gets exposed to the higher temperature. Steel starts losing its strength after 500^{0}C. Concrete strength also significantly reduced after this temperature. Fire causes the high temperatures in RC structures, and fire temperature may reaches 1000^{0}C to 1200^{0}C, and as duration of fire gets longer; there is always a chance that temperature within concrete at the level of reinforcement exceeds the critical value. There are many factors which can affect the fire temperature. They can be listed as follows;

- The size and shape of the compartment/room,
- The fuel properties such as, amount, distribution and type of fuel in the enclosure,
- The openings in the compartment, their amount, distribution and form
- The form and type of construction materials for the roof (or ceiling), walls and floor of the enclosure.

It is always beneficial to control the temperature at reinforcing bars by controlling the fire temperature. Temperature at reinforcing bar is dependent on the surface temperature of concrete (or fire temperature), cover thickness to reinforcement, duration of fire and material properties of concrete.

Cover to the reinforcement is directly affecting the temperature in reinforcing bars. Higher is the cover more is the resistance and vice a versa. Concrete is less conductive than steel, thus temperature at the reinforcing bar is not as high as surface temperature. This is why concrete acts as barrier to higher temperature. But as duration of fire increases temperature inside the concrete keeps increasing. Therefore it is very important to provide sufficient cover to reinforcement to protect it from higher temperature for decided duration.

ACI provisions: Depending on concrete surface exposure to earth or whether different cover thicknesses to protect the reinforcement are given in its section 7.7.1. These conditions are based on moisture changes and not only on temperature change. The minimum cover thickness is 20 mm (0.75 in) for no direct exposure conditions. For exposed concrete minimum cover is 50 mm (2 in). In case of corrosive environments, concrete proportioning are modify accordingly. Additionally minimum of 50 mm (2 in) cover for walls/slabs and 65 mm (2-1/2 in) for other members is recommended. In case of fire resistance criteria, additional cover if required should be provided.

Eurocode provisions: In Eurocode 2 part 1-2, the cover requirement for reinforcement is given for different concrete members. The critical temperature for reinforcement is taken as 500^{0}C. Accordingly the member dimensions and minimum cover thickness values are given in tabular form for different hour of fire resistance. Minimum cover thickness for fire resistance of 1 hr and more is 20 mm. Therefore according to critical temperature minimum cover can be obtained for a particular fire resistance.

Indian Standard IS456 provisions: In IS 456 concrete cover thickness to the reinforcement is determined based on durability requirements and fire resistance requirements. Cover thickness requirements from the durability point of view are given by classifying the environment from mild to extreme (in 5 steps) and having the minimum cover ranging from 20 to 75 mm.

Fire resistance criteria: It is said that structure should have adequate fire resistance to flame penetration, heat transmission and failure. Fire resistance is measured in terms of time in hours as per IS 1642. The fire resistance of an element of structure or combination of elements is determined from either research data available or the fire resistance test carried out in laboratory as per IS 3809. According to IS 456 the fire resistance is dependent on size of member, cover to reinforcement and properties of concrete. Minimum sizes of members are given in “Figure 1” in IS 456. The minimum cover required for appropriate fire resistance for the different members is given in Table 1.1.

Table 2. Nominal cover to meet specified period of fire resistance (IS 456)

Fire Resistance Hr	Nominal cover in mm						
	Beam		Slab		Ribs		Column
	SS	C	SS	C	SS	C	
0.5	20	20	20	20	20	20	40
1	20	20	20	20	20	20	40
1.5	20	20	25	20	35	20	40
2	40	30	35	25	45	35	40
3	60	40	45	35	55	45	40
4	70	50	55	45	65	55	40

This data is only applicable for a normal weight aggregate concrete. Further, a fire test can be performed to have a better understanding of the behaviour of member in fire. This test method is described in IS 3809.

IS 1642 has also provides the data for minimum dimensions and cover thickness for various kinds of building members. The size and cover is given according to fire resistance as well as the importance of the building.

5. CONCLUSION

Controlling the fire temperature can reduce the demand of cover thickness. Fire temperature can be controlled by increasing the compartment size, reducing the openings. The components of concrete cement and aggregate are chemically inert and hence virtually non-combustible. Because of the slow rate of heat transfer of concrete, it acts as a fire shield, protecting adjacent rooms from flames and maintaining its structural integrity despite exposure to intense heat. Cover to the reinforcement is directly affecting the temperature in reinforcing bars. The higher is the cover more is the resistance and vice a versa. Concrete is less conductive than steel, thus the temperature of the reinforcing bar is not as high as surface temperature. Previous researches showed that reinforcement steel and concrete shows same expansion up to 400^0C. After that steel expands faster than concrete. At temperature near to 700^0C load bearing capacity reduces to 20% of the designed value. Thermal conductivity of concrete varies with temperature. In general, thermal conductivity of concrete decreases with increase in temperature.

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