IMPACT OF FIRE ON STEEL REINFORCEMENT OF R.C.C STRUCTURES

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Technology
in
STRUCTURAL ENGINEERING

By

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Department of Civil Engineering
National Institute Of Technology
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Under the Guidance of
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CERTIFICATE

This is to certify that the thesis titled **"IMPACT OF FIRE ON STEEL REINFORCEMENT OF R.C.C STRUCTURES"**, submitted to the National Institute of Technology, Rourkela by **Mr. Raja Sekhar Mamillapalli**, Roll No. **207CE210** for the award of the degree of Master of Technology in **Civil Engineering** ***(Structural engineering)***, is a bonafide record of research work carried out by him under my supervision and guidance. The candidate has fulfilled all the prescribed requirements. The thesis, which is based on candidate's own work, has not been submitted elsewhere for a degree/diploma.

Prof. Uttam Kumar Mishra
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Date: 26th May 2009
Place: Rourkela

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RAJA SEKHAR MAMILLAPALLI

CONTENTS

ABSTRACT

With the increased incidents of major fires in buildings; assessment, repairs and rehabilitation of fire damaged structures has become a topical interest. This is a specialized field involves expertise in many areas like concrete technology, material science and testing, structural engineering, repair materials and techniques etc. Research and developmental efforts are being carried out in this area and other related disciplines. In this topic the experience of real life problems are presented which add immense value to this. This topic also gives a comprehensive knowledge on the overall strategy for the restoration of fire damaged buildings and also presents a critical appraisal of the assessment procedures by different non destructive techniques, specifications and execution of repair techniques.

The experimentation has been done to find out the impact of the fire on reinforcement steel bars by heating the bars to 100°,300°,600°,900° centigrade of 6 samples each. The heated samples are rapidly cooled by quenching in water and normally by air cooling. The change in the mechanical properties are studied using universal testing machine (UTM) and the microscopic study of grain size and grain structure is studied by scanning electron microscope (SEM).

The general conclusion is that majority of fire damaged RCC structures are repairable. But the impact of elevated temperature above 900°C on the reinforcement bars was observed that there is significant reduction in ductility when rapidly cooled by quenching. In the same case when cooled in normal atmospheric conditions the impact of temperature on ductility is not high. By heating the reinforcement bars, the mechanical properties can be changed without varying the chemical composition.

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Chapter 1

INTRODUCTION

1.INTRODUCTION

With the increased incidents of major fires and fire accidents in buildings; assessment, repair and rehabilitation of fire damaged structures has become a topical interest. This specialized field involves expertise in many areas like concrete technology, material science and testing, structural engineering, repair materials and techniques etc. Research and development efforts are being carried out in these related disciplines. Any structure can undergo fire accident, but because of this the structure cannot be denied neither abandoned. To make a structure functionally viable after the damage due to fire has become a challenge for the civil engineering community. The problem is where to start and how to proceed. It is vitally important that we create buildings and structures that protect both people and property as effectively as possible. Annual statistics on losses caused by fires in homes and elsewhere make for some unpleasant readings and sadly through these events we learn more about fire safety design.

We are all aware of the damage that fire can cause in terms of loss of life, homes and livelihoods. A study of 16 industrialized nations (13 in Europe plus the USA, Canada and Japan) found that, in a typical year, the number of people killed by fires was 1 to 2 per 100,000 inhabitants and the total cost of fire damage amounted to 0.2% to 0.3% of GNP. In the USA specifically, statistics collected by the National Fire Protection Association (USA) for the year 2000 showed that more than 4,000 deaths, over 100,000 injuries and more than $10bn of property damage were caused by fire. UK statistics suggest that of the half a million fires per annum attended by firefighters, about one third occur in occupied buildings and these result in around 600 fatalities (almost all of which happen in dwellings). The loss of business resulting from fires in commercial and office buildings runs into millions of pounds each year. The extent of such damage depends on a number of factors such as building design and use, structural performance, fire extinguishing devices and evacuation procedures. Although fire safety standards are written with this express purpose, it is understandably the safety of people that assumes the greater importance. Appropriate design and choice of materials is crucial in ensuring fire safe construction. Codes and regulations on fire safety are updated continually, usually as a result of research and development.

An original method s illustrated for assessing the fire damage to reinforced-concrete buildings by Pietro Croce et al. Microstructure of fire damaged concrete is investigated by

Wei Lin et al [8] by using scanning electron microscope and stereo microscope for the concrete which has been heated to a temperature of 900°C to get the visual information that would otherwise be impossible to see with the naked eye will help to understand the behavior of concrete in fire. A case of assessment of the structure of Novi Sad Open was presented by R. Folic et al [6]. Strength and durability recovery of fire damaged concrete after post-fire-curing was presented by Chi-Sun poon et al [5] in 2001. M. A. Riley from Sir William Halcrow & partners Ltd has presented a ape on possible new method for the assessment of fire-damaged concrete [4]. N. R. Short et al [2] worked in the area of assessment of fire damaged concrete using color image analysis. The effects of rapid cooling by water quenching on the stiffness properties of fire-damaged concrete was studied by A. Y Nassif et al [13] of Londan University in the year 1999.

1.1 EXPERIENCE OF FIRES:

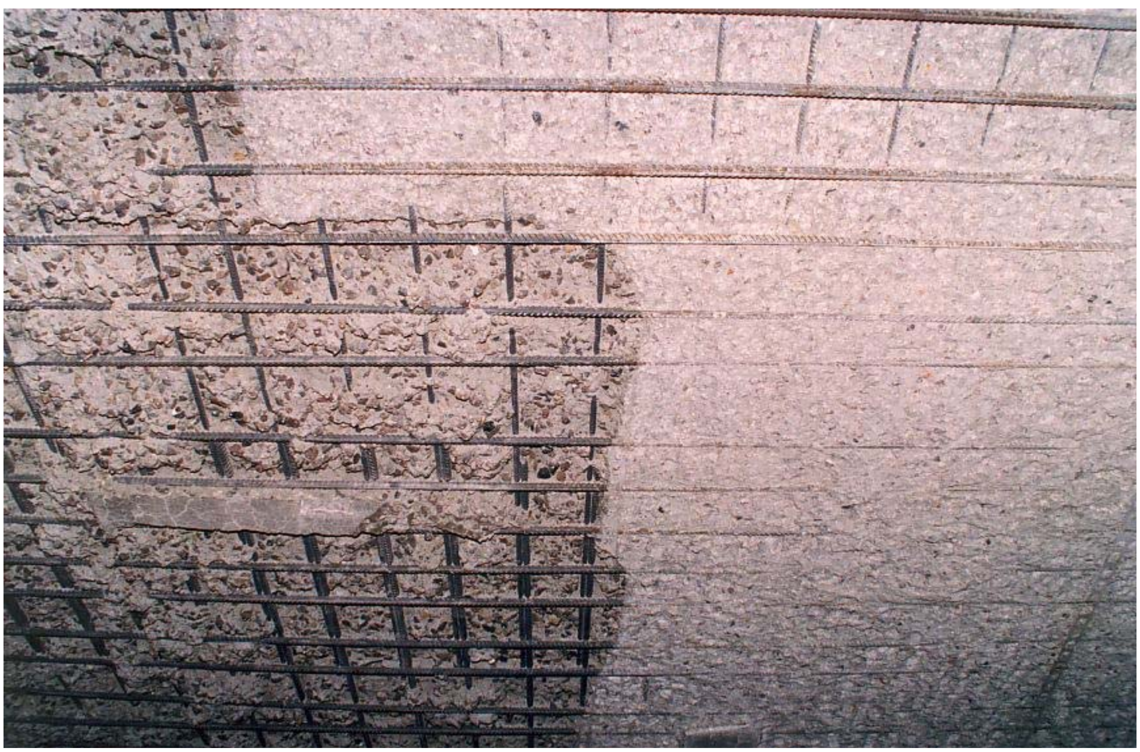

Fig 1.1: fire damaged slab

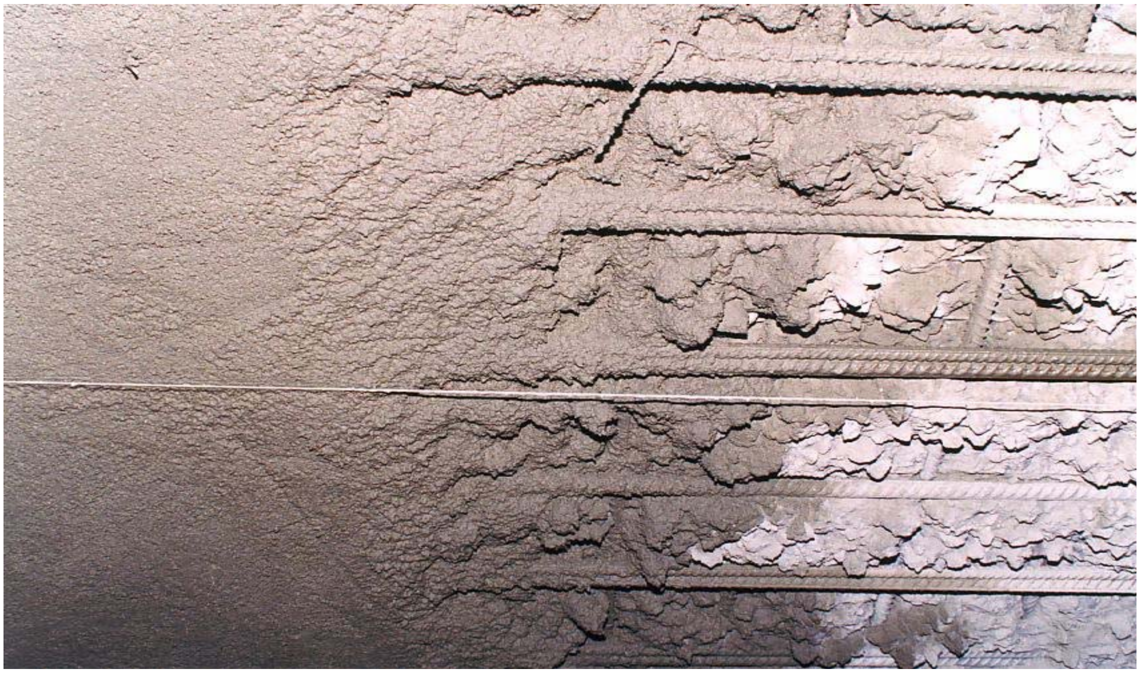

Fig 1.2: concreting of fire damaged slab

1. Most of the structures were repaired. Of those that were not, many could have been but were demolished for reasons other than the damage sustained.
2. Almost without exception, the structures performed well during and after the fire.

1.2 WHAT HAPPENS TO CONCRETE IN A FIRE

Fires are caused by accident, energy sources or natural means, but the majority of fires in buildings are caused by human error. Once a fire starts and the contents and/or materials in a building are burning, then the fire spreads via radiation, convection or conduction with flames reaching temperatures of between 600°C and 1200°C. Harm is caused by a combination of the effects of smoke and gases, which are emitted from burning materials, and the effects of flames and high air temperatures.

Concrete provides protection against heat from fire.

Fig1.3: Concrete against fire

1.3 CHANGES OF CONCRETE IN FIRE:

Concrete does not burn – it cannot be 'set on fire' like other materials in a building and it does not emit any toxic fumes when affected by fire. It will also not produce smoke or drip molten particles, unlike some plastics and metals, so it does not add to the fire load. For these reasons concrete is said to have a high degree of fire resistance and, in the majority of applications, concrete can be described as virtually 'fireproof'. This excellent performance is due in the main to concrete's constituent materials (i.e. cement and aggregates) which, when chemically combined within concrete, form a material that is essentially inert and, importantly for fire safety design, has a relatively poor thermal conductivity. It is this slow rate of heat transfer (conductivity) that enables concrete to act as an effective fire shield not only between adjacent spaces, but also to protect itself from fire damage. The rate of increase of temperature through the cross section of a concrete element is relatively slow and so internal zones do not reach the same high temperatures as a surface exposed to flames. A standard ISO 834/BS 476 fire test on 160 mm wide x 300 mm deep concrete beams has shown that, after one hour of exposure on three sides, while a temperature of 600°C is reached at 16 mm from the surface, this value halves to just 300°C at 42 mm from the surface – a temperature gradient of 300 degrees in about an inch of concrete! Even after a prolonged period, the internal temperature of concrete remains relatively low; this enables it to retain structural capacity and fire shielding properties as a separating element.

Table 1.1: concrete in fire – physiochemical process

Temperature (°C)	What happens
1000	
900	Air temperatures in fires rarely exceed this level, but flame temperatures can rise to 1200°C and beyond.
800	
700	
600	Above this temperature, concrete is not functioning at its full structural capacity.
550-600	Cement-based materials experience considerable creep and lose their loadbearing capacity.
400	
300	Strength loss starts, but in reality only the first few centimetres of concrete exposed to a fire will get any hotter than this, and internally the temperature is well below this.
250-420	Some spalling may take place, with pieces of concrete breaking away from the surface.

Changes caused by heating of various types of natural stone that may be observed visually or microscopically (compiled from Chakrabarti et al, 1996; Hajpál & Török, 2004; Koca et al, 2006 and Sippel et al, 2007)

Heating temperature	Stone type: Limestone	Sandstone	Marble	Granite
250°C 300°C 400°C	Pink or reddish-brown discoloration starts at 250-300°C but may not become visible until 400°C Discoloration becomes more redish at 400°C	Red discoloration starts at 250-300°C but may not become visible until 400°C	Heating marble through a range of temperatures causes non-reversible expansion known as thermal hysteresis	At less than 573°C, if heating rate is less than 1°C per minute the thermal expansion is fully reversible. If heating rate is greater than 5°C per minute the expansion is not totally reversible
600°C	Calcination of calcium carbonate comences at 600°C	Heating above 573°C causes internal rupturing of quartz grains with associated weakening and friability Clay minerals in the cement disintegrate (kaolinite up to 600°C, chlorite above 600°C)	Above 600°C complete disruption due to differential expansion, becomes friable and reduces to powder	Develops cracks or shatter at 573°C due to quartz expansion
800°C	Calcium carbonate calcines to a grey-white powder at 800-1000 °C with associated loss of strength	Red discoloration may persist until 1000°C Any calcium carbonate cement calcines to powder at 800-1000 °C causing disintegration		Differential thermal expansions at higher temperatures (900°C) gives rise to tensile and compressive stresses causing permanent strain in the stone
1000°C +	Melting starts	Melting starts	Melting starts	Melting starts

Table 1.2: Changes caused by heating various types of stone

The surface appearance of structural members give an idea on the extent of heat to which these members might have been subjected to during the fire. The structural conditions as observed give a great deal of information on its physical condition and help to assess the physical damage suffered by the members. As stated earlier, these information are very vital for assigning the appropriate damage classifications and planning the repair techniques. It is however to be kept in view that these are subjective observations and results would depend upon the experience and skill of the person carrying out the investigations. Inspite of these drawbacks, this information is necessary and when examined with the information received from other methods, provide a valuable tool taking decisions on type of repairs to be carried out. The various aspects covered by the spread sheets are briefly discussed below.

A) Condition of plaster and finish

The reinforced concrete structural members are either kept exposed or rendered with cement mortor which, in general in this building is 1:3 (1 cement :3 sand) in some locations these members have also been cladded with other materials (wood/marble). The condition of these finishes are catogerised and recorded into five groups; unaffected, peeling, substantial loss, total loss and destroyed.

B) Color

The color of concrete may change as a result of heat due to fire may and may give an idea of the maximum temperature attained. A correlation between the decolouration due to fire and a possible temperature attained is available in technical report no.33:assessment and repair of concrete structures by concrete society, U.K. Due to fire decolouration takes place and the possible change in concrete is normal, pink, whitish grey and puff.

Fig 1.4: Color change in the concrete due to elevated temperature

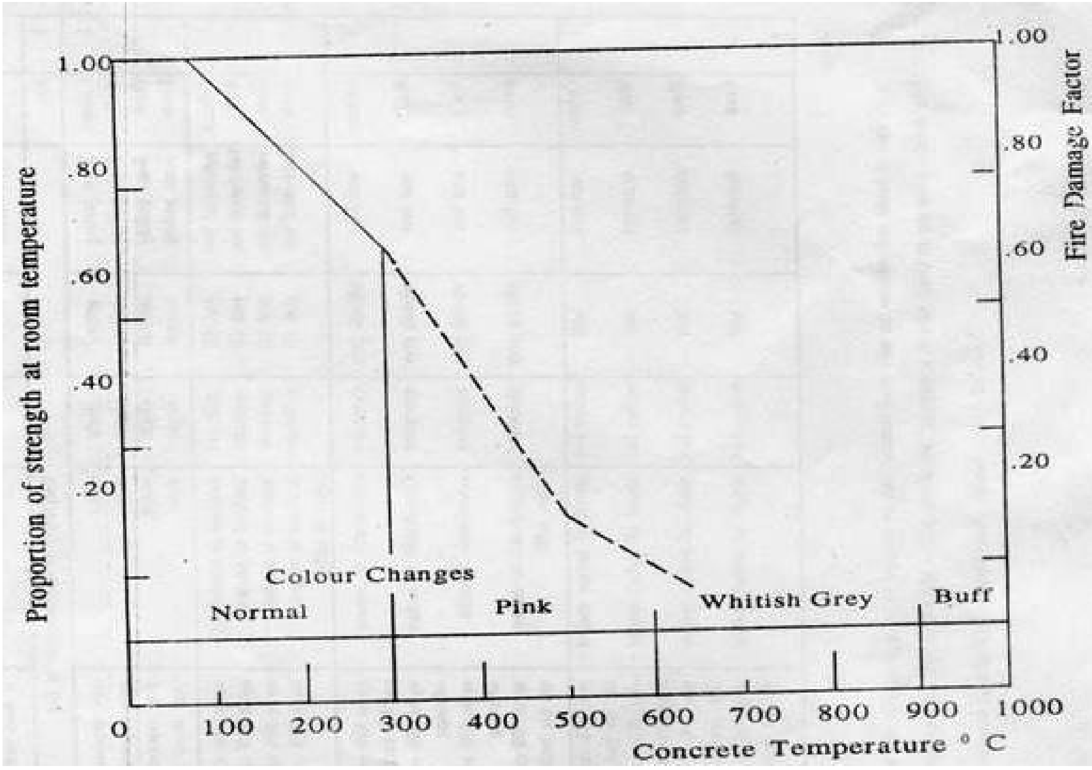

Fig 1.5: temperature vs proportion of strength at room temperature

C) Crazing

The development of fine cracks on the surface of the concrete due to sudden cooling of surface with water is termed as crazing. These fine cracks are restricted to surface layer and no structural significance on material has been accounted for. These are recorded in spread sheets under four categories; unaffected,slight, moderate, extensive and surface lost.

D) Spalling of concrete

Spalling is the deteriotion process in which a portion of concrete (particularly cover) has separated and fallen out from the bidy of the concrete member. Due to spalling, the reinforcement gets exposed, composite action between concrete and steel reinforcement is reduced. The spalling seriously affects strength, stiffness and durability of member and is important parameter in deciding the degree of damage. Five types of spalling considered; unaffected, minor, localized to corners, considerable to corners and all surface spalled.

E) Exposure condition of reinforcements correlation

The extent of exposure condition of the main reinforcement and links (stirrups) of structural members are recorded in the spread sheets with the classifications of exposure as 25%, 50% and 50% with the indication of the buckling condition of the main reinforcements.

F) Cracks

Concrete members exposed to high temperature during fire may develop severe cracks which may extend across the body of the member. These cracks observed during visual inspections are recorded in spread sheets and also in the sketches of the members. Cracking is classified as minor and major with the recording of length of cracks

G) Distortion

The extent of distortion of the structural members affected by fire in the form of deformations (deflections, twisting etc) are also recorded into three categories; none, slight but insignificant and severe and significant.

H) Delamination of concrete

Delamination of concrete means that a layer or some part of concrete has separated out from the parent body but still not fallen out. The delamination can be detected by tapping of concrete surface with light hammer. A ‘dull thud’ sound of concrete would indicatedelamination. In the spread sheets extent of delamination in terms of surface area has to be recorded.

Table 1.3: Delamination of concrete

Class of Damage	Element	Surface appearance of concrete			Structural condition			
		Condition of Plaster/finish	Colour	Crazing	Spalling	Exposure and condition of main reinforcement (1)	Cracks	Deflection/ Distortion
0	Any	Unaffected or beyond extent of fire						
1	Column	Some peeling	normal	slight	minor	none exposed	none	none
	Wall	Some peeling	normal	slight	minor	none exposed	none	none
	Floor	Some peeling	normal	slight	minor	none exposed	none	none
	Beam	Some peeling	normal	slight	minor	Very minor exposure	none	none
2	Column	Substantial loss	pink (2)	moderate	localised to corners	up to 25% exposed, none buckled	none	none
	Wall	Substantial loss	pink (2)	moderate	localised to patches	up to 10% exposed, all adhering	none	none
	Floor	Substantial loss	pink (2)	moderate	localised to patches	up to 10% exposed, all adhering	none	none
	Beam	Substantial loss	pink (2)	moderate	localised to corners minor to soffit	up to 25% exposed, none buckled	none	none
3	Column	total loss	whitish grey	extensive	considerable to corners	up to 50% exposed, not more than one bar buckled	minor	none
	Wall	total loss	whitish grey	extensive	Considerable to surface	up to 20% exposed, generally adhering	small	not significant
	Floor	total loss	whitish grey	extensive	considerable to soffit	up to 20% exposed, generally adhering	small	not significant
	Beam	total loss	whitish grey	extensive	Considerable to corners sides, soffit	up to 50% exposed not more than one bar buckled	small	not significant
4	Column	destroyed	buff	surface lost	almost all surface spalled	over 50% exposed, more than one bar buckled	major	any distortion
	Wall	destroyed	buff	surface lost	almost all surface spalled	over 20% exposed, much separated from concrete	severe and significant	severe and significant
	Floor	destroyed	buff	surface lost	almost all surface spalled	over 20% exposed, much separated from concrete	severe and significant	severe and significant
	Beam	destroyed	buff	surface lost	almost all surface spalled	over 50% exposed, more than one bar exposed	severe and Significant	" "

Notes:-

(1) In the case of beams and columns the main reinforcement shall be assumed to be in the corners only unless other information exists

(2) Pink discolouration due to ferric salts in aggregates. Not always present and seldom in calcareous aggregate.

1.4 List of tests to be conducted

Non destructive Insitu field testing

1) Ultrasonic Pulse Test (UPV):
2) Schmid hammer test
3) Core test

Laboratory Tests

1) Thermogravimetric Analysis (TGA): Thermo gravimetric analysis consists of finding change in weight of a material with increase in temperature. This plot is called a Thermogram. The loss of weight indicates decompostition or evaporation of the material. This technique allows to find out the temperature range in which a

material will remain stable and the temperature at which it would undergo decomposition.

2) Differential Thermal Analysis (DTA): The principle on which DTA is based is that when a material is slowly heated, its temperature rises but when the material undergoes any endothermic reaction viz. losing water, losing CO_2, change in crystalline structure or decomposition, its temperature remains constant. The results of DTA are presented in the form of DTA curves. The sample and an inert material are heated in separate crucibles and the difference of temperature between the two is recorded by means of thermocouples which generates an electrical signal whenever there is a temperature difference between the reference and the sample. When there is no endothermic reaction in a sample, there would not be any difference of temperature between the reference and the sample and hence no electrical signal would occur.

3) X-Ray Diffraction (XRD): X-ray diffraction technique is based on the principle that a crystal of a substance has a unique diffraction pattern. When monochromatic X-ray beam falls on a crystal it gets reflected by the various crystalline planes. Interference occurs among the various reflected beams resulting in a diffraction pattern consisting of dark and bright fringes depending upon the phase difference among the interfering beams.A crystal whose composition is unknown can be identified by obtaining its diffraction pattern and comparing it with diffraction patterns of already identified crystals. The diffraction pattern of a single crystal consists of a series of diffraction lines.

1.5 DAMAGE CLASSIFICATION OF STRUCTURAL MEMBERS:

Based on the information collected from the spread sheets indicating the condition of surface appearance of concrete (plaster/finish, colour, crazing), structural conditions and further correlated with the results of NDTS and laboratory tests, the structural members have been designated with various damage classifications. Combined with the personal experience of the expert, the visual inspection and the various tests present a fairly accurate condition of the damaged structural element. Since the reinforced concrete is a highly variable matrix, sometime the results of different tests appear to give somewhat contradictory results but with experience, these can be reconciled. Based on the damage classifications, the repair classification and repair requirements are given below;

CRITERIA FOR DAMAGE CLASSIFICATIONS:

Table 1.4: Damage classifications

Class of damage	**Repair classification**	**Repair Requirements**
Class 1	Superficial	For repair, use cement mortar trowelling using cement slurry bonding
Class 2	General	Non-structural or minor structural repairs like restoring cover to reinforcement using cement polymer slurry as bonding layer and nominal light fabric reinforcement or using epoxy mortar over the primary coat of epoxy primer. No fabric for small patches of area less than 0.09 sq.m
Class 3	Principal Repair	Where concrete strength is significantlyreduced, strengthening to be carried out with shotcreting in case of slabs and beams and jacking in case of columns. For less damaged columns shotcreting is also proposed. The bonding material used shall be epoxy formulation.Additional reinforcementshallbe provided in accordance with load carrying requirement of the member. Both residual and final strength to be checked by design procedure.
Class 4	Major repair	Repair method is demolition

TABLE - 3.4 : TABLE SHOWING VISUAL INSPECTION, NDTS & DAMAGE CLASSIFICATION OF STRUCTURAL MEMBERS

				VISUAL INSPECTION											N.D.T. & LABORATORY TESTS							DAMAGE CLASSIFICATION		
				SURFACE APPEARANCE			STRUCTURAL CONDITIONS																	
S.No	Structural Element & Its Location	Spread sheet No. (Consultants Part-II)	Grid Drg. No. (Consultants Part-III)	Condition of Plaster /Finish	Colour	Crazing	Spalling	Exposure & Condition of main reinforcement	Exposure & Condition of Links/Stirrups	Cracks	Distortion/Deflection	Const. Joint	Honeycombing	Delamination-Hollow Sounding	Ultrasonic Pulse Velocity Km/Sec.	Rebound Indices	Condition of concrete as per Ultrasonic Pulse Velocity	Equivalent cube strength of concrete from cores N/mm²	D.T.A Test (NCCBM)	X.R.D. Test (NCCBM)	T.G.A. Test (Consultant)	Consultant	Department	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A-Columns **Auditorium** 2nd Floor Level to Terrace																								
(i)	A28	3	7,7A	Destroyed	Normal	Surface Lost	All Most All Surface Lost	Over 50% Exposed More Than One Bar Buckled	Over 50% Exposed	Minor	Not Signi-ficant	2	1.0 M²	0.1 M²	U.P.V Not Possible Due To Cracked conc.	-	Poor	13.21	Temp> 500°C (0-3 cm From surface)	-	-	4	4	
(ii)	A17	4	7,7A	Some Peeling	Not Accessible	Slight	Un-Affe-cted	None Exposed	None Exposed	Major 1.0M	Severe & Signi-ficant	2	-	0.5 M²	0 - 3.54	-	Poor To Medium	9.00	Temp> 500°C (0-2.5cm From Surface) Ref. Fig.15	-	200-300°C Sample No.34	3	3 4 At Nib Portion Ref. TGA	
1st Floor Level to 2nd Floor Level																								
(i)	A65	5	9,9A	Destroyed	Whitish Grey	Surface Lost	Almost All Surface Spalled	Over 50% Exposed No Bar Buckled	Over 50% Exposed	Major 2.5M	Severe & Signi-ficant	2	0.5 M²	1.5 M²	0 - 1.60	-	Poor	One Broken Core Obtained	Temp> 500°C Ref.Fig.15	-	-	4	D	D=Demolish
(ii)	A62	5	9,9A	Destroyed	Whitish Grey	Surface Lost	Almost All Surface Spalled	Over 50% Exposed No Bar Buckled	Over 50% Exposed	Major 3.0M	None	2	0.3 M²	2.0 M²	-Do-	-	-Do-	-Do-	-Do-	-	-	4	D	
(iii)	A28	6	10,10A	Destroyed	Normal	Moderate	Localised To Corners	None Exposed	None Exposed	Major 0.4M	Not Signi-ficant	2	0.4 M²	0.2 M²	i)3.55-3.93 (Up to 1.5M Height) ii)3.06-3.00	38-52 -	Good Medium	22.44, 28.76	Temp> 500°C Ref. Fig15	-	-	2	3	
(iv)	A27	6	10,10A	Destroyed	Pink	Extensive	Consider-able To Corners	Up to 50% Exposed Not More-Than One Bar Buckled	Up to 25% Exposed	None	None	2	-	2.0 M²	(1.5 to 2M Height iii) 0-2.72 Above 2M	-	Poor	-	-	-	-	3	3	
(v)	A20	7	9,9A	Destroyed	Pink	Moderate	-Do-	Up to 25% Exposed None Buckled	-Do-	Major 0.5M	None	2	0.3 M²	0.5 M²	0-3.44 (Up to 3.5m Height	-	Poor to Medium	Broken Core Obtained	-	-	Temp 100°-200°C Sample No.19	3	3	

Table 1.5: Damage classification of structural members

1.6 METHOD OF REPRESENTING CLASS OF DAMAGES IN THE DRAWINGS:

The information on class of damage, is tabulated in the grid sheets in the form of drawings for the site references The grid drawing plans are prepared in conformity with the original structural drawings for each floor i.e the same column nos. beam nos. and slab nos. are adopted as had been done in the original structural drawings. Each structural member like column, beam and slab is marked with class of damage in different colour for each floor in grid drawing and then these are consolidated in tabulated form under schedule of damage classification i.e. separately for columns, beams and slabs and members having same class of damage are grouped together. The grid drawing for a particular floor show damage classification of beams and slabs of that particular floor as seen from the bottom and of the columns supporting that particular floor.

The damage classification for columns, beams and slabs have been marked in red ink, black ink and green ink respectively on the grid drawings. The members unmarked are unaffected and members marked 'O' are also unaffected. Reference to spread sheet numbers are also indicated in the grid drawings for each floor. Similarly, reference of grid drawing is also shown in spread sheets for the co-relation of the data. Another grid drawing(plate 3.6) of the same floor is prepared in which class of repair corresponding to the class of damage is marked in different colours as per the legends mentioned below:

Slab

Structurally unaffected	Left as it is
Superficial repairs	yellow colour
General repairs	Green colour
Principal repairs	Red colour
Major repairs	Shaded black

Beam & column members

Superficial repairs	○
General repairs	●
Principal repairs	★
Major repairs	*

With above approach, the grid drawings have been prepared which, at a glance, reveal the damage identification of structural members and its solution for repair and rehabilitation.

1.7 Objective:

The present work includes

i. To study the impact of fire on the reinforcement bars heated at various temperatures, cooled rapidly by quenching in water and normalized b cooling in the atmospheric temperature.
ii. Study the characteristic changes in the mechanical properties of the bars by Tensile strength testing using Universal Testing Machine.
iii. Study of micro structure of the bars using Scanning Electron Microscope (SEM).

Chapter 2

EXPERIMENTAL WORK

2. EXPERIMENTAL WORK

2.1 INTRODUCTION

The specimens for testing were Sri TMT bar of 12mm diameter. 54 bars were cut to 40 cm size. 6 Specimens were tested for the mechanical properties using UTM before heating at normal temperature and the properties were tabulated. 12 specimens each were heated in the electrical furnace at 100°, 300°, 600° and 900°C for an hour without any disturbance. After heating, out of 12 specimens for each temperature 6 samples were quenched in water for rapid cooling and the other 6 were kept aside for normal cooling at atmospheric temperature. These specimens later were tested for mechanical properties with UTM and microstructure study using SEM.

2.2 EQUIPMENT

i. Universal Testing Machine
ii. Scanning Electron Microscope
iii. Electrical Furnace

2.3 UTM TESTING:

The 12mm steel bar is cut to a length of 40 cm and gave a gauge length of 60mm. The specimen is fixed on the machine and the required data on the computer is given. Test is conducted at a load rate of 300 kg/min for all the specimens. An extensometer is fixed to the specimen during the test to read the elongation. The data of the test is noted in computer during the test by default s it is setup. The graph of load versus deformation and load versus elongation is drawn on the computer. After the test all the other parameters like ultimate load, maximum extension in mm, area in mm^2, ultimate stress, elongation in percent, reduction in in area, young’s modulus, yield stress, .1% and .2% proff stress and many other parameters can be observed.

Fig 2.1: UTM testing setup

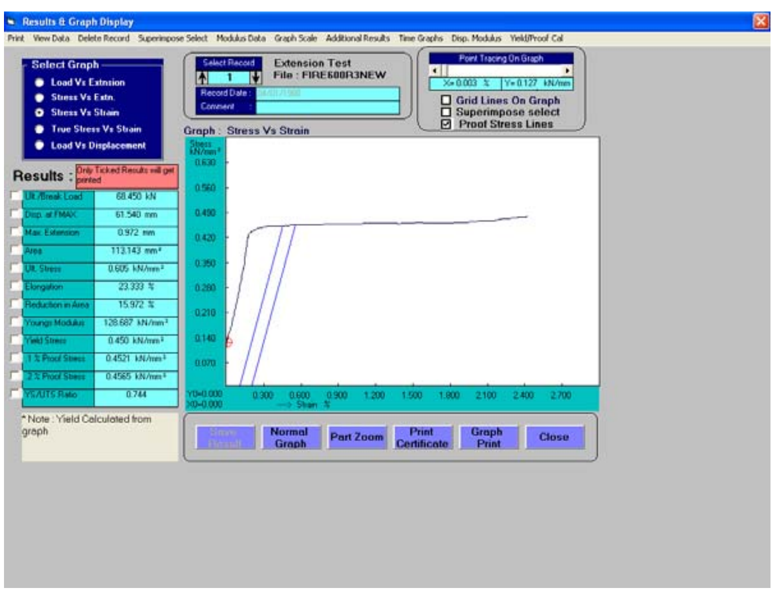

Fig 2.2: Screenshot of the result of tensile test using UTM

2.4: Tensile testing

Tensile testing is performed in accordance with ASTM D-638 as well as ISO 527 combined tensile and flexural procedure. Tensile properties are the most important single indication of strength in a material. The force needed to pull the specimen apart is determined, along with how much the material stretches before it breaks. The tensile modulus is the ratio of stress to strain below the proportional limit of the material. This is the most useful tensile data as parts should be designed to accommodate stresses to a degree well below it.

2.5: SEM

Scanning Electron Microscopy has done by JSM- 6480LV at magnification of 5 microns (x5000) and 10 microns (x1000). The specimens are made in a size of 12mm diameter and 10mm length. Before testing the specimens are to be finely polished in all the edges and neatly cleaned with acetone for the clear view of the gain size and grain structure.

Fig 2.3: Setup of SEM

Fig 2.4:Inner view of SEM

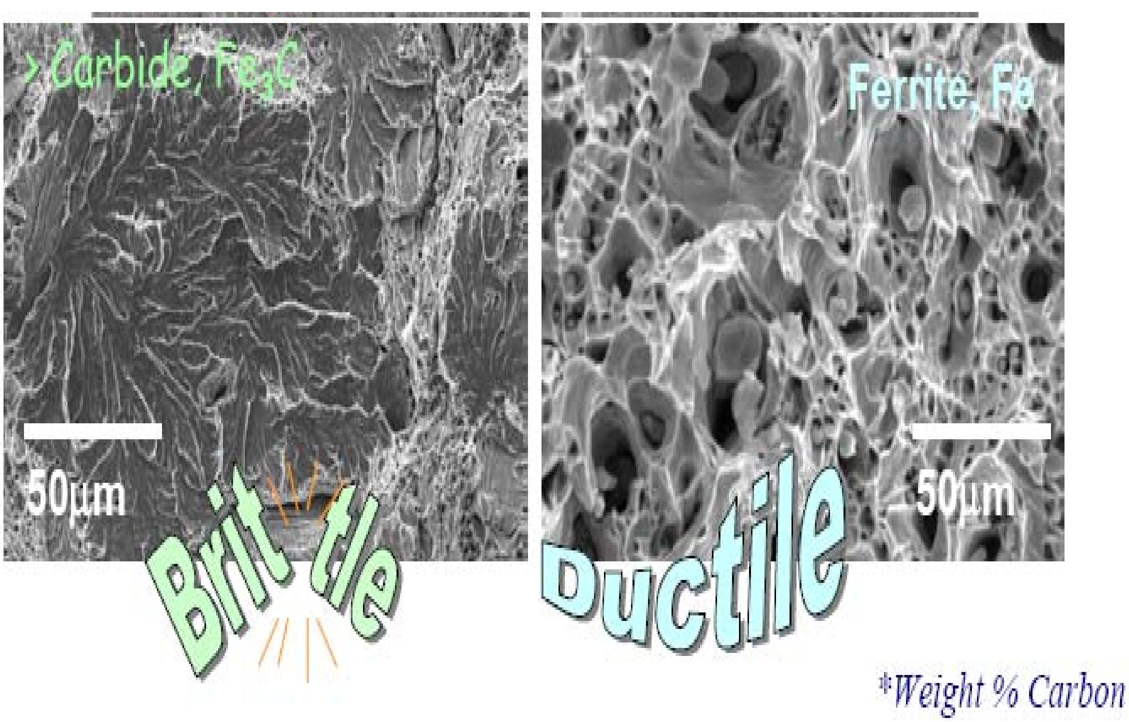

Fig 2.5: SEM properties of steel bar

2.6 Electric furnace:

The electric furnace is used to heat the specimens. The maximum temperature attained in this furnace is 1000°C. The inner depth of the furnace is 45mm. initially the furnace is heated to the required temperature by switching on it and when the required temperature is attained then 6 specimens put inside with the doo closing tightly so that no air enter inside. The specimens are kept for a duration of 1 hour inside the furnace and later 3 specimens are quenched in water for rapid cooling and the other 3 are kept aside for atmospheric time. The 3 specimens which are quenched in water are removed after 15 minutes. Each time 6 bars are kept at temperatures of 100°C, 300°C, 600°C, 900°C and the same is repeated.

Fig 2.6: Electric furnace

Chapter 3

RESULTS AND DISCUSSIONS

3. RESULTS AND DISCUSSIONS

Results from computerized UTM:

s.no	Temperature in ° C	Ultimate load (kN)	Ultimate stress (kN/mm^2)	Yield stress (kN/mm^2)	Max. extension (mm)	Elongation (%)	.2% proof stress
1	Room temp 27	67.1	0.583	0.466	1.63	28.3	0.465
2	100	66.1	0.584	0.469	1.66	15	0.461
3	300	65.5	0.582	0.451	1.422	30	0.44
4	600	68.4	0.606	0.453	0.972	23.3	0.456
5	900	78.3	0.692	0.469	0.206	11.6	0.534

Table 3.1: Properties for rapid cooing conditions

s.no	Temperature in ° C	Ultimate load (kN)	Ultimate stress (kN/mm^2)	Yield stress (kN/mm^2)	Max. extension (mm)	Elongation (%)	.2% proof stress (kN/mm^2)
1	27	67.1	0.593	0.466	1.63	28.3	0.465
2	100	66.5	0.588	0.448	1.139	30.2	0.455
3	300	63.7	0.571	0.436	1.12	28.3	0.429
4	600	64.3	0.574	0.484	0.76	27.45	0.449
5	900	65.5	0.585	0.465	0.62	26.6	0.437

Table 3.2: Properties for ordinary cooing conditions

For Rapid cooling conditions from table 3.1:

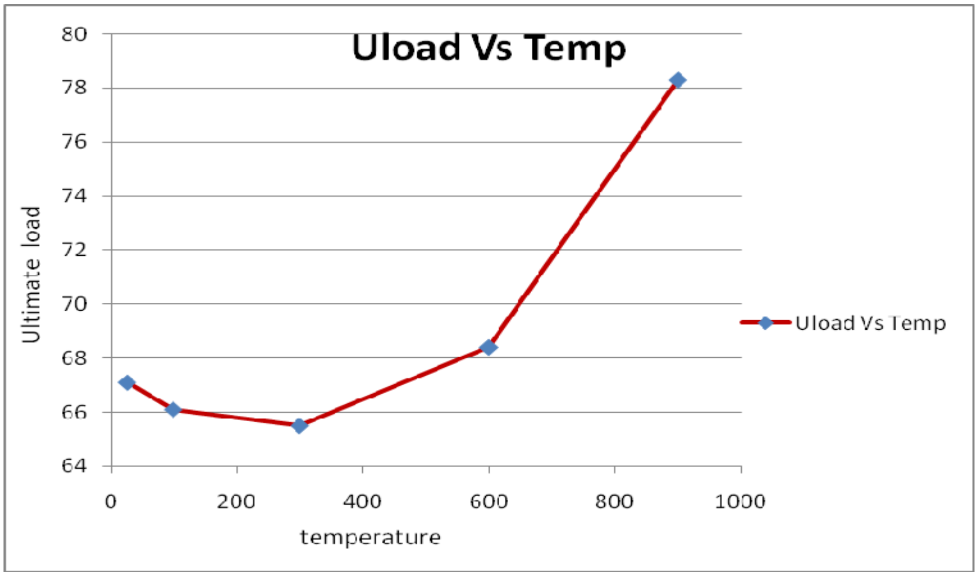

Fig 3.1: Temperature vs ultimate load

From the graph it can be observed that the ultimate load initially decreases from and then gradually increases , this happens due to the microstructure of the bar. For high temperatures the grain size decereases.

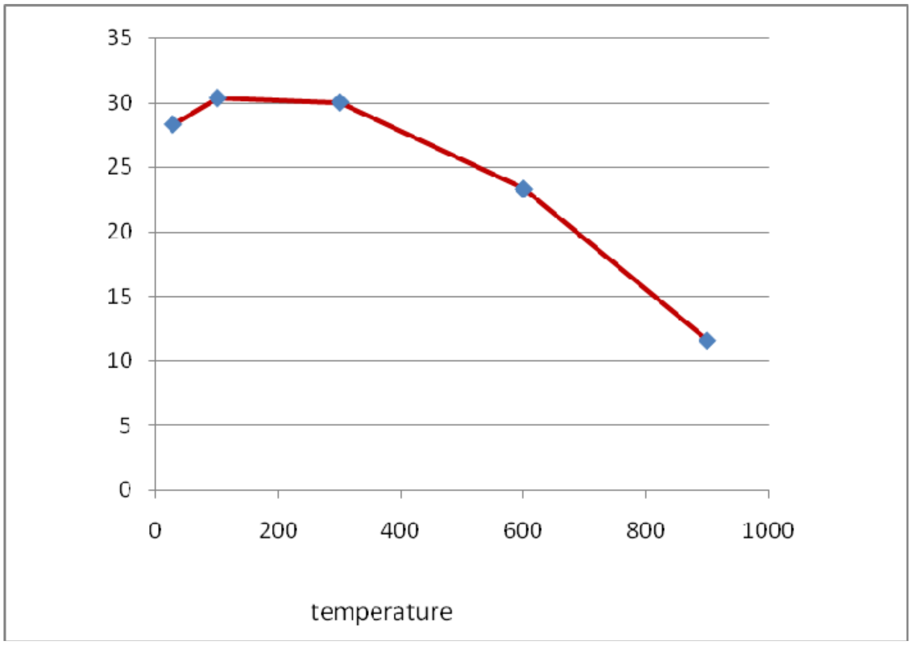

Fig 3.2: Temperature vs% elongation

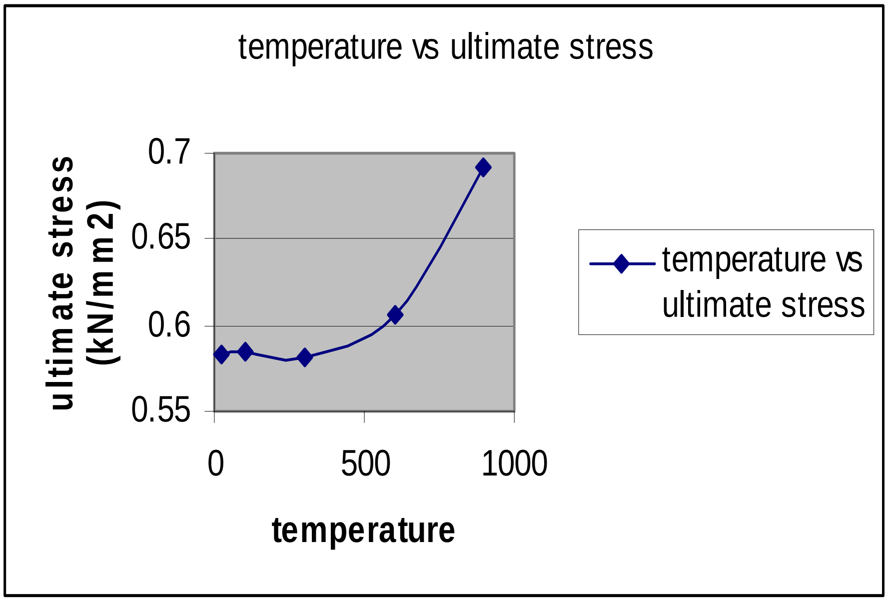

Fig 3.3: Temperature vs Ultimate stress

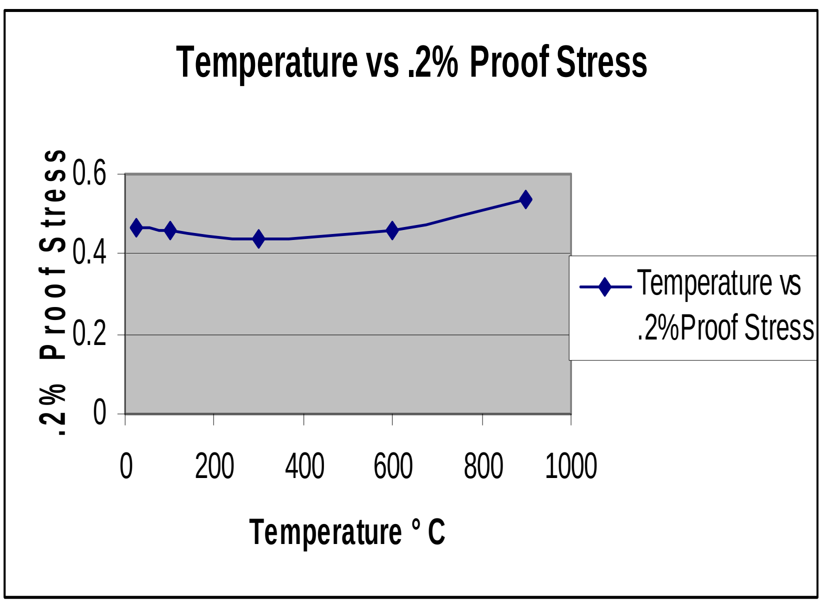

Fig 3.4: .2%Proff stress vs temperature

For ordinary cooling conditions from table 3.2:

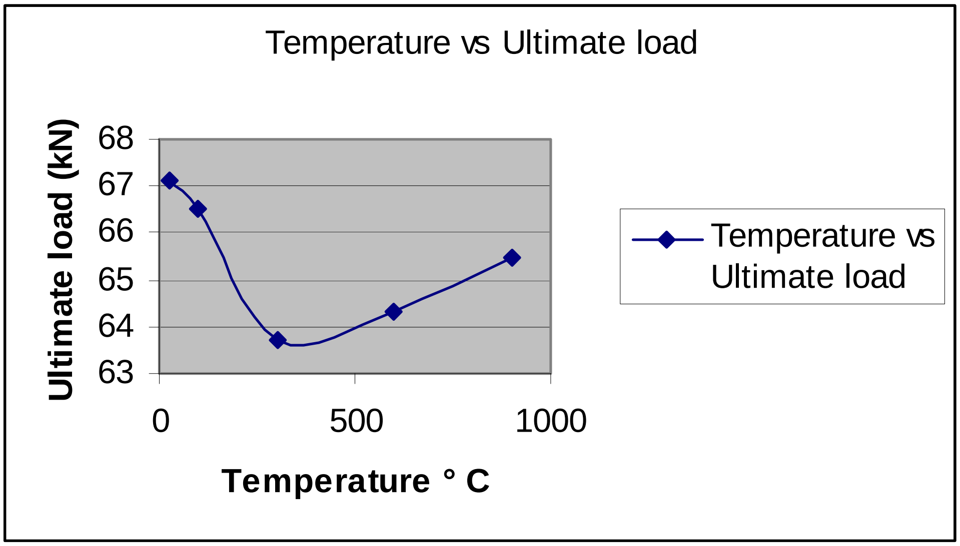

Fig 3.5: Temperature vs Ultimate load

From the Fig 3.5, the ultimate load carrying ot the specimen was reduced drom the specimen before heating.

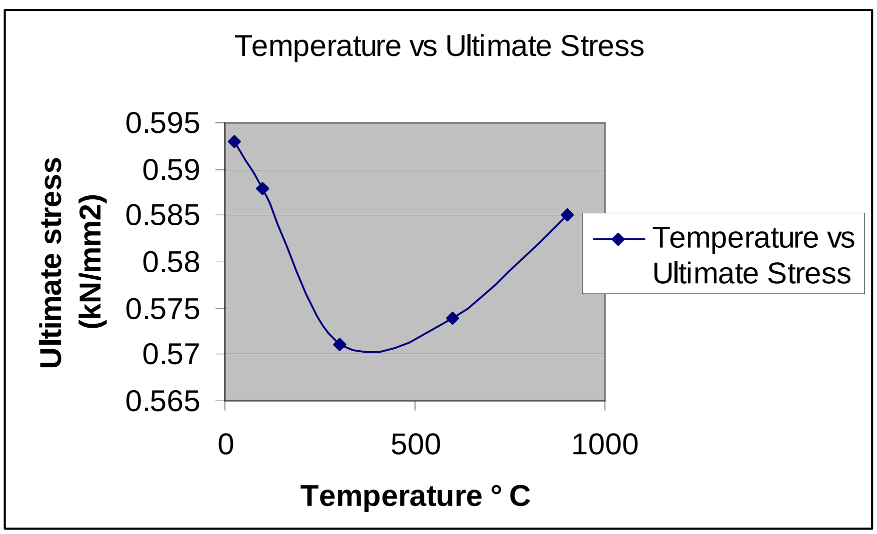

Fig 3.6: Temperature vs Ultimate stress

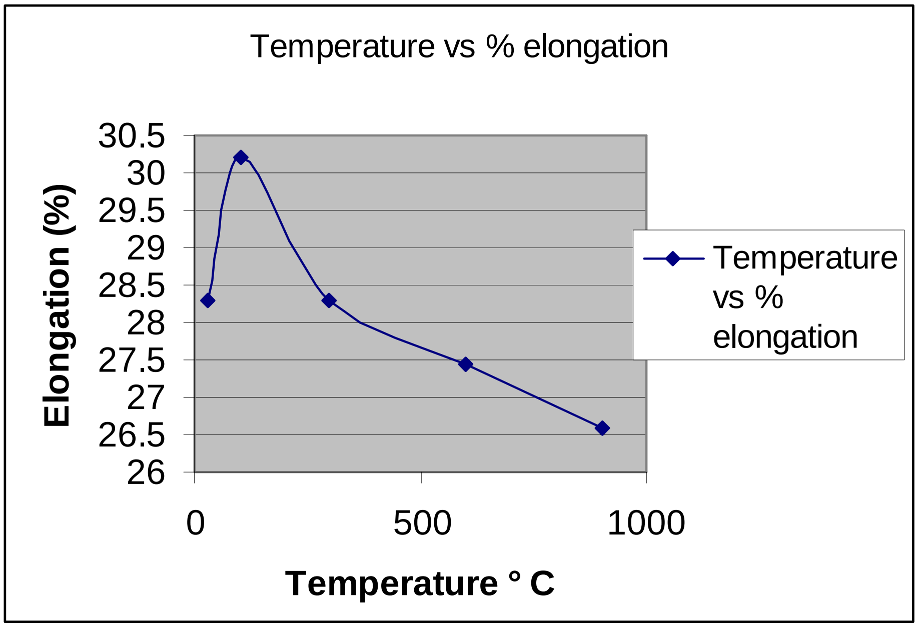

Fig 3.7: temperature vs elongation

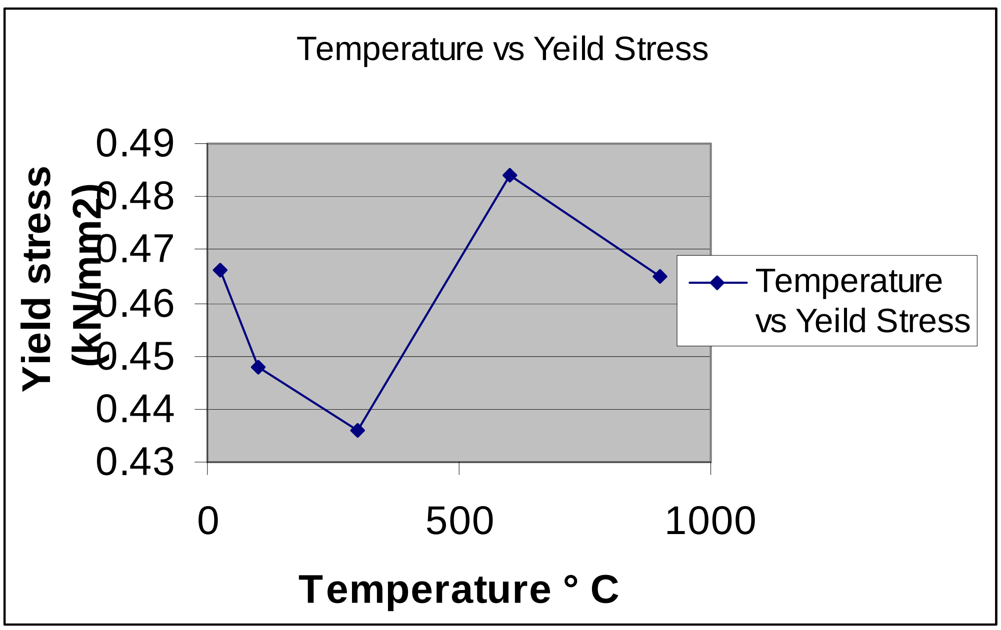

Fig 3.8: Temperature vs yeild Stress

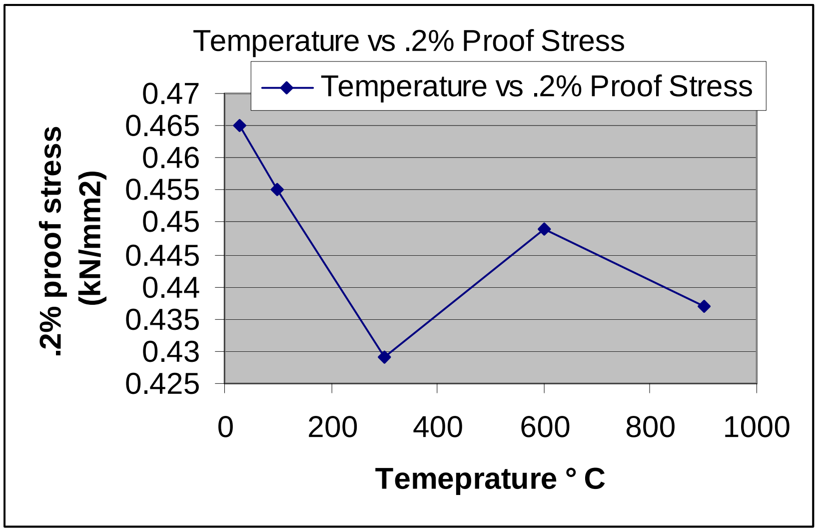

Fig.3.9: Temperature vs .2% Proof stress

SEM Analyses:

Pictures are taken at the magnification of 10 microns and 5 microns.

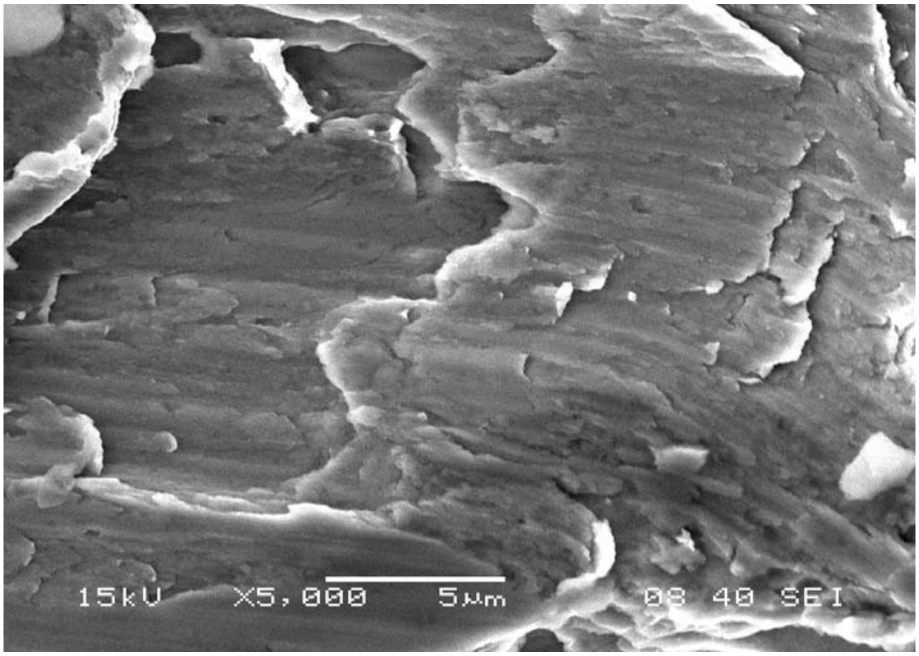

Fig 3.10: 100° C Ordinary cooling at magnification of 5 microns

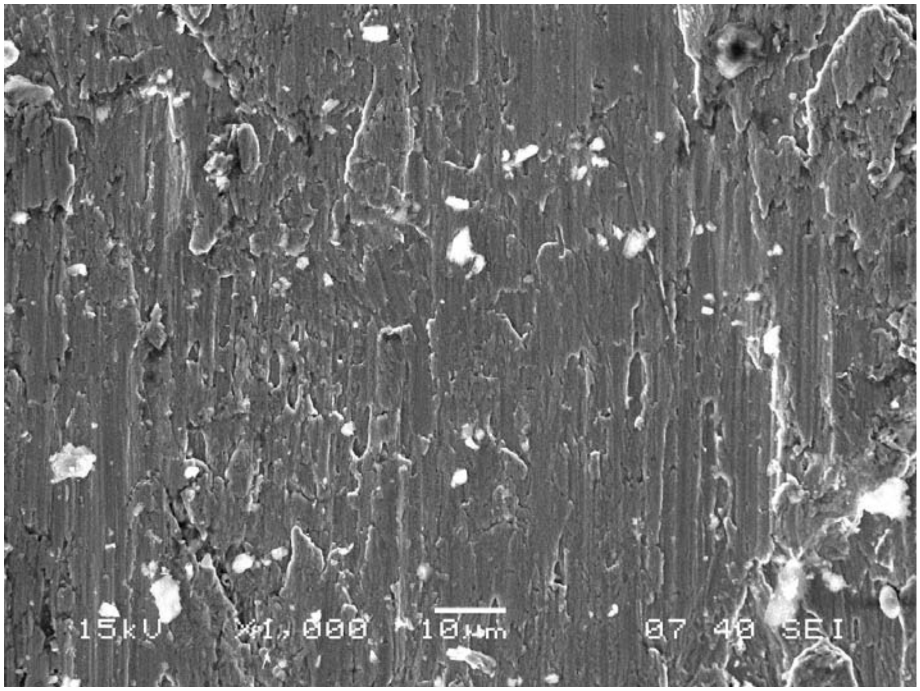

Fig 3.11: 100° C Ordinary cooling at magnification of 10 microns

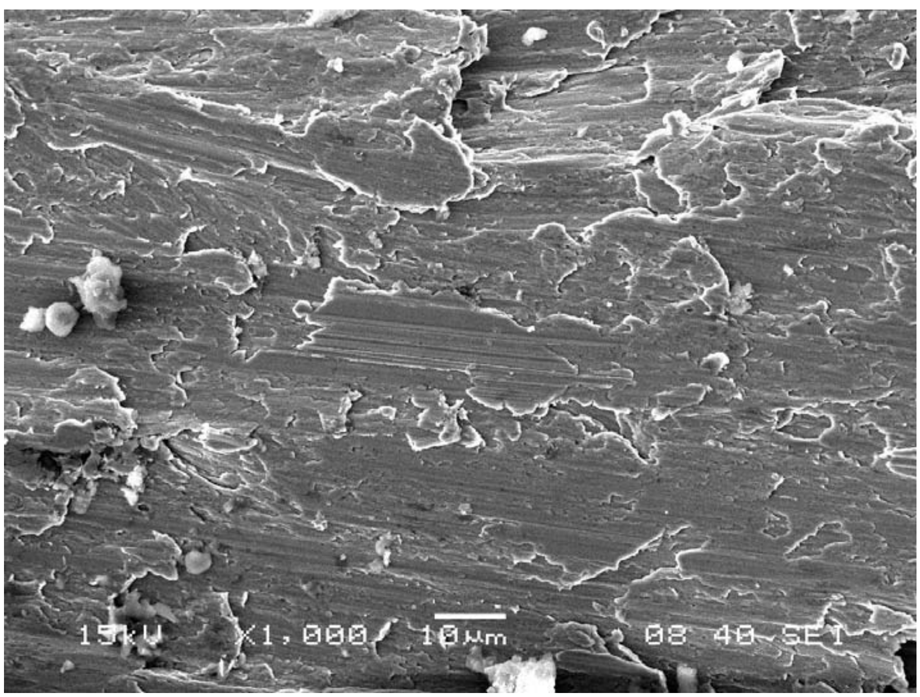

Fig 3.12: 300° C Ordinary cooling at magnification of 10 microns

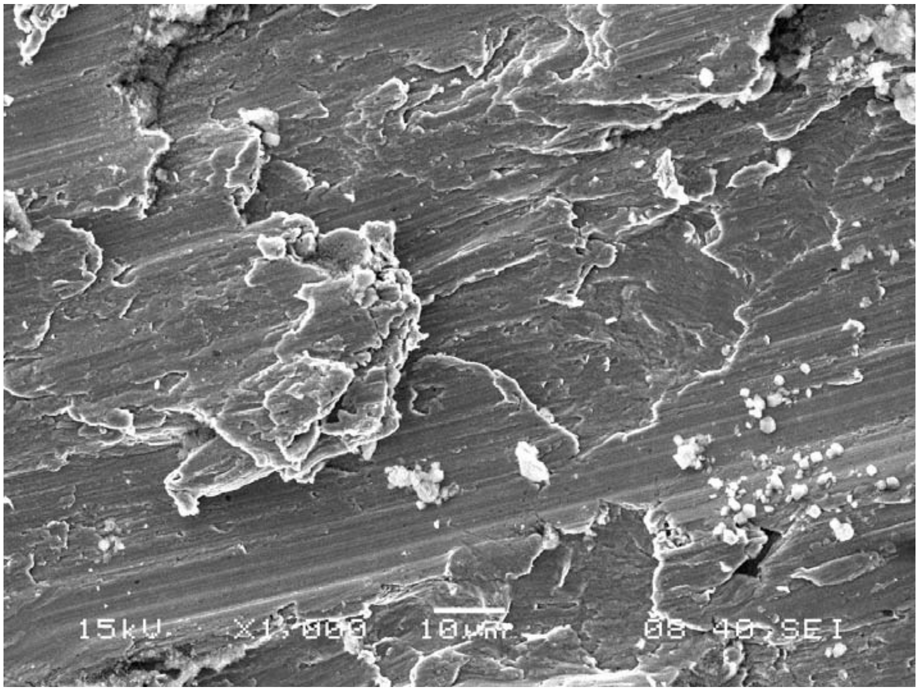

Fig 3.14: 300° C Rapid cooling at magnification of 10 microns

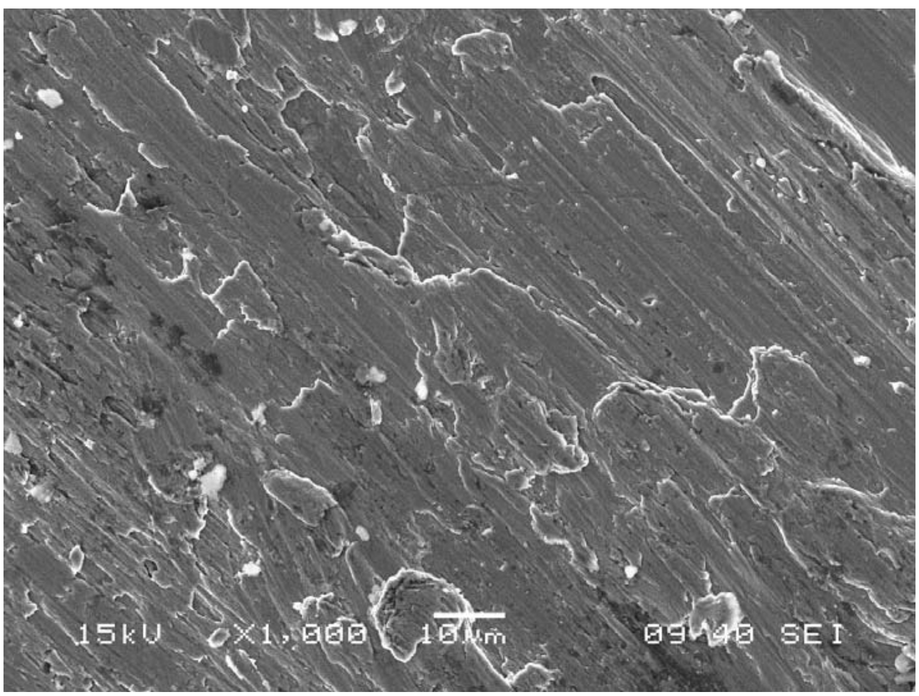

Fig 3.14: 900° C ordinary cooling at 10 micron

4. CONCLUSION

i. The impact of fire on the reinforcement bars heated at various temperatures of 100° C, 300° C, 600° C, 900° C, cooled rapidly by quenching in water and normally cooled in the atmospheric temperature were studied and it is observed that the ductility of rapidly cooled bars after heating to high temperature to 900 ° C.

ii. Studying the characteristic changes in the mechanical properties of the bars by Tensile strength testing using Universal Testing Machine shows that the increase in ultimate load and decrease in percentage elongation of the specimen which mean that there is significant decrease in ductility of the specimen.

iii. Study of micro structure of the bars using Scanning Electron Microscope (SEM) also shows that the microstructure of highly heated specimens varies without varying the chemical composition which would have negative impact on the structure.

References

1. Roberto Felicetti, DIS – Politecnico di Milano, P.za L. da Vinci 32, 20133 Milano,Italy 17 The drilling resistance test for the assessment of fire damaged concrete. April 2006

2. N.R. ShortU, J.A. Purkiss, S.E. Guise School of Engineering and Applied Science, Aston Uni¨ersity, Aston Triangle, Birmingham B4 7ET, UK Assessment of fire damaged concrete using colour image analysis. Received 30 August 1999;

3. Roberto Felicetti Department of Structural Engineering (DIS), Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, Italy. New NDT techniques for the assessment of fire-damaged concrete structures. Matteo Colombo, September 2006

4. M.A Riley,Msc. Possible new method for the assessment of fire-damaged structures. Sir william halcrow and patners- 1991

5. Chi-Sun poon, Salman Azhar, Mike Anson, Yuk-Lung Wong. Strength and durability recovery of fire-damaged concrete after post-fire-curing. Honkong polytechnic university-2000

6. R.Folic, V.Radojanin, M.Malesev. The assessment of the structure of Novi Sad open University damaged in fire. University of NoviSad, Yugoslavia-2002

7. Jisn-Zuusng Xiao, Jie Li, Zhan-Fei Huang Fire response of high-performance concrete frames and their post-fire seismic performance. ACI

8. Wei-Ming, T.D.Lin, L.J.Powers-Couche. Microstructure of fire-damaged concrete.ACI

9. Dr.A.Kumar, V.Kumar, Behaviour of RCC Beams after Exposure to Elevated Temperatures.

10. Jones, C.D. Repair of fire damaged structures.Source: Elsevier Applied Science Publications, p 237-251, 1986

11. Dorsch, David F. Assessment and repair of fire-damaged concrete structures Source: Innovation in Repair Techniques of Concrete Structures, p 16-26, 1993

12. Sarkar, Alok Source: Restoration of fire damaged structures: A case study Indian Concrete Journal, v 82, n 4, p 17-21, April 2008

13. Nassif, A.Y.; Rigden, S.; Burley, Effects of rapid cooling by water quenching on the stiffness properties of fire-damaged concrete. E- Source: Magazine of Concrete Research, v 51, n 4, p 255-261, August 1999

14. Cooke, R.A. and Rodger, H., Principles of Fire Investigation. 1985. Principles of Fire Investigation. Kent: Institute of Fire Engineers.

15. Chung, J.H., Consolazio, G.R. and Mc Vay, M.C., Finite element stress analysis of a reinforced high-strength concrete column in severe fires. Computers and Structures, 84(21), p.1338-1352. . 2006

16. Concrete and Fire: Using concrete to achieve safe, efficient buildings and structures. The Concrete Centre, 2004

17. Fletcher, I.A., Borg,A., Hitchen, N. and Welch, S., Performance of concrete in fire: A review of the state of the art, with a case study of the Windsor Tower fire. Proceedings of the 4th International Workshop in Structures in Fire, Averio, Portugal, 10-12 May 2006, p.779-790.037 . 2006.

18. . Milke, J., Analytical methods to evaluate fire resistance of structural members. Journal of Structural Engineering, 1999.125(10),p.1179-1187.038

19. Khoury, G.A., Effect of fire on concrete and concrete structures. 2000.

20. Effect of fire on concrete and concrete structures. Progress in Structural Engineering and Materials, 2(4), p.429-447.

21. Franssen, J.M. and Dotreppe, J.C., 2003. Fire Tests and Calculation Methods for Circular Concrete Columns. Fire Technology, 39, p.89-97.

22. Kumar, A. and Kumar, V., Behaviour of RCC Beams after Exposure to Elevated Temperatures. Journal of the Institution of Engineers. India. 84(3),p.165-170.2003

UTM under working condition

Working on for results for mechanical properties of steel

Specimen failed on UTM

Failed specimen

Shear failure of specimen