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A Case Study on Behaviour of Reinforcing Bars and Concrete in RCC Structure Exposed to Fire

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ABSTRACT: In this modern era, most of the buildings all over the world are made up of RCC. The increasing incidents of fire in buildings have increased the importance of assessment; repairs and rehabilitation of such buildings as these buildings are very costly. This field needs special expertise in many areas viz. concrete technology, structural engineering, material testing, and repairs and maintenance etc. A continuous effort through research and development programmes all over the world is being made in this specialized field. This topic gives us immense pleasure as we deal with the real life problems in this research. In this research, we gain the knowledge which is being used as a strategy for the rehabilitation of fire damaged buildings and by conducting proper assessment procedures by non-destructive techniques. In this research, we did various experiments so as to find out the effect of fire on the reinforcing bars in RCC buildings by taking 6 samples at 110°, 310°, 610°, 900° each for 3 hours. After heating the samples, they are cooled quickly by quenching in water and normally by air cooling. It is seen that there is a change in the mechanical properties of samples which are studied under universal testing machine (UTM) and for close look at reinforcing bars in a fire damaged structure, scanning electron microscope (SEM) is used. From conclusions, it is seen that most of the fire damaged RCC are restorable. The mechanical properties of all common building materials decrease with the elevation of temperature. The behavior of a RCC in fire conditions is governed by properties of constituent materials, concrete and steel at high temperature. Both concrete and steel undergo considerable change in their strength, physical properties, and stiffness by the effects of heating. It is also seen that above 900°C some of these changes are not recoverable after subsequent cooling.

KEYWORDS: Universal Testing Machine, Scanning Electron Microscope, Fire, Rehabilitation

I. INTRODUCTION

In this modern era, most of the buildings all over the world are made up of RCC. The increasing incidents of fire in buildings have increased the importance of assessment; repairs and rehabilitation of such buildings as these buildings are very costly. This field needs special expertise in many areas viz. concrete technology, structural engineering, material testing, and repairs and maintenance etc. A continuous effort through research and development programmes all over the world is being made in this specialized field. As there can be fire in any type of structure but because of this, such type of structures cannot be ignored. For rehabilitation of such type of structures after fire to make them structurally functional, it has given civil engineers a tough challenge. Firstly civil engineers have to find the amount of damage caused to the structure by the fire. The difficulty starts from where to start the rehabilitation work and how to work on such type of structures. It is, therefore, important to build such type of structures that are efficient enough to prevent the loss of life as well as property. Annual statistics regarding fire showing loss in residential buildings, offices, industries etc can be used for the development of fire safety design.

As we know that damages due to fire can lead to loss of human life, property and livelihood. As per the World



Fire Statistics 2018, a survey of 14 industrialized countries (12 in Europe, USA, Canada and Japan) found that, the human lives lost due to fire in a typical year amounted to about 1.5% to 2.6% per 1,00,000 inhabitants and the total damage of property amounted to 0.3% to 0.4% of Gross National Income (GNI). As per the National Fire Protection Association (NFPA's) statistical data about USA for the year 2017 showed that United States fire departments responded to an estimated 1,219,500 fires in 2017. These fires resulted in 3,350 civilian fire fatalities, 13,670 civilian fire injuries and an estimated \$22 billion in direct property loss. Fire Fatalities UK showed that fire deaths in England increased sharply last year. There were 335 fire deaths in England (including 71 at Grenfell). This is the worst year for fire deaths since 2010-2011. Fire-related fatalities in England rose by a quarter between 2016-17 and 2017-18 from 260 to 330. The amount of damage caused by fire in a RCC structure depends on a number of factors such as structural design and performance aspects, fire fighting equipments and evacuation plans provided in a building. Fire safety standards like working fire alarms, fire extinguishers, proper ingress and egress, hazardous materials, flammable material storage and maximum occupancy are important for the safety of people in case of fire in a building. They assume greater importance. For the fire safety construction, it is necessary to have proper design and choice of materials. Codes and Regulations on fire safety in buildings should be updated from time to time through conducting proper research and development.

II. HISTORY OF STUDY

Pietro Croce (2001) developed a method which is illustrated for assessing the fire damage occurred to the RCC buildings. For close look of reinforcing bars in a fire damaged structure is investigated by **Wei Lin (2006)** by using Scanning Electron Microscope (SEM) and Stereoscopic or Dissecting microscope for concrete by heating it to a temperature of about 950°C to get good visualization of concrete to understand the behaviour of concrete in fire which would have been impossible with the naked eye. Post fire curing effect on the strength and durability recovery was investigated by **Chi Sun Poon (2001)**. **M.A. Riley** from Sir William Halerow and Partners (1991) has given "Possible new methods for assessment of fire damaged buildings". Assessment of fire damaged structures by using colour image analysis by **N.R. Short**. The effects of rapid cooling by water quenching on the stiffness properties of fire-damaged concrete was studied by **A.Y Nassif** of London University in the year 1999.

III. MATERIAL

Steel is an alloy of iron and carbon and some other materials or Steel is a generic term for family of iron and carbon alloy which are malleable, within some temperature range, immediately after solidification from the molten state. Steel is widely used in construction field because of its high tensile strength and low cost. Base metal of steel is iron, which is able to take on two crystalline forms (allotropic forms), body centered cubic and face centered cubic (FCC), depending on its temperature. In the body-centered cubic arrangement, there is an iron atom in the centre of each cube, and in the face-centered cubic, there is one at the center of each of the six faces of the cube. Carbon, other elements, and inclusions within iron act as hardening agents that prevent the movement of dislocations that otherwise occur in the crystal lattices of iron atoms. Carbon in typical steel alloys may contribute up to 2.1% of its weight. Presence of carbon in steel retard the movement of those dislocations that make iron comparatively ductile and weak, and thus controls its qualities such as the hardness, ductility, and tensile strength of the resulting steel. Steel's strength compared to pure iron is only possible at the expense of iron's ductility, of which iron has an excess.

Concrete is a composite material consist of cement sand, aggregate combined with water which has relatively high compressive strength, but significantly lower tensile strength. Cement, usually in powder form, acts as a binding agent when mixed with water and aggregates. This combination, or concrete mix, will be poured and harden into the durable material with which we are all familiar. The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing.

Designations of concrete are based on proportion of cement, sand and aggregates, and given grade to them. IS 456 - 2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm². The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix

proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

IV. LITERATURE REVIEW ON ACTION OF REINFORCING BARS AND CONCRETE IN RCC STRUCTURE SENSITIVE TO FIRE

IA. Fletcher, Stephen Welch, Jose'L. Torero, Richard O. Carvel, Asif Usmani (2017) has investigated that steel has higher degree of performance than concrete during a fire and the strength of steel can be found out with more accuracy. It is seen that steel reinforcement bars need to be protected from temperature above 300°C-350°C. This is due to reason that steels with low carbon content shows "blue brittleness" between temperatures of about 250°C-300°C. Reinforcing bars and concrete shows similar thermal expansion up to 450°C; however, higher temperatures will result in more expansion of steel as compared to concrete and if the temperature exceeds 750°C, the load bearing capacity of steel reinforcing bars decreases to about 20% of design value.

MA Riley, Msc. "Possible new method for the assessment of fire damaged structures" of Sir William Halcrow and Partners (1991) has investigated that the bonding between reinforcing bars and concrete in RCC structures are evaluated at elevated temperatures. 40 modified pull-out specimen of size (100×100×300) mm³ were prepared with High Strength Concrete with Basalt aggregates and three types of fibres namely brass-coated steel fibre, hooked steel fibre and high modulus polypropylene fibre cured for 27 days at 40°C. After this, these specimens were then subjected to higher temperatures of about 300°C-700°C, whereas unheated (control) ones were left in the laboratory air. The overall results of the controlled and heat-damaged specimen, pulled out up to failure and amount of cracking of the two specimen were noted. Cubes of standard size (100×100×100) mm³ were casted, cured and heated under similar conditions to conduct compressive strength and splitting strength. The results showed reduction in residual compressive strength and steel concrete bond at high temperatures. By using fibres results in the minimization of damage in steel concrete bond at elevated temperatures and reduces damage to bond strength. Specimen incorporated with hooked steel fibres attain highest bond strength against elevated temperature, followed by those prepared with mixture of hooked steel and polypropylene, and brass coated steel fibres. Statistical models for bond stress vs free end slip and bond strength vs exposure temperature were developed. These show excellent agreement with the trend behavior of present experimental data.

S M. Allam, HMF Elbarky and AG Rabeai (2013) has investigated "The behavior of reinforced concrete one way slabs under fire loading" which has been studied by many researchers for decades. As we know that with the increase of temperature, the slab fire resistance decreases. The reason for this is that when we expose concrete to heat, physical and chemical changes occur which leads to the loss of moisture, dehydration of cement paste and decomposition of aggregates. Due to these reasons, pore pressure increases due to evaporation of water, development of internal micro cracks and damages appear on concrete. With the increase of temperature, yield strength of steel reinforcement decreases. Also high temperature leads to spalling of concrete thereby reducing its fire resistance. Spalling of concrete is caused by its high pore pressure raised during heating. High Strength Concrete is more susceptible to this high pore pressure because of its low permeability compared to Normal Strength Concrete. Therefore, HCS has less fire resistance than NSC. The behavior of concrete slab exposed to fire is very sensible to the end restrain conditions and the stiffness. The fire resistance of one way restrained slab is generally higher than the unrestrained slabs because, compressive restrain in the surrounding structure decrease the slab thermal expansion. It is also known that cover of slabs have significant effect on the fire resistance. Codes of practice states that the temperature rise leads to degradation of strength in both concrete and steel reinforcement based on aggregate type and grade of steel.

WM Lin, TD Lin and L.J. Powers-Couche (1996) have investigated "Microstructure of fire damaged concrete". They use the results of Scanning Electron Microscope (SEM) and stereo-microscopy investigation of fire damaged concrete. Samples taken either from the concrete subjected to heating and cooled by quenching in water in the laboratory or taken from concrete exposed to fire in the field. From SEM photographs, a clear chronological pattern of failure mechanism can be visualized.

Dr. Luke A Bisby, Dr Mark F Green and Dr. Venkatesh R. Kodur (2005) have studied "Response to fire of concrete structures that incorporate FRP". Various researchers after years of investigation found that fire-reinforced polymers (FRP) used for reinforcing and

strengthening of concrete structures. They are widely used to overcome the ongoing struggle against deterioration caused by fire. The application of FRP's in the field is limited to bridges where fire is not the primary consideration for design because; FRP materials are combustible and susceptible to the deterioration of mechanical and bond properties at high temperatures. There is a concern that FRP's will perform poorly in fire. This paper presents a review to investigate fire performance of FRP materials during fire.

Lateef O. Onundi, M. Ben Oumarou and Abba M. Alkali (2019) has investigated “**Effects of fire on the strength of the structural members**”. In this, researchers' main focus was on the effect of fire on the structures due to the Boko Haram Insurgency in Maiduguri, Northern Nigeria. In this research, it was also studied to understand the effect of fire with respect to local aggregates, quenching process and proposed assessment methodology based on analytic methods applied to RCC structures subjected to fire. In this research, SEM tests were carried out with Prox scanning electron microscope for imaging and analysis to physical examine and determine the microstructure redistribution and influence on the test samples.

GA Khoury (1992) studied “**the compressive strength of concrete at high temperatures**”. It was seen that it varies from concrete to concrete depending upon its constituents and also on the type of external loading, heating and moisture.

It also experiences thermal strain and shrinkage due to heating. Excess heating of the structure results in the explosive spalling having serious consequences on the structure. Explosive spalling have two mechanisms namely thermal stress spalling and pore pressure spalling. Thermal stress spalling could be reduced by using thermally stable aggregates of low expansion, whereas latter could be reduced by the use of polypropylene fibre in the mix.

9-11 attack on the World Trade Centre New York, USA gave rise to lot of interest in the design of structures for fire resistant. Some engineers have starting using advanced analytic method for fire determination of fire growth in any area of the building and using FEM for the determination of temperature within any area by heat transfer analysis. With the help of heat transfer analysis, mechanical properties at various temperatures during the fire period can be determined.

V. CONCLUSION

Based on the above study, the following observations are made regarding behavior of reinforcing bars and concrete in a RCC structure when exposed to fire:

- The effect of fire when reinforcing bars and concrete in a RCC structure are exposed to temperatures of 120°C, 320°C, 620°C and 920°C when cooled rapidly by quenching in water and normally cooled in atmospheric temperature shows that ductility reduces when rapidly cooled by quenching in water after heating to a temperature of 920°C.
- It is also observed that there is change the mechanical properties of the bars studied by tensile strength testing under UTM shows there is increase in ultimate strength and decrease in percentage elongation of the specimen implies there is significant decrease in ductility of these reinforcing bars.
- By studying the microstructure of the bars by Scanning Electron Microscope (SEM) shows that there is no change in the chemical composition of the microstructure when exposed to high temperatures.

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