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INVESTIGATION OF THE EFFECT OF FIRE EXPOSURE ON THE BEHAVIOR OF CONFINED REACTIVE POWDER CONCRETE COLUMNS UNDER DIFFERENT LOAD ECCENTRICITIES

Zainab Ali Ghali AL-ZIRJAWI

Master's Thesis

Supervisor

Assoc. Prof. Dr. Sepanta NAİMİ

Istanbul, 2023

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The thesis titled INVESTIGATION OF THE EFFECT OF FIRE EXPOSURE ON THE BEHAVIOR OF CONFINED REACTIVE POWDER CONCRETE COLUMNS UNDER DIFFERENT LOAD ECCENTRICITIES prepared and presented by ZAINAB ALI GHALI AL-ZIRJAWI and submitted on 14/04/2023 as been **accepted unanimously** for the degree of Master of Science in Civil Engineering.

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I hereby declare that this thesis meets all format and submission requirements of a Master's thesis.

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Zainab Ali Ghali AL-ZIRJAWI

Signature

DEDICATION

At first and before everything, praise be to Allah. Without Allah guidance and help I could not have presented this work. I am heartily thankful to my supervisor Lec. Assoc. Prof. Dr. Sepanta NAİMİ for his encouragement, guidance, and support from the beginning to the end which enabled me to develop an understanding of the subject. His advice on research has been invaluable. Most importantly, none of this would have been possible without the love and patience of my father Eng. Ali Ghali", my mother" and "my family" to whom this research is dedicated to. They have always been there for me and I am thankful for everything they have helped me achieve. Special thanks go to my best friend especially "Samaa Rashad" who was always helping me get through difficult times, and to everyone who help me push forward this research

PREFACE

I would like to extend my sincere thanks to Assoc. Prof. Dr. Sepanta NAİMİ, lecturer at Altınbaş University, Department of Civil Engineering, who was my supervisor throughout the writing of this research and who gave me the right direction by providing much correct advice, instructions, and information. Would also like to thank Assoc. Prof. Dr. Sepanta NAİMİ, Head of the Civil Engineering Department at Altınbaş University, who in turn assisted immediately to solve all technical problems from laboratories and others. Also thanks to all the friends who supported, encouraged me and gave me valuable advice and information.

ABSTRACT

INVESTIGATION OF THE EFFECT OF FIRE EXPOSURE ON THE BEHAVIOR OF NORMAL AND CONFINED REACTIVE POWDER CONCRETE COLUMNS UNDER DIFFERENT LOAD ECCENTRICITIES

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In recent years, the growth of urban cities building has improved the building process, improving the specification of structural design for high-strength building products that element length is a dominant factor in the design of building. Because of Reactive Powder Concrete (RPC) outstanding high strength and durability characteristics, RPC has more attention in building construction nowadays. Therefore, any additions of improving elements will be helpful to maintain good performance of concrete in different situations such as exposing to fire.

The current research aims to investigate the changes of reactive powder concrete strength under various burning temps (200, 400 and 600 degree centigrade) experimentally. The work was done by using three groups of samples each group subject to specific burning temp for 1 hr, and each group divided into four subgroups to show the changes in concrete cover (15 and 30) mm and applying Ø5@200mm and without secondary reinforcement.

The next section is a 3D-dimension analysing of finite elements utilizing ABAQUS / standard 2018 software package. There was a comparison between the outcomes of the test and the outcomes of numerical model.

The comparison between the RPC columns' experimental and numerical outcomes indicated strong agreement. The sum of the variation between mathematical and laboratory outcomes approximately (2.5 -7.7) percent. The numerical part was divided into two main parts fist one deals with similar experimental cases, but with applying axial and uniaxial load (20 mm eccentric) from center of column and subject to similar burning temperatures as experimental part. While the second part consists with similar cases as first one, but with wrap the column with a sheet of steel that reduce the losing in strength resulting from exposure to burning.

The obtained findings show that increasing burning temps from 200 to 600 lead to reduce the compressive, tensile and flexural strength for reactive powder concrete. Also, increase concrete cover from 15 to 30mm lead to enhance the concrete column against firing and using secondary reinforcement for similar concrete cover lead to increase the concrete resistance against fire significantly.

Keywords: Concrete Cover, Reactive Powder Concrete, ABAQUS, Concretes Nornal Concretes Strength, Polypropylene.

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ABBREVIATIONS

RPC	:	Reactive Powder Concretes
NCS	:	Nornal Concretes Strength
FEM	:	Finite Element Analysis
HRPC	:	Hybrid Reactive Powder Concretes
HSC	:	High Strength Concrete
NSC	:	Nornal Strength Concrete
SRPC	:	Steel-Fiber Reinforced Reactive Powder Concretes
PP	:	Polypropylene
PRPC	:	Polypropylene Fiber Strengthened Reactive Powder Concretes
PPF	:	Polypropylene-Fibers
HRWRA	:	High-Ranges Water Reduction Additives
H-TRIS	:	Heat -Transfer Rate Indcing System

LIST OF SYMBOLS

D	:	Cylinder’s Diameter
L	:	Cylinder’s Length
P	:	Max Practical Load in Splitting Test
f_{sp}	:	Strength Under Splitting Tension
σ	:	Stress
ε	:	Strain
h	:	Prisms’ Depth
b	:	Prisms’ Width
fr	:	Rupture’s Modulus
T	:	Temperature

1. INTRODUCTION

1.1 GENERAL OVERVIEW

Reactive powder concretes (RPC) has garnered a lot of interest from the building sector recently. This is because it can provide better structural performance than conventional, normal concretes strength (NCS), including high durability and durability. High rise buildings have just begun to use high-strength concretes that was previously only used for infrastructure projects, offshore structures, and bridges. Columns are one of the main applications of RPC in construction [1].

RPC is defined as a fiber-reinforced, super-plasticized combination with high silicate fumes and cement, a low water/binding proportion, and very fine quartz sand (0.15-0.60 mm) as an alternative to conventional aggregates. Eliminating coarse aggregate will improve the RPC's performance and microstructure by reducing heterogeneity between the cement matrix and aggregate. However, because coarse aggregate isn't utilised and very fine-grained sand is employed instead, the cementitious materials utilised in RPC can reach (900–1200 kg/m3).[2], [3].

A hardened concrete's resistance to abrasion and compressive strengthare improved by silica fume, which also reduces permeability and enhances reinforcing steel resistance to corrosion. As a micro-filler in between fine aggregates and cement, it filled in the residual gaps. Additional significant effect of silica fume is the improvement of the regions of interface transition between binder and aggregates as well as between fibres and binder. Additionally, it reacts with calcium hydroxide obtained from the Portland cement's hydration to produce additional calcium-silicate-hydrate and so strengthen the link between the aggregates and cement, increasing the final strength [4]. On the other hand, by incorporating silica fume into the cement paste, the special heat is increased and the thermal conductivity is decreased [5], [6].

Because of its exceptional qualities, (RPC) is particularly appealing for structural applications. By employing RPC to transmit loads to the foundation, columns significantly reduce their dead loads and reduce foundation settling. High-rise structures may have more useable floor area as a finding of this [7].

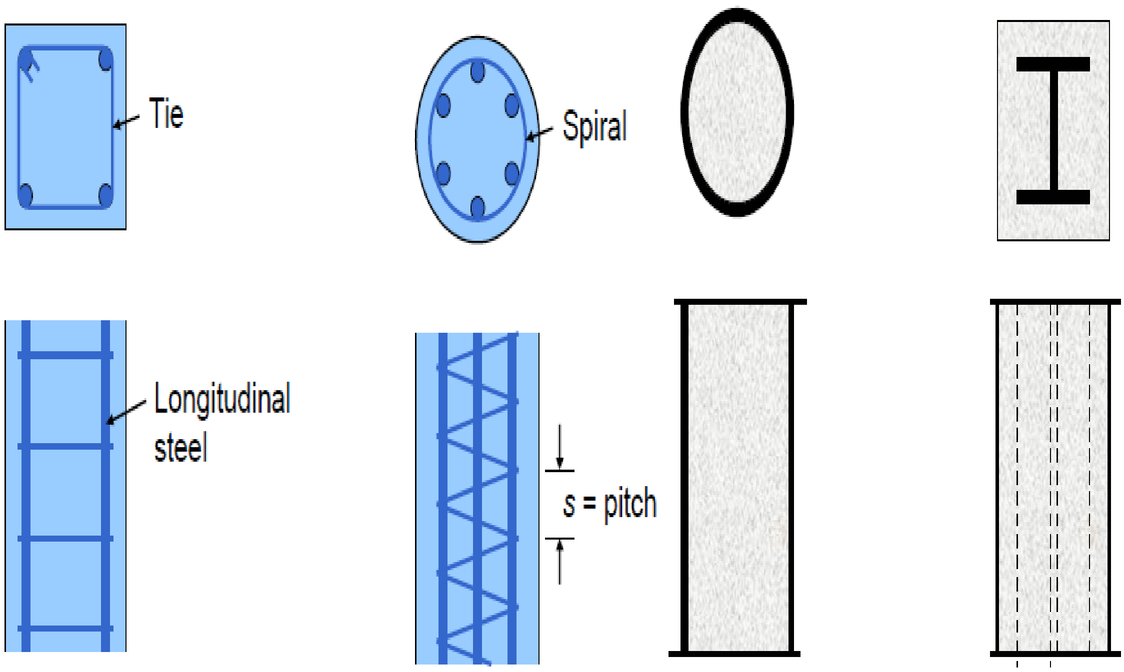
1.2 COLUMN BEHAVIOR AT NORMAL TEMP

Any part utilised primarily to carry compressive axial load and with a length to minimum lateral dimension ratio of three or greater is referred to as a column [8]**.** Since it carries loads to the foundations and supports and has a vital point where it might collapse, the column is also thought of as one of the most crucial structural components. Concrete columns may be divided into three types and are often reinforced with transverse and longitudinal steel as shown in Figure 1.1 [9]**.**

a. Tied columns: which have a circular, rectangular or square cross section with lateral ties and longitudinal bars.

b. Columns with spiral reinforcement: which have a cross sections (circular or square) with longitudinal bars circular shape arrangement and with closely spaced spirals.

c. Composite columns: longitudinally strengthened with different shapes of steel structural, tubing or pipes with or without extra bars and lateral reinforcement.



(a)Tied (b) Spirally (c) Composite

Figure 1.1: Reinforcement Kinds for Concrete Columns [9].

1.2.1 Eccentrically Loaded Columns

In practice, columns are generally loaded axially since some bending is almost always available owing to any original slight crookedness of columns, the pattern in which loading is implemented by slabs and beams, and the moments introduced by ongoing building [10].

Even if calculations of the design demonstrate that a member has to be purely loaded axially, inevitable building imperfections will bring consequently and eccentricity bending on the member. In practice, many columns are subject to bending about one axis of the column as opposed to axially loaded columns. Under uniaxial bending, these columns are loaded. Other columns (particularly corner columns) might have to concurrently withstand biaxial bending over both axes. Most reinforced concrete columns over their bending axes are symmetrically strengthened. For a column under uniaxial bending, however, if the eccentricity is big, an unsymmetrical bar pattern may be more economical as shown in figure 1.2 [11].

Columns can be categorized as slender or short, depending on the structural conduct. A short column is one of the columns in which the impact of length and response of deflection under load is very low and deemed negligible and the ultimate load at a specified eccentricity can only be controlled by the materials strength and the cross section sizes. The slender column influences the ultimate load by the slenderness, which causes extra bending since transverse deformations.

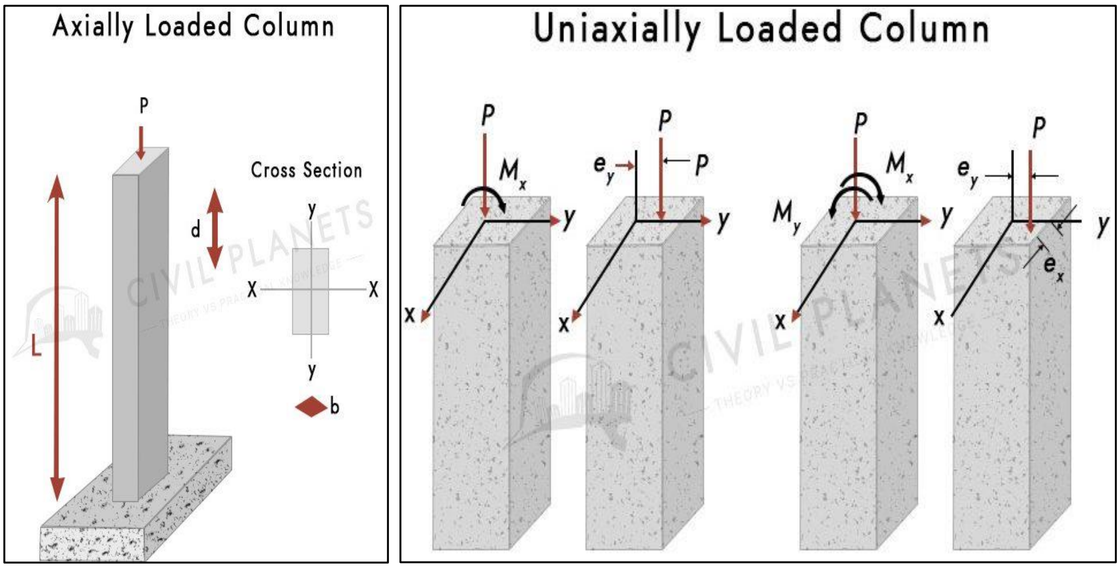


Figure 1.2: Columns That are Subject to Various Loading Kinds [10].

1.2.2 Protective Cover of Concrete

The cover of concrete in the strengthened concrete is the minimal distance between the external concrete surface and the embedded reinforcement surface [8] as shown in Figure (1.3) [12].

For three primary reasons, the cover of concrete should have a minimum thickness:

a. To safeguard the bars of steel reinforcement from impacts of the environment to avoid their corrosion [13].

b. Providing thermally insulation that protects the steel bars against fire.

c. To provide adequate embedding of reinforcing bars to allow them to be tightened without slipping.

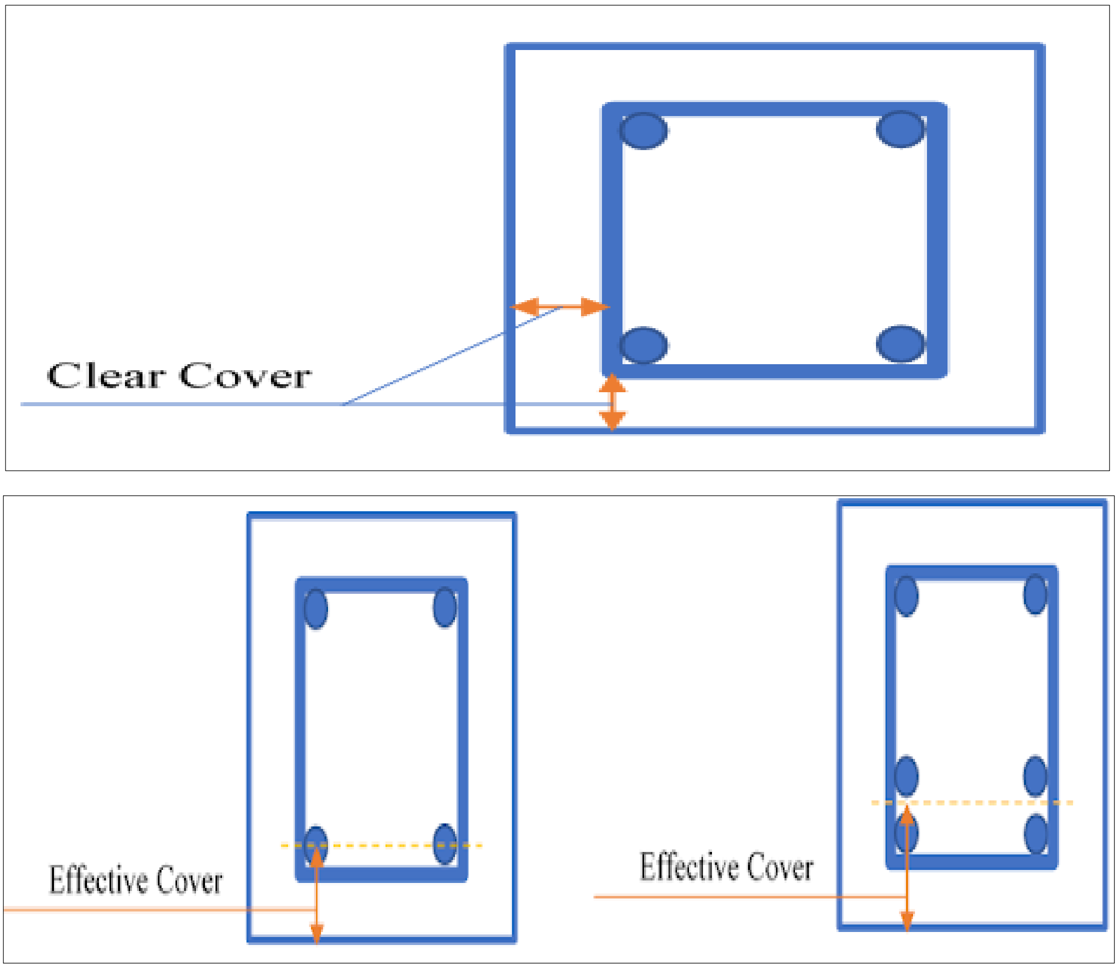


Figure 1.3: The Protective Cover for Concrete [12].

1.3 COLUMN BEHAVIOR AFTER EXPOSURE TO FIRE

According to fire design rules, high-rise building columns must typically have a resistance to fire for 1-4 hours, based on the usage and occupation of the building, to provide occupants enough time to safely leave the building before it collapses. [14].

Another significant parameter to be taken in the consideration of the fire reinforced concrete columns design is the concrete minimum cover thickness for reinforcement. Almost every collapse in the fire-damaged concrete structure is since either poor detail or steel reinforcement failures in severe instances [15], [16]. The reason is that the reinforcement is generally positioned close the concrete member surface. The reinforcement is therefore subject to a greater temp raise and its strength is first influenced compared to the primary concrete body [15].

Thermal gradients develop in the concrete cross section when exposure to fire. With the increased temps the humidity of concrete becomes vapor and thus produces pore pressure. If this pressure exceeds the tensile strength of the concrete, pieces of peeling referred as spalling [17].

Depending on the architectural and structural construction of the structure, a column might well be exposed to fire on one, two, three, or all sides in the case of a fire. (For example, a wall may be utilized to protect the column from fire on one, two, or all three sides. On the opposite face, a column can be placed in the room's middle, revealing its four sides. This causes heat gradients to increase, which may finding in uniaxial (1-side or 3-side) or biaxial column bending (2 adjoining sides). The extra moments placed on the column induce additional deformations and lessen the column's ability to support a given load, both of which lower the column's fire resistance. The type of fire scenario significantly affects how restraining loads in concrete members (RC) columns develop [14].

1.4 SIGNIFICANCE OF THE RESEARCH

One of the main uses of (RPC) in buildings is structural framing composed of beams and columns which constitute the main load-bearing parts. Thus providing adequate fire safety requirements for these columns is one of the main building design safety requirements. The cause for this requirement can be explained by the fact that, if other measures to prohibit the failure since fire, the members resistant against fire for adequate time is the last defense [18]. In addition, the mechanical behaviour of hybrid reactive powder structures under different burning duration with increasing temps, has rarely been researched. Consequently, the findings of this research provide a useful reference for future building applications and design.

1.5 AIM AND WORK OBJECTIVES

The primary goal of the current project is to investigate the experimental and numerical behaviour of reinforced columns made of reactive powder concrete that have been exposed to flames with axial and eccentric loads.

The objectives of this current investigation are outlined as following:

a. Study of the impact of duration of fire exposure (1 hour) on some mechanical characteristics of RPC specimens, for example flexural strength, splitting tensile and strength compressive strength, and comparison of findings with control samples (at ambient temps 200, 400 and 600 degree centigrade).

b. Examine the impact of concrete cover on final concrete strength after one hour of exposure to fire on the structural behaviour of reactive powder concrete columns (RPC). We'll evaluate the axial displacement features, mid-height lateral displacement, load against displacements, and maximal load bearing capacity.

c. The behavior and mode of failure of reinforced concrete column samples before and after exposure to fire.

d. Strengthening the columns that subject to high burning temp with steel sheet in order to reduce the loss in strength that resulting from exposure to fire numerically by ABAQUS.

1.6 THESIS'S OUTLINE

The current thesis contains of six chapters as follows:

The First Chapter offers a general overview on RPC and reinforced concrete columns, as well as some general information about fire impact on concrete structures, particularly reinforced concrete columns. In addition to the study outline, it describes the research significance, the problem and the objectives.

The Second Chapter involves a relevant literature review which investigated the reinforced concretes columns behavior that exposure to flame of fire, composition, and mechanical characteristics.

The Third Chapter defines all the details that related to the experimental work such as the material details, devices, mixing and casting processes, the burning process, the test procedure and the loading condition after burning.

The Fourth Chapter involves the experimental tests' findings of (RPC) samples, with analyzing and discussion of the findings.

The Five Chapter The theoretical analysis of the models by the Computer Program (ABAQUS) in the F.E.M.

Chapter 6 involves the main conclusions from the current study and suggestions that can be utilized to develop this study future.

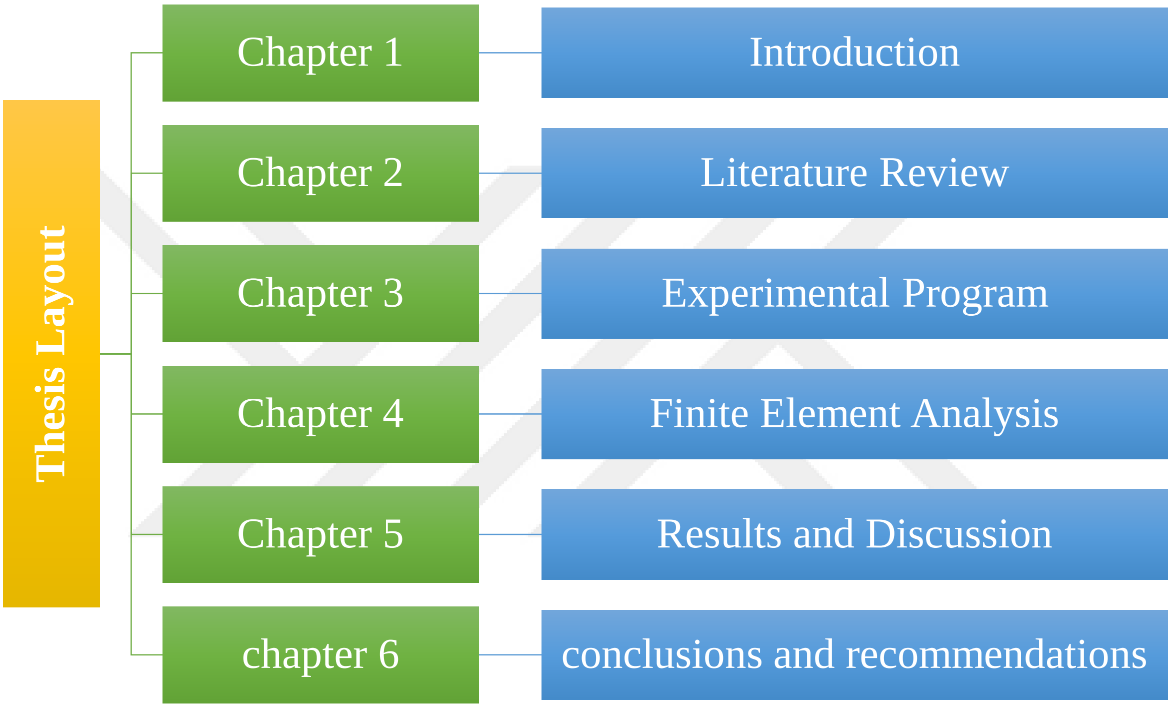


Figure 1.4: Thesis layout.

2. REVIEWING OF LITERATURES

2.1 INTRODUCTION

The columns are the most serious structural members in the building so that any failure in the part of the column could lead to building collapse. Therefore any additions of strengthening element will be helpful to the get good performance of concrete in different situations such as expose to fire. This chapter mention theories and experimental studies that related to behavior and change in the mechanical features of RC and hybrid RC columns before and after expose to fire.

2.2 THE IMPACT OF HIGH TEMPS ON THE RPC

Tai et.al. [19] explored the association between strain and stress of RPC after subject to high temps. They tested cylindrical samples with dimensions (diameter=5 cm and height= 10 cm) at the normal temp of room and high temp ranges between (200 and 800) degree centigrade. All samples were produced utilizing (normal cement, quartz powder, fume of silica, sand quartz type, superplasticizer, water and steel fibers) with proportion of $w/b=19X10^{-2}$ and a three various fractions steel fiber volume (1, 2 and 3)%. The outcomes showed that after heating from (200 to 300)°C the residual RPC's compressive strength improved better than that at the normal temp of room, but clearly reduced at 300°C. Also the peak strains of the residual RPC was firstly increased until 500°C, after that it is gradually decreased at the temp greater than 500 degree centigrade.

Bashandy [20] studied the performance of RPC subjected to high temps of (2, 3 and 5)x100 °C for two and four hrs. The research parameters were amount of cement, heating temps, amount of steel fiber and the time of heating. He was prepared cubes samples and Cylinders samples with dimensions (10×10×10 cm) and (diameter =10 cm and height= 20 cm in) respectively. Then the sample placed at water for curing purposes (at 75 degree centigrade for three days then placed at 25 degree centigrade for another three days then exit from water for drying place until the specific ages of testing. After subject to extreme temps, RPC samples were tested by tension and compression tests. The findings concluded that RPC could be utilized at high temps that reach to 300°C for heating duration reach to 4 hours considered with fade of strength. The RPC strength at normal temp of the room also raise with increment the amount of cement, but after subject to extreme temps the residual strength reduced with increase either temp or heating period. Also, the adding of steel fibers improved the residual RPC strength.

Table 2.1: The Features of Many RPC Mixtures [20].

Mix Code	Cement *(kg/m³)*	W/C *18% (kg/m³)*	Sand *(kg/m³)*	S.P. *10% C (kg/m³)*	Silica fume *30% C (kg/m³)*	Steel Fiber Content *(kg/m³)*	Curing process
M1	700	126	1250	70	210	--	at 75℃ for 3 days then, at 25°C for other 3 days
M2	750	135		75	225		
M3	800	144		80	240		
F1	700	126		70	210	40	
F2	750	135		75	225		
F3	800	144		80	240		

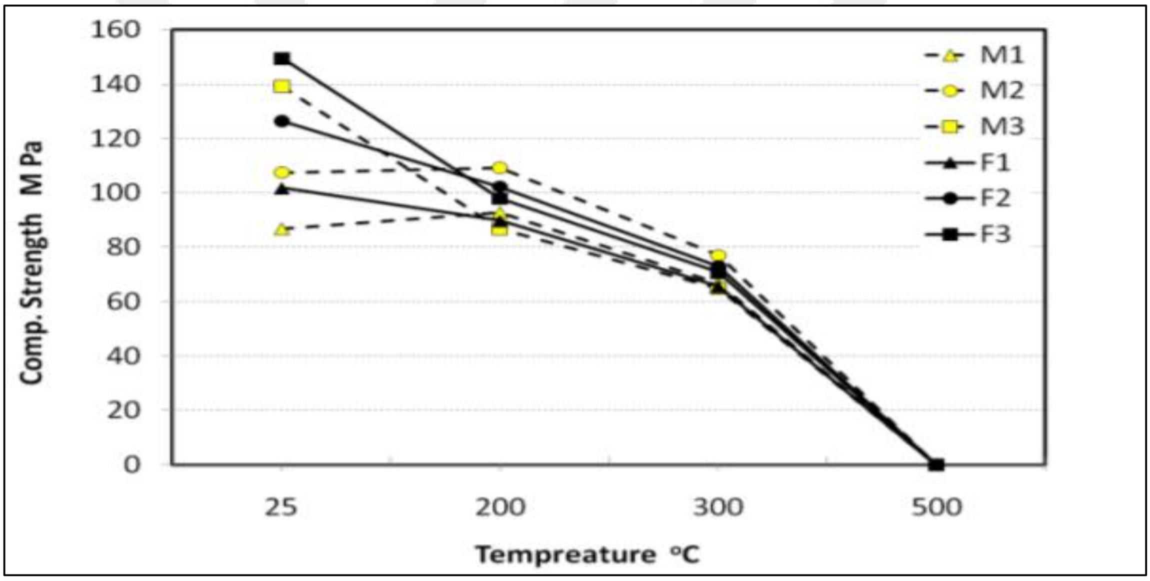


Figure 2.1: The Elevated Temp's Effect on Compression Strength of RPC [20].

The mechanical and microstructure characteristics of RPC that combined with polypropylene fibre at an extreme temp were examined by Zheng, et al, [21]. Utilizing various RPC samples, the compressive and tensile strengths were tested across the temp range of 20 to 800 degree centigrade. In this investigation, the PP fibre concentration, explosive spalling, and sample dimensions have also been examined. The outcomes of the trial revealed that:

a. A rising in PP fiber amount reduced the explosive spalling of RPC. Adding 2.73 kg.m^{-3} PP fiber could prevent explosive spalling and improved the RPC's strengths against compressive and tensile.

b. The RPC cube compressive strength that contain PP fibers was decreased at 100 ℃ and it is decreased at temp higher than 600 ℃, but it is increased at temp rages (200 to 600) degree centigrade. The RPC cube compressive strength reduced with increasing the PP fiber content at temp less than 200 degree centigrade, but it increased when the PP fiber amount increased at temp rages between (300 and 800) ℃.

c. The RPC's tensile strength that contain PP fibers was decreased at 200 ° C and it is decreased at temp ranges (400 to 800) ℃, but it is increased at temp rages (200 to 300) ℃. The RPC's tensile strength also increased with increasing the PP fiber content at temp rages (20 to 800) ° C. The RPC with PP fibers can also have a greater compressive and tensile strengths comparison with HSC and NSC.

Canbaz [22] investigated the extreme temp effect on RPC without or with the addition of fibers. The samples were produced from cement, sand (quartz type), powder of quartz, steel wire, fume of silica, a superplasticizer, fibers of polypropylene, and water. After casting and curing, they were subject to temps of (100, 400, 700, and 900) degree centigrade for 3 h. The findings showed that, at extreme temps, RPC with 1percent polypropylene fibre performs better mechanically than RPC without polypropylene fibre. RPC with PP fibre has a greater compression strength at 400 degree centigrade than RPC without PP fibre. Additionally, RPC with 1percent polypropylene fibre lost around 50% of its strength before being exposed to a maximum temp of 900 degree centigrade, while samples without PP fibres suffered a significant loss in strength. According to the findings of this study, it is advised that 1percent polypropylene fibre be added to RPC.

Ju et al. [23] observed the influence of fibers (polypropylene) on the RPC thermo-mechanical characteristics subject to extreme temps of equal to 350 degree centigrade and features that reaches equal to 600 ° C and the spalling behavior at different volume fractions. These characteristics include the spilling conduct and residual strength.

Several findings were drawn by Ju et al. [23] First: the remain strengths of the heated polypropylene-fiber RPC, involving split tensile strength, flexural tensile strength and compressive strength, increased comparison with ambient temp strengths at temps below

300 degree centigrade. Second: the decrease in remain strengths in condition of the temp is greater than 300 degree centigrade. Mass loss is primarily resulting from water evaporation in microvoids, that involves bound water, free gel and liquid water. This occurs in all RPC samples especially at temps above 150 degree centigrade. The mass loss rapidly increased at different proportions when the temp was between (150 and 350) degree centigrade, high content of fiber may finding in more mass loss. Nevertheless, a constant rate for increasing mass losses when the temp rises higher than 350 degree centigrade, independent of the fiber amount. Heating duration also has a clear impact on weight loss, particularly in RPC, which is strengthened by fiber (polypropylene).

The internal measuring of temp for the samples at various locations specifies that the amount of fiber in the heated samples affects the development of the internal temps. The high amount of fiber in the samples decreases internal temp. The scanning electron microscopy confirms that the melting of fiber (polypropylene) in the heated RPC could be generated a sufficient amount of channels. This can help form passages, assist with moisture movement at elevated temps and release vapor pressure.

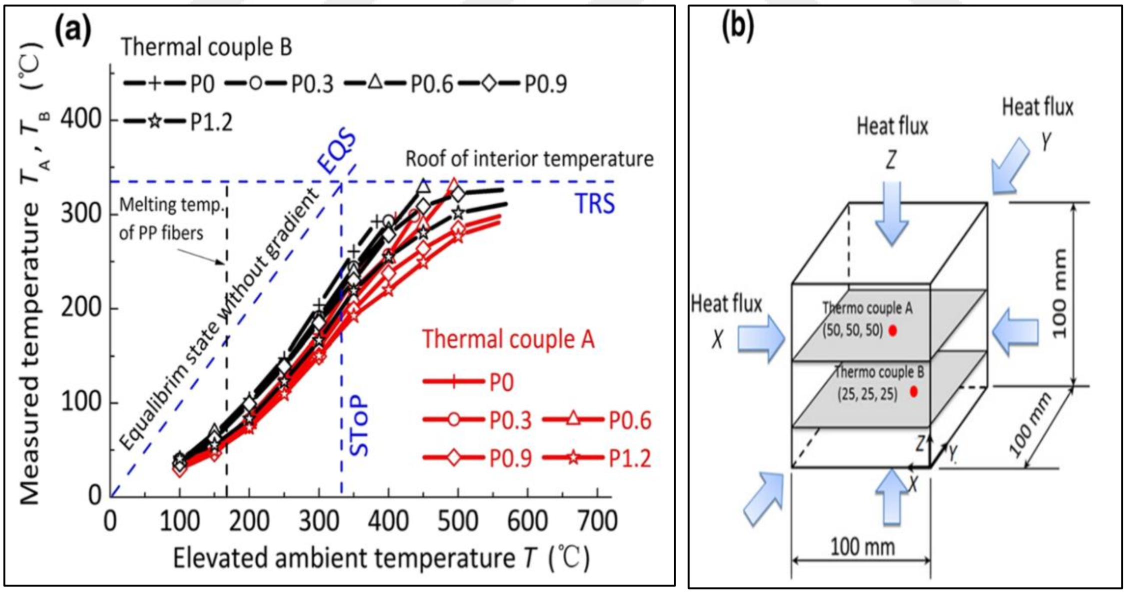


Figure 2.2: The Variation in the Measured Indoor Temps with Two Fiber Dosages and High Temps of Furnace at Two Chosen Locations A and B. Ju et. al. (2015), (A) The PP Notation Related to Fibers of Polypropylene and (B) The Size Sample and the Direction Heat Flux.

Ali, et al, [24] studied the RPC mechanical characteristics after subject to flame of fire. There are four temp levels (150, 200, 300 and 400) degree centigrade utilized in this research for subject duration about 60 minute. The findings detected that: at 150 degree centigrade, the mechanical features were improved by additional cementitious materials hydration and at temps' fire about 200-400 degree centigrade there will be a significant decrement in the flexural strength, compressive-strength, tensile-splitting and elasticity modulus.

Abid [25] studied the high temp impact of residual the characteristics of RPC. The findings detected that there is deterioration in compressive-strength, tensile-splitting and modulus of elasticity with the extreme temp level. The mechanical remaining features were used in three stages depending on the temp level:

a. There will be an increment in strength at 350 ℃.

b. From 350-800 degree centigrade a point of notable decreasing in strength and

c. RPC samples was lost all its strength at the final phase once the temp raise equal to greater than 800 degree centigrade. Adding polypropylene fibers resulted in a decrease in RPC's mechanical characteristics at room temp by reducing its elastic module. Although they can enhance the resistant against spalling at elevated temps with increased residual compressive strength of the RPC.

2.3 RPC AND HYBRID-FIBERS SUBJECTS TO ELEVATED TEMP

Peng et al. [26] researched resistant of RPC fire after exposing to extreme temps, particularly residual mechanical characteristics and explosive spalling event. The mechanical residual characteristics involve compressive strength and tensile splitting strength. RPC is made-up of cement, fume of silica, sand with fine particle, steel-fiber, and fiber (polypropylene) in this research. It was subject to the impact of raised temps between (200 and 600) degree centigrade. In the sum up of the findings, the mechanical characteristics were improved after being under the influence of extreme temps between (200 and 400) degree centigrade, which could be explained by the additional products of cementation hydration which activated by increasing the temp. Tensile-splitting-strength started to decline after reaches the temp to 200 degree centigrade, while compressive strength began to decline after reaches the temp to 400 degree centigrade.

The spalling test outcome also indicated that RPC was susceptible to explosive spalling under the impact high temp at a small w / b proportion (less than 0.20). Incorporating hybrid fiber such as fibers of (polypropylene and steel) is an interesting technique to enhance RPC's resistance against explosive spalling, which should be a major goal to improve its fire resistance.

Zheng et al. [27] investigated the influence of extreme temps on RPC's mechanical characteristics. The impacts of spalling and temp of steel fiber and polypropylene-fiber had been investigated. Scanning electron microscopy helped specify the RPC microstructure. Findings found that adding the fibers of steel and polypropylene at fractions volume of (2 and 0.2)% could avoid spalling and improve tensile and compressive strength respectively. The compressive-strength of the cube reduces when the temp was 100 degree centigrade, while the raising of temp from (200 to 500) degree centigrade improves the compressive-strength, but it returns to decrease at temps higher than 600 degree centigrade. On the other hand, the tensile strength decrease at 200 degree centigrade, but it increases between (200 and 300) degree centigrade and the returns to decrease above 300 degree centigrade. The academics and researchers observed that the cavities will form when the temp raise up for more than 200 degree centigrade as a result of melting of polypropylene-fibres in the RPC matrix, which will provide micro-channels to release water vapor pressure in the RPC pores to reduce explosive spalling. RPC's compressive strength decreases with increment the amount of polypropylene-fibres at temp less than 300 degree centigrade, but increases above 300 degree centigrade with the same steel fibres amount. While the compressive strength increases with the increment of the amount of steel fibres at a temp below 100 degree centigrade, but this decreases above 200 degree centigrade with the same fibres (polypropylene) owing to variations in thermal expansion between matrix and steel fibres.

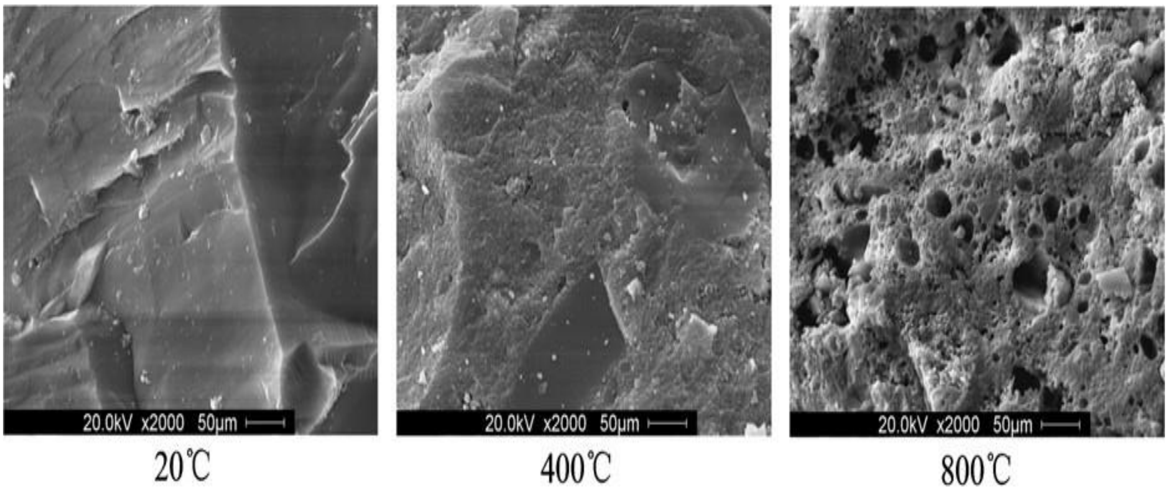


Figure 2.3: RPC Matrix Under SEM Micro-Graphs [27].

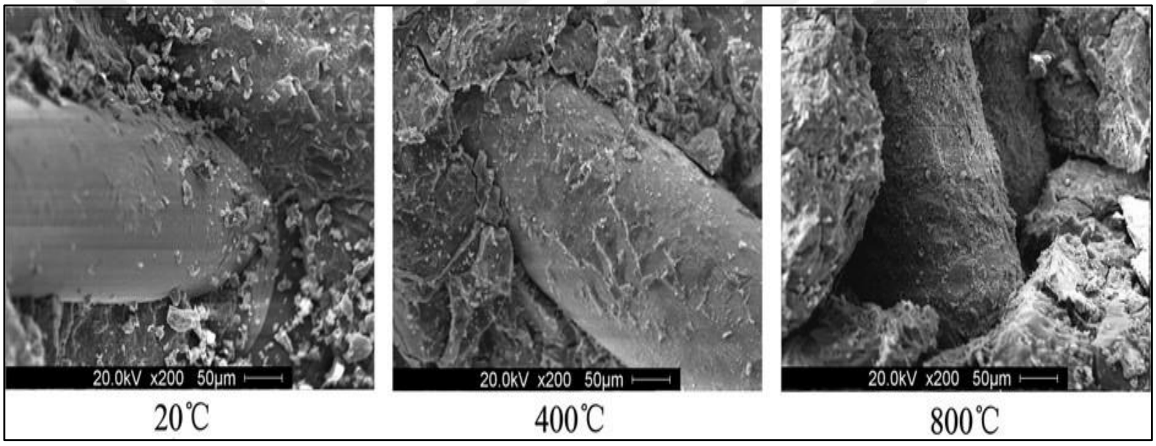


Figure 2.4: Bonding Interface Under SEM Micro-Graphs Between Matrix and Steel Fiber [27].

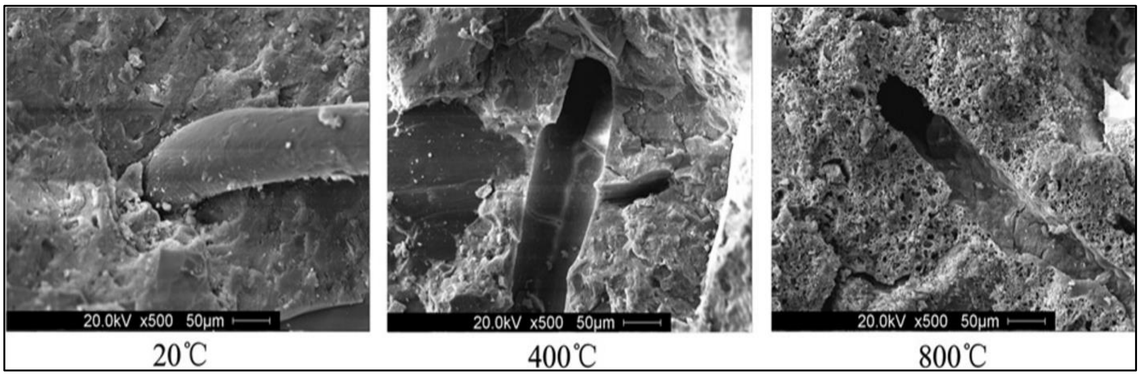


Figure 2.5: SEM Micrographs of PPF and PPF Melting Channel [27].

After extreme temp exposure, Haiyan [28] researched the tensile characteristics of hybrid fiber-reinforced RPC. The samples utilized fibers of steel and polypropylene. The tensile strength (in bending) was evaluated directly and indirectly thru tensile experiment on dogbone samples and prism bending experiment. After exposure to extreme temp reaching for 900 degree centigrade, the experimental findings showed that the residual flexural and direct tensile strength of hybrid fiber strengthened RPC improved significantly with high steel fiber amount, but reduced significantly linearly as the temp rise. Otherwise, polypropylene has a negative impact on RPC's mechanical strength that is subjected to smaller temps, but could enhance RPC's strength when subjected to greater temps. When compare NSC and HSC with the hybrid fiber-reinforced RPC also has great resistance ability to extreme temp.

Figure 2.6: HRPC Flexural Failure's Type After Extreme Temps, Haiyan (2016).

Abid et al. [29] studied the influence of fibers of hybrid (steel + PP), steel and polypropylene (PP) on the reactive powder concrete (RPC) mechanical characteristics at extreme temps. The consideration of mechanical characteristics includes cubic compressive-strength, axial or prismatic-compressive-strength, flexural-strength, split-tensile strength, strain peak, modulus of elasticity and the behavior of stress-strain. Testing was performed at a target temp at extreme temps of (120, 300, 500, 700 and 900) degree centigrade. Steel-fiber reinforced RPC (SRPC) demonstrated a behavior of ductility and hybrid-fiber reinforced RPC (HRPC). PP fiber strengthened RPC (PRPC) demonstrated brittle conduct equal to 300 μC, but further heating rendered the microstructure porous and it became ductile. Overall, HRPC and SRPC were stronger than PRPC because of higher elasticity modulus, higher strength. Fiber-reinforced RPC was found to have better resistant for fire than standard concrete kinds based on comparative studies with the demands of design codes and prior study.

2.4 COLUMN BEHAVIOR UNDER FIRE EXPOSURE

Lie, [30] conducted theoretical and experimental research on the reinforced concrete column in order to identify fire resistance. In this study, forty-one columns have been tested. The variables studied would include load level, the effective length of the column, the amount of steel reinforcement, cross-section area and shape, concrete strength, moisture content, heat expansion to axial restraint, aggregate type and eccentricity of the load. The findings showed the following:

a. The aggregate kind had the greater impact on the reinforced concrete columns against fire resistance especially the utilizing of carbonate aggregate, rather than aggregate (siliceous type), will assist to boost the column's fire resistance.

b. The shape of column had effect on fire resistances such as in the rectangular columns that had higher resistant against fire than the columns with the same thickness, but has a square shape.

c. Increasing in the effective length of the columns and the amount of reinforcing steel lead to small increases in fire resistance.

d. The applying of same eccentricity loads can cause a little decrement in the resistance against fire.

e. The impact of axial column expansion, amount of concrete moisture, concrete-strength, and restraint is negligible.

Aldea and Franssen, [31] managed six fire tests on NSC and HSC short columns to determine the parameters influencing fire induced spalling. The parameters were reinforcement, diameter and number of steel bars and concrete strength. The study showed that HSC columns had early spalling at the corners but no spalling happened in NSC columns. The research also reach conclusion that the material properties have higher effect on failure modes under fire conditions compared to structural detailing. But the study was limited by standard subject to fire effect under concentric loading.

Kodur & Sultan, [18] conducted the tests of fire-resistance on three concrete strengthened columns. One of the columns was produced from ordinary concrete strength while the other two were of elevated concrete strength. The temps inside the column rise rapidly to about 100 degree centigrade for all these columns and then the temp increase rate reduced. The behavior of the HSC columns at extreme temps obviously varies from that of the columns of the NSC. The fire resistance of the HSC columns is smaller than the fire resistance of the columns' NSC.

Kodur et al, [32] Fire resistance test findings were presented on 5 kinds of concrete strengthened columns. High-strength concrete (HSC) and normal-strength concrete (NSC), fiber reinforcement such as fibers of (steel and polypropylene) and aggregate type (carbonate and siliceous aggregate) which are considered the main factors in the research. NSC produced one of these specimens and the four other specimens were produced by HSC. All column sizes were (length =3,810 mm and a cross-section of 305 mm square). The length subjected to fire was approximately 3 m. HSC column structural behavior data at extreme temps were recorded. The findings demonstrated that the fire resistance behavior of HSC columns at extreme temps is considerably distinct comparison with columns of NSC in that fire resistance of HSC columns is smaller than those columns of NSC. The findings also demonstrated that the adding of fibers of steel and polypropylene in HSC resulted in improved HSC column ductility and increased fire resistance. In HSC columns, the presence of polypropylene fibers could reduce spalling and increase fire resistance.

Kodur et al, [33] Investigated the prediction of the concrete column with high-strength against fire-resistance behavior. The experimental investigation consisted of tests for fire resistance with various parameters on 15 RC columns. The length of all columns were 3.81 m and the main strengthening was a square cross-section of 305 mm and 4Ø 25 mm. Four concrete batches have been utilized to produce the columns. Reinforcement of polypropylene and steel fibers have been introduced to Batches 4 and 3 respectively. Batch 2's coarse aggregate was carbonate form while the other batches were produced with aggregate (siliceous type). The experiments were conducted by exposing the columns to heat in a specially constructed furnace for testing. The column end requirements were fixed-fixed for all experiments under concentrated loads. Table (2-1) compares the measurements and prediction resistant for fire in the four HPC columns. The time between the applying fire loads until failing is described as the column's fire resistance. The concrete spalling was maximum column produced of aggregate (siliceous type). The existence of carbonate aggregate helped minimize column spalling. Less spalling (about 15 percent) was the column with polypropylene fibers.

Table 2.2: Test Parameters' Summary and HPC Columns' Findings [33].

Columns Details	Dimensions of Column (cm)	Strength of Concrete (fc)		Factored resistance (Cr) (kN)	Test load (C) (kN)	Load intensity (C/Cr)	Fire resistance
		day 28 (MPa)	Test day (MPa)				Test (h:min)
Contained siliceous	30.5 x 30.5	60.6	99.6	$3.697x10^3$	$2x10^3$	0.54	3:22
Contained carbonate	30.5 x 30.5	60.4	72.7	$2.805 x10^3$	$2x10^3$	0.71	5:05
Contained steel fibers.	30.5 x 30.5	63.2	89.1	$3.349 x10^3$	$2.2 x10^3$	0.66	3:26
Contained polypropylene fibers	30.5 x 30.5	51.9	86.8	$3.266 x10^3$	$2.2 x10^3$	0.67	3:53

Ali et al, [34] researched the fire-prone behavior of high-strength concrete. Thirty High resistance concrete columns were utilized. They were exposed to two rates of heating at the first fifty min of heating with attention to explosive spalling. In all instances, then major and serious spalling occurred in the first minor spalling. In the late heating moment, explosive spalling never occurs. Since the loss of significant components of the column section, explosive spalling could also lead to premature column failure (buckling).

Kadhum, et al, [35] studied the behavior of RC columns and its load carrying capacity after exposure to fire. One hundred and twenty-eight column specimens were tested and classified into two serieses regarding to the compressive strength (series A with 30Mpa and series B with 40 MPa). Also each series were divided into 3 groups with various eccentricity (0, 30, and 80 mm), fire flame temp levels of (25,400, 600 and 750 °C), periods of exposure (1and1.5) hour ,concrete cover (15 and 30 mm)and spacing of ties (no ties, 250, 150 and 50mm). All columns dimensions with1500 mm long and (150×150mm) in cross section .The columns had upper and lower brackets in order to withstand eccentric loads. The test findings showed that curves of load vs. deflection refer to response of deleterious since the exposing to fire. It was also noted that the maximum crack width expands with the increase in fire temp and the quantity of spacing between lateral steel ties. There are two failure kinds: combined failure of compression and flexural for eccentric charged column samples and failure since compression for concentrated loaded column samples. At 400 degree centigrade, the failure form remained unchanged for concentrated and eccentric loaded samples. The failure form remained constant at 600 and 750 degree centigrade, but scabbing happened in the concrete cover. This is occurred as a finding of the flow water vapor pressure that leads to internal pressure stresses on the concrete surface layers that are unconfined by the strengthening of the tie leading to the scab of these layers. Furthermore, when the fire flame temp increased, the cracking appeared early.

Raut and Kodur, [14] eccentricity in loading can be causes biaxial bending in RC columns under fire conditions. Fire flame that induced spalling can cause biaxial bending especially in HSC columns. However, there are few studies and data on the effect of biaxial bending caused by the fire, especially in columns exposed to burn asymmetric, and their effect on the strength of these columns. The working program included fire resistance tests on six RC columns (half of it HSC, one from NSC, and the other from the HSC with polypropylene fibers (HSCP)).The tested columns have cross section 203x203 mm, 3350 mm long, and reinforced by lateral reinforcement Ø10@200 mm and had main reinforcement 4 Ø20 mm. The test findings conclude that the most significant variables affecting RC column fire resistance are concrete strength (permeability), scenario fo fire, biaxial bending resulting from 1, 2, or 3 side exposure, slender ratio, eccentricity of load, and ratio of load. HSC column fire resistance is 65 percent lower than that acquired under certain situations in NSC columns. With the addition of polypropylene-fibers to the concrete mix, the resistant of fire for columns' HSC increased by three times as well as the kind of subject to fire has a significant impact on the fire resistance of RC columns. With the addition of polypropylene-fibers to the concrete mix, the resistant of fire for columns' HSC increased by three times as well as the kind of subject to fire has a significant impact on the fire resistance of RC columns. The model, depending on a macroscopic approach to finite elements, uses time-dependent moment vs curvature (M-κ) interactions to determine RC column reaction under fire conditions.

Nassar [36] studied RC columns behavior at extreme temps. Polypropylene (PP) fibers were used in several samples of RC columns. Three mixture of concrete were prepared by using various Polypropylene amounts (0.0, 0.5 and 0.75) kg/m³. The dimensions of RC columns were (10x10x30) cm. The specimens were heated up for two, four and six hrs. at (400, 600 and 800) degree centigrade and confirmed for compressive strength. Moreover, reinforcement steel bars behavior were investigated and insert into the concrete specimens with 20 mm and 30 mm for covers of concrete. Then after heating to 800 degree centigrade for six hrs. these bars were taken and examined for maximum elongation ratio and yield stress. The finding after analyzing showed the best PP quantity to be utilized was $75x10^{-2}$ kg/m³ where the compressive strength was reduction 20 %, this percentage was greater than samples without pp at 400 degree centigrade for 6 hours. in addition concrete cover of about 3 cm help in promoting resistant against fire for protection concrete structures and the steel reinforcement bars, while it is 5% higher than in the specimens column with 20 mm concrete cover at six hrs. and 600 degree centigrade.

Bikhiet [37] presented an experimental involve examination of 15 columns specimens (15*15*100) cm excepting only one sample to (600) degree centigrade fire and exposed to axial load. The evaluation the decreasing in compressive capacity after exposure to fire. The major investigated parameters that measured were concrete strength, loads applying level, fire duration, the percentage of longitudinal reinforcement, longitudinal reinforcement yield strength, and bar diameter. The findings showed that the first crack appeared at eighty percentage of column failure load for un-exposed columns to fire in compared with that of columns exposed to fire which first crack occurred at fifty percentage of column failure load. Columns with a comparable proportion of strengthening, but lower bar diameters acquired less lateral strain and lower vertical displacement than columns had larger bar diameters. Using high-grade steel as the primary reinforcement could demonstrate a 55 percent greater failure force than that of the column strengthened with mild steel.

Seręga [38] investigated the impact of spacing of transverse reinforcement on a circular cross-section fire resistance of axially loaded HSC columns. The outcome indicated that a premature failure could finding in columns with a spacing suggested by the code requirements for designing concrete structures. This was since the inelastic buckling between neighboring ties of the main reinforcement bars. Also, for the columns with congested spacing of transverse reinforcement, the containment impact was not noticed. As a result of high gradients of temp produced a tensile stresses in the column cross-section plane throughout the whole heating time.

Bodalal et al. [39] studied the high strength concrete (HSC) columns behavior after exposed to extreme temp that created from fire. In this research, the HSC spalling failure mode was observed in addition to spalling temp and the fire resistance criteria. The results showed that the fire more adversely affects high strength concrete (HSC) columns in compared with columns of normal strength concrete (NSC). With increasing temp, risk of spalling increased because of the reduction in the concrete tensile strength. Furthermore, the occurrence of spalling combined with faster degradation of compressive strength with extreme temp could lead to reduction in fire resistance in HSC columns.

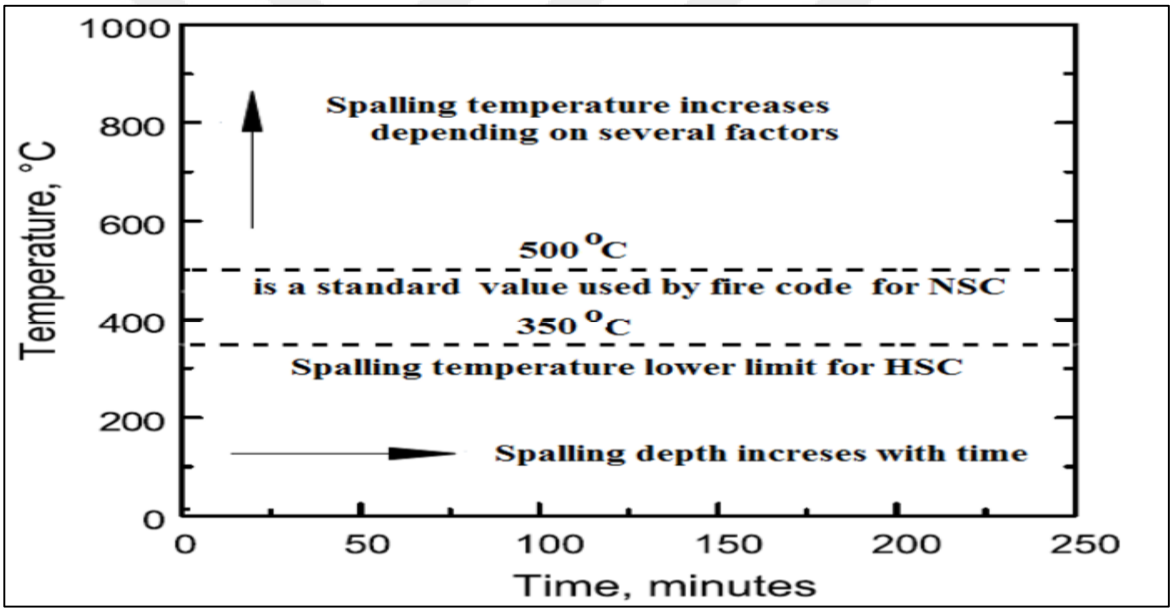


Figure 2.7: Effect of Increasing Temps on Spalling Incident of NSC and HSC [39].

Khaliq and Kodur [40] studied the effect of adding of steel fiber and /or polypropylene-fiber on the performance of HSC columns under the effect of fire case. Five columns of various fiber contents (HSC, HSC-P, HSC-S, HSC-H and NSC) were examined. Relative fire performance of these columns was evaluated by comparing the thermal response, spalling progression, structural response, and failure times. The experimental results showed that: the NSC columns showed high fire resistance in comparing with plain HSC because of fire-induced spalling in HSC. Although, the addition of various types of fibers and combined fibers can lead to decrease fire-induced spalling in HSC columns. The adding of polypropylene to HSC lessen fire-induced spalling by its effect on relieving pore pressure developed thru enhanced porosity in concrete that appear since melt of polypropylene fiber. Also, the adding of steel fiber can help in enhancement the tensile strength of HSC and slowdown its degradation at extreme temps. Otherwise, the adding of hybrid (polypropylene and steel) fibers is the most effective way to decrease fire-induced spalling.

Abdulraheem [41] examined the behavior of reinforced reactive powder concrete (RPC) columns that subjected to concentrated load after exposure to fire. An experimental research was engaged in the first portion of this research to verify that the model created is adequate. The second part consisted using a sequentially coupled heat displacement study to model the RPC columns using a three-dimensional finite element (FE) with the ABAQUS program. Fire-induced spalling also occurs on the basis of concrete pore pressure calculations. The findings showed that approximately (39–45 percent) of RPC columns with bearing ability were lost after exposure to 600 degree centigrade and 1 h flame length. By raising concrete cover and introducing lateral connections, the post-fire conduct of RPC columns scarcely enhanced.

2.5 THE CONCRETE SPALLING UNDER FIRE EXPOSURE

In order to investigate the relationship between the residual mechanical properties of high-performance fibre toughened concrete and explosive spalling after high temps subject, Peng, et al, [42] undertook experimental research. Remaining mechanical properties that were estimated were divided into tensile, strength, compressive, and energy from fracture. Concrete series have been created utilizing OPC (ordinary Portland cement) and crushed calcite. Concrete fracture energy has risen with the addition of steel fibre, polypropylene fibre, and hybrid fibre (both polypropylene fibre and steel fibre). The residual mechanical qualities of fiber-toughened high-performance concrete were examined after exposure to high temps between 200 and 800 degree centigrade.

The residual strength decreased over 400 degree centigrade and the residual energy of the fracture was substantially greater than before heating. The research also demonstrated that the use of hybrid fiber appears to be a successful way of developing concrete resistance to explosive spalling.

Maluk et al, [43] investigated the impact of polypropylene-fiber addition and its dose on concrete spalling caused by heat. A novel method for testing and apparatus including Heat-Transfer Rate Inducing System (H-TRIS) were utilized for test medium-scale concrete samples that subjected to standard subject to fires. The findings demonstrated that:

a. The dose of PP fibers (PP mass per m^3 of fresh concrete) is the sole parameter that prescribed by available design guidelines, both individual fiber length and the PP fiber cross-section may have clear influences on the effectiveness of PP fibers on decreasing the propensity for the heat-induced concrete spalling .

b. The current guidelines for spalling PP fibers are not sufficient to prevent spalling for the HPC mixtures tested.

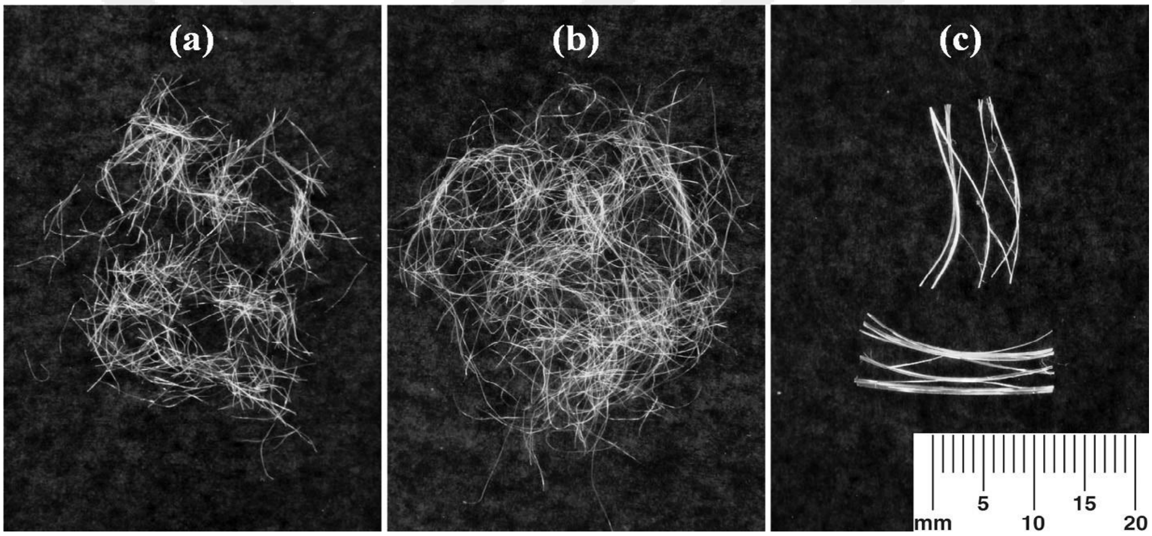


Figure 2.8: Photos Show Types PP Fibers [43]; (A) 0.6 cm Monofilament (32 lm Diameter), (B) 1.2 cm Multifilament; (C) 2 cm Fibrillated.

Yermak et al, [44] investigated the subject to fire impact on various high strength concretes mixtures (70 MPa) which were produced with various natures of aggregates, length, moisture content and dosage of polypropylene-fibers (PPF) and steel-fibers (SF). Plain concrete (without fibers) and $0.6x10^2$ kg/m^3 of SF and concrete with 75 $x10^{-2}$ kg/m^3 of PPF did not spall but Concretes with $0.6x10^2$ kg/m^3 of SF show spalling.

Microstructure, hydric, characteristics of concretes such as mechanical and thermal were examined. The using of steel-fibers will control and develop cracking appearance, which decrease the size of the new pores and the stress relaxation phenomenon. PPF increased the permeability and porosity of concretes.

2.5.1 Spalling Types

Klingsch**,** [45] classified the concrete Spalling at extreme temps into the following classes:

a. Explosive spalling: violent break-off at extreme temps of concrete fragments.

b. Surface spalling: violent break-up at extreme temps of concrete layers.

c. Aggregate spalling: aggregates splitting as a result of their changes or decomposition at extreme temps.

d. Corner spalling: removal of concrete cover at extreme temp from edges owing to two-sided temp effect.

e. Post-cooling spalling: non-violent breakdown throughout cooling of concrete fragments.

f. Sloughing off spalling: non-violent cracking of concrete pieces after exposure to extreme temps for longer periods.

2.5.2 Mechanisms of Spalling

Dwaikat [46]: stated that there are conflict picture on the spalling occurrence in RC members and its mechanism while other researchers notified explosive spalling in concrete members but other studies notified few or no significant spalling that led to one explain that there are many factors influence on the spalling . Most of researchers considered the main reasons of spalling are:

a. Low concrete permeability.

b. Migration of moisture at extreme temps.

Kodur, [47] explained two broad theories on which the spalling phenomenon couuld occur due first: Pressure build-up that believe the occurrence of spalling because of build-up of pore pressure throughout heating. Since low permeability of HSC, it is believed to be more susceptible to this pressure build-up in compared with NSC. The high density (and low permeability) of HSC lead to that the extremely high water vapor pressure which generated throughout exposure to fire cannot escape. The chunks of concrete fall off from the structural member when the pore pressure be more than the tensile strength of concrete. This falling off could often be explosive depending on concrete characteristics and the fire [48], [49]. Second: restricted heat expansion, which believes that spalling outcomes from the restricted thermal expansion that then occurs near the heated surface, leads to the growth of parallelly compressive stresses to the surface's heated. Brittle concrete fractures (spalling) result in these compressive stresses being released. The pressure of the pores was involved in the start of instability in the form of explosive heat spalling [50].

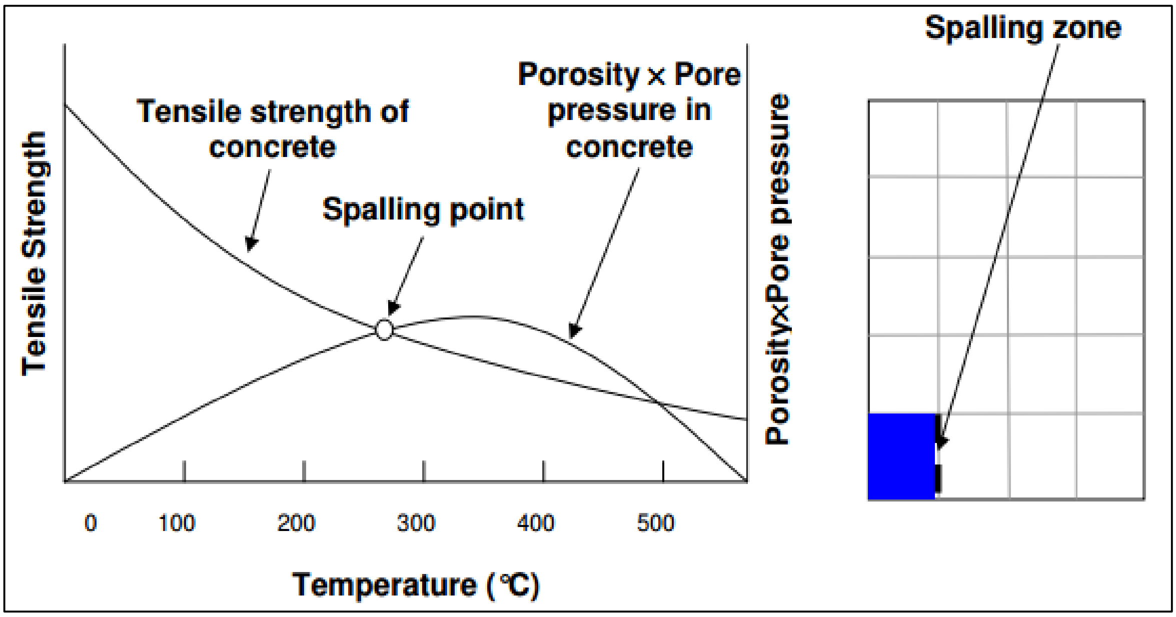


Figure 2.9: Illustration of Occurrence of Spalling [48].

2.6 CONCLUDING REMARKS

This chapter review the researches that contain many details about the mechanical characteristics of hybrid reactive powder concrete with hybrid fiber and reactive powder concrete after extreme temp exposure. In addition, these researches study the fire consequence on the behavior of concrete with or without the addition of fiber. The conclusions from these researches are summarized as the following:

a. In comparison with normal concrete, the RPC structure is characterized by high density, brittleness, compaction with low permeability. The permeability has an effect on spalling that occur since high internal vapor pressure from high water content.

b. The addition of various fiber types for example (steel and/or polypropylene) could improve the behavior of fire resistance for RPC columns significantly.

c. The adding of fiber-polypropylene can help in decrement the concrete spalling. This is since the melting of pp fiber after exposure to extreme temp causing adequate number of channels in form of small passages help in releasing of vapor pressure.

d. The impact of subject to fire on the load carrying capacity of strengthened concrete columns can cause of concrete spalling cover and reduction in the mechanical properties.

3. EXPERIMENTAL PART

3.1 INTRODUCTION

This section gives the details about the experiment programing that led to obtain the objectives which mentioned in chapter one. These details involve materials components used and its mechanical properties, mix proportions, mix methods, curing and firing conditions.

The parameters of this research for experimental investigation were:

a. Types of fibers (steel fibers).

b. Duration of subject to fire (1 hour).

c. The temp of burning is (200, 400 and 600 degree centigrade).

d. concrete type is normal and reactive powder concretes.

e. concrete cover is (15 and 30 mm) which is suitable to prevent concrete collapse throughout one hour of firing.

3.2 THE PROGRAM OF EXPERIMENTAL

3.2.1 General Depiction

In this research, the program of experiment consists of two stages:

The first part involves the choosing, preparation of raw materials, the characteristics of the materials physically and the chemically utilized in this project. Then, preparing the proper mixing procedure with the adopted optimal mixture proportions is presented. Finally, casting specimens and column samples and curing for the specified curing (3, 7, 28 and 56 days) are described.

The second part involves study the effect of adopted variables on RPC column samples' behavior and samples with exposure to fire for (1 hour). When the subject and unsubjects concrete samples and columns specimens reach the required age, they prepared and tested after the burning process is finished .Sixteen column specimens in this research were confirmed under eccentric compress loading pending failure. These columns were organized into four sets dependent on the following variables: concrete cover, temperature, presence secondary reinforcement or not, and strength and unstrength columns by steel plates.

3.3 MATERIAL PROPERTIES OF THE TESTED SPECIMENS

Finding the qualities of materials in accordance with (ASTM) and other standards was an advantage of standardized testing like (IQS) was adopted in the current study.

3.3.1 Cement

The applied cement in this project was Portland cement (Ordinary Type 1), cement that manufactured in the north part of Iraq commercially known as Karasta, which is locally taken from market and keeping in dry area to prevent exposing to various atmosphere surroundings depending on Iraqi standardization [51]. This cement is complied with the EN 197 [52], the chemical and physical analysis test findings are verified in Tables (3.1 and 3.2) respectively, all of these tests have been conducted in civil engineering labs of Babylon university.

Table 3.1: Chemical Analysis for Krasta Cement.

Chemical Composition	Percentage by Weight	Limit of (EN 197-1:2011)
Lime (CaO)	62.79	---
Silica (SiO_2)	20.58	---
Alumina (Al_2O_3)	5.6	---
Iron Oxide (Fe_2O_3)	3.28	---
Magnesia (MgO)	2.79	5% max
Sulfate (SO_3)	2.35	2.5 if C3A $\leq$5 2.8 if C3A >5
Chloride content	0.02	$\leq$ 0.10 %
Loss on Ignition (L.O.I.)	1.94	5% max
Insoluble Residue (I.R.)	1.00	---
Lime Saturation Factor (L.S.F.)	0.9	---
Main Compounds (Bogue's Equation)		
Tricalcium Silicate (C_3S)	50.12	---
Dicalcium Silicate (C_2S)	21.26	---
Tricalcium Aluminate (C_3A)	9.29	---
Tetracalcium Aluminoferrite (C_4AF)	9.98	---

Table 3.2: Physical Krasta Cement Features.

Physical features	Test findings	Limit of IQS NO. 5/1984
Specific Surface Area (Blaine Technique) m^2/kg	314	≥ 230
Setting Time (Vicat's Apparatus)		
Initial, (min)	122	≥ 45 min
Final, (min)	3:13	≤ 10 hrs
Soundness By Autoclave Technique	0.18 %	≤ 0.8 %
Compressive Strength (MPa) at:		
Three Days	19.0	>15
Seven Days	28.0	> 23

3.3.2 Fine Aggregate

Fine aggregates from Al-Ekhaidhir, which served as the sand for producing RPC, has been utilised for these operations. Table (3.3) and Figure show the grade of the sand utilised (3-2). The results showed that the fine aggregate grading within the Iraqi Specification criteria (IQS No. 45) [53] after removing the coarse size of particle (higher than 600 μm). The physical evaluations of fine aggregate, including their sulphate amount, fineness modulus, absorption, and specific gravity are listed in Table (3.4). These characteristics meet the standards of Iraqi specification IQS No. 45 [53].

As previously stated, the max size of fine sand utilized for RPC manufacture was 600 μm to provide density indemnification. Sand's particle sizes range from 150 to 600 μm.

Table 3.3: Sand Grading Results Associated with Requisites' (IQS no.45/1984).

Size of The Sieve (mm)	Cumulative Passing	Limits of IQS No.45/1984 as in (Zone 2)
10	100	100
4.75	97	90-100
2.36	81	75-100
1.18	70	55-90
0.60	54	35-59
0.30	21	8-30
0.15	7	0-10

Table 3.4: Physical and Chemical Features for Utilized Sand.

Physical Features		
Features	**Test Findings**	**Iraqi Specification No.45/1984**
Specific Gravity	2.65	
Absorption	0.94%	
Fine Material Passing From Sieve (75 µm)	4.2%	Max ≤ 5.0%
Fineness Modulus	2.6	
Chemical Features		
Sulfate Content	0.15%	Max ≤ 0.5%

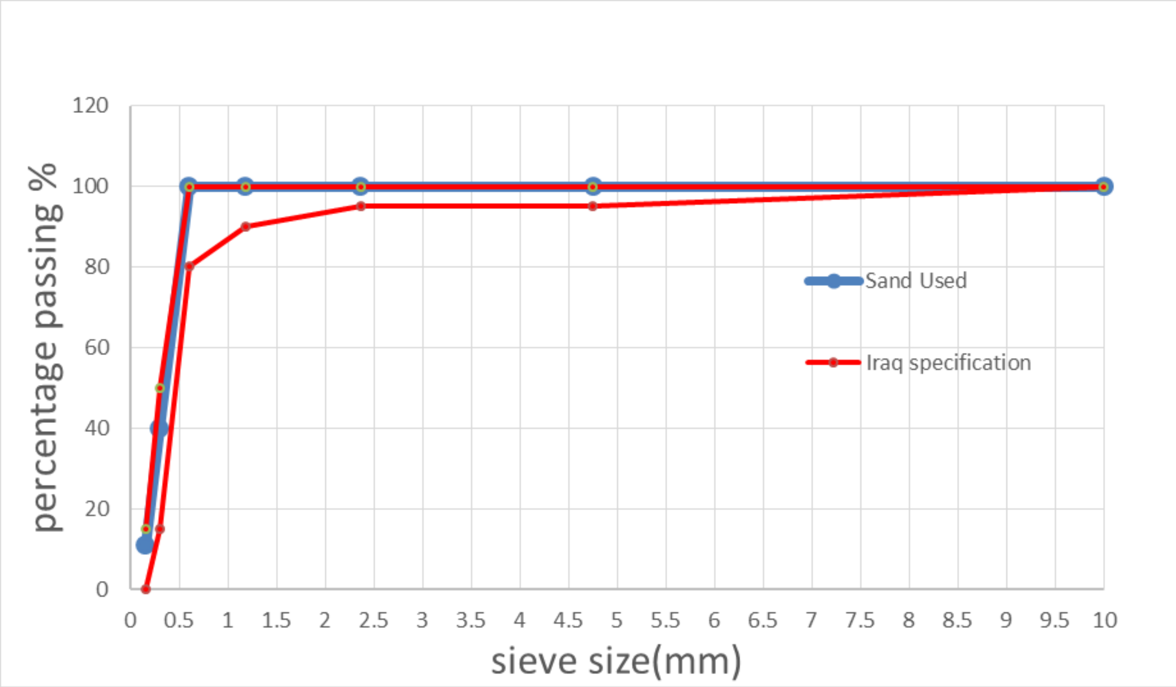


Figure 3.1: Fine Aggregates Distribution Curve Comparing with Iraqi Requirements [53].

3.3.3 Microsilica Fume (SF)

The Institute of Concrete in US (ACI) described fume of silica as very good uncrystalline silica prepared in ovens (electric arc) as a secondary material from the manufacture of silicon-containing elemental silicon or alloys (ACI 116R/2005). The fume of silica applied by the chemical business (CONMIX) as demonstrated in Figure (3.3), commercially known as Mega Add MS (D). It is described as (gray) colored powder and varies particle size ranges (0.1-1)µm in. The regular particle size of the silica fume is lower in sized (100) times comparing with the cement particle size in relations of particle diameter. The SF of is produced depending on the necessities ASTM C1240 [54]. The SF is applied to filling the space between cement and fine aggregates particles, rheology improvement and secondary hydration production. This is by reason of the improvement in the of the matrix of cement densification and besides to the enhancement of the bonding between the aggregates and cement paste in the interfacial area.

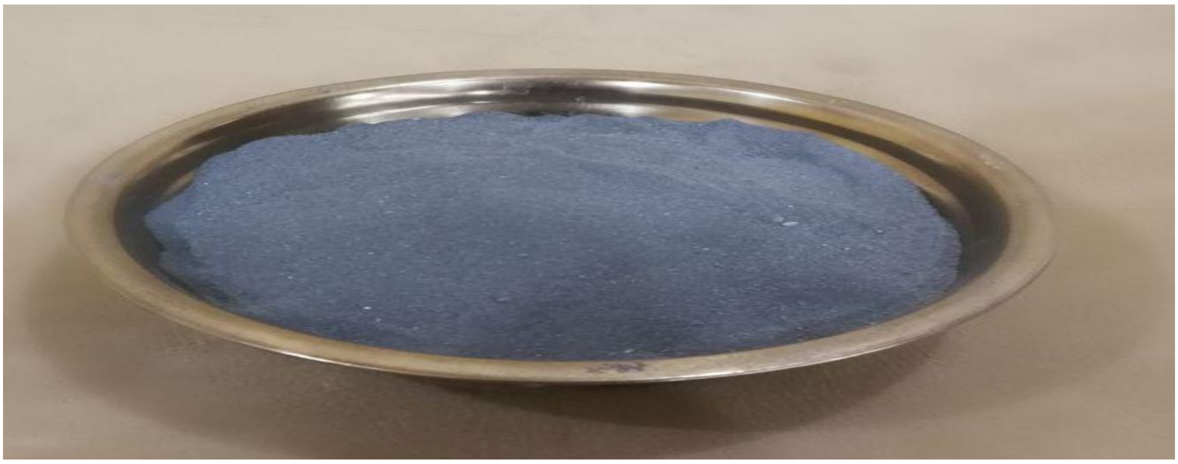


Figure 3.2: The Fume of Microsilica.

Tables (3-6) and (3-7) display the features, chemically analyzed composition and physical features specifications of the SF applied in this study in accordance with (ASTM C1240) requirements [55].

Table 3.5: The Results of Utilized Fume of Silica Chemical Analyzing.

Oxide Compositions	Oxide amount %	ASTM C-1240 Limitations
SiO_2	90-93	≥ 85
Al_2O_3	0.2-0.7	---
Fe_2O_3	1.0-2.0	---
Na_2O	0.2-0.6	---
K_2O	1.0-1.3	---
CaO	0.2-0.7	< 1
MgO	0.9-1.3	---
SO_3	0.25-0.35	< 2
L.O.I.	1.0-2.5	≤ 6.0

Table 3.6: The Utilized Fume of Silica Physical Features.

Physical Characteristics	Findings	**ASTM C1240** [56]
Strength activity index	130%	Lower or equal to105
Percent retained on 455 µm (No. 325) sieve, max,	1.7	Higher or equal to 10
Specific surface, Minimal, (m^2/g)	23	Lower or equal to 15

3.3.4 High-Ranges Water Reduction Additives (HRWRA)

Third-generation superplasticizer for concrete and mortar (Hyperplast PC200) used in this study seems to be an import from the (DCP) company. This Super-Plasticizer would be a long-chained, chloride-free polymer that is specifically designed to allow the water content of the concrete mixture to be high-effective. Therefore, it could be utilized in RPC to obtain highest concrete performance and durability. Hyperplast PC200 conform with (ASTM C494**)** [57], based on doses that utilized. In concrete mixture it is better to add with water to obtain optimum performance. Table (3.8) displays the technical depiction of Hyperplast PC200.

Table 3.7: Technical Depiction of Hyperplast PC200.

Chemical Basis	Aqueous Solution of Modified Polycarboxylate
Freezing Point	≈ -3 degree centigrade
Colour	Light yellow liquid
Specific Gravity	1.05 ± 0.02
Air Entrainment	Naturally less than 2percent additional air is entrained controlling mixture at consistent amounts.
Chloride amount	None
Toxicity	Not categorized as dangerous substantial.
Storages	Kept at temps between 2 and 50 degree centigrade.
Firing	Nonflammable

3.3.5 Water

In the experimental activities of this study, water taps have been used in mixing and curing of concrete. The mixing water's temperature (25±2 degree centigrade) has been kept.

3.3.6 Steel Fibers

In this project, RPC ductility were improved by using ultra-fine steel fibers and the chemical analysis of the fibers and other characteristics presented in Tables 3.9 and 3.10. The (Ganzhou Daye Metallic fibers Co., Ltd, China) made this kind, as presented in Figure (3.4). These fibers was a nominal length=1.3cm and a nominal diameter=0.02cm with the feature proportion (Lf/df=65). The virgin fibers have gold colored because of the presence of thin brass coating. The steel fibers volume range from 0.25 to 2 percent.

Table 3.8: Micro Steel Fiber Composition Chemically.

Elements	Amount (%)
Carbon (C)	0.80
Manganese (MN)	0.75
Phosphorus (P)	0.035
Sulfur (S)	0.035
Silicon (Si)	0.3

Table 3.9: Micro Steel Fiber Characteristics.

Feature	Requirements
Surface	Brass coated
Relative Density	7825 Kg/m^3
Tensile Strength	Minimum 2400 MPa
Form	Straight
Melting Point	1500 °C
Average Length	13±1 mm
Diameter	0.2 mm±0.05 mm
Aspect Ratio (Lf/Df)	65
Type	WSF0213

Figure 3.3: Ultra-Fine Steel Fiber After and Before Amplification.

3.3.7 Steel Reinforced Bars

Figures (3.5 and 3.6) illustrates the usage of deformed steel bars with diameters of (Ø 5 mm) as a secondary reinforcement (ties) and (Ø 6 mm) as a main reinforcement. As shown in Table (3.11), the reinforcement bars' mechanical properties were determined using a digital computer in addition to the testing apparatus.

Table 3.10: Steel Bars’ Specification and Testing Results.

Bar Diameter (mm)	Actual bar Diameter (mm)	Yield Stress Fy (MPa)	Ultimate strength Fu (MPa)
5 Ø	4.83	552	602
6 Ø	5.90	560	607

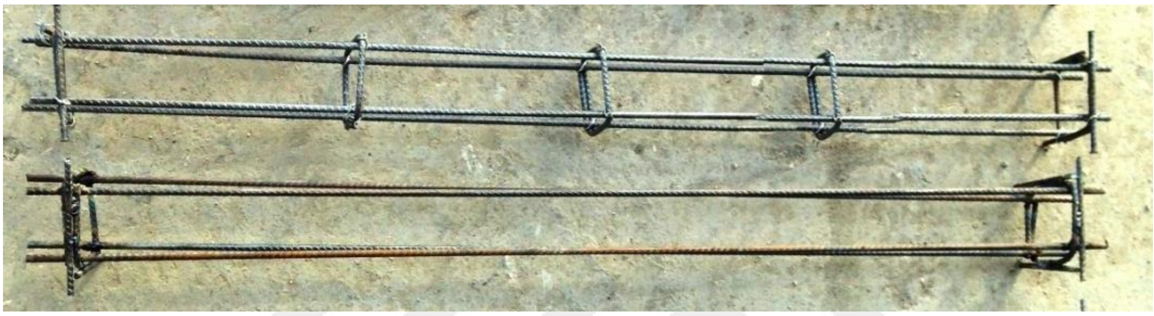


Figure 3.4: Specifics of Longitudinal and Tie Reinforcement of Tested Column.

Figure 3.5: Tensile Test by Universal Device.

3.4 DETERMINING OF RPC MIX WORKABILITY

The flow ability of the RPC mixes for each percentage of variables were verified by table of mortar flow testing rendering to (ASTM C1437) [58]. The flow can be express as a percentage of increase of dishonorable mortar mass diameter to the primary dishonorable (10 cm) diameter.

(A) Device for Flow Table Test (B) Diameter Measurement.

Figure 3.6: The Testing Flow Table Process.

$$\text{flow } \% = \frac{\text{D} - 100}{100} * 100 \qquad (3.1)$$

Whereas: D:Middling spreading mixture’s diameter dignified in 4-direction, (mm).

The flow table results displayed that the diffuse concrete’s diameter between 20.5 and 22.5 cm is enough to provide the features of desired RPC flow (110±5).

3.4.1 Concrete Trial Mixes

The trial mixed method works optimum for choosing RPC ratios. Low water to cementing substance ratios and high OPC contents are required to achieve high strengths. To help with mix designs, the unit strength obtained for every cement unit utilized in a cubic meter of concretes may be shown as strength efficacy.

Numerous blending ratios have been developed by experimenting with the mixture proportions that were taken into account from the previous literatures.

By replacing the aggregates and conventional sand used in this type of concrete with ground quartz that is smaller than 600 microns in size, homogeneity is increased. To produce better strength, a varied quantity of typical Portland cement's high cement content is employed. Using low water-cement ratio, which was 0.17 is a noteworthy trait as shown in table 3.12.

Table 3.11: Mixture Design for the Tested Samples and Columns.

Cement Kg/m^3	**Sand Kg/m^3**	**Gravel Kg/m^3**	**Silica Fume Kg/m^3**	**Steel Fiber Kg/m^3**	**W/Cm**	**Super Plasticizer by wt. of Cementious (%)**
950	1050	---	210	156.5	0.17	6.5

3.4.2 Description of the Tested Column Specimens

Examining the structural behaviour of reactive powder concrete columns subjected to fire flame at two adjacent sides is the main goal of this work. The experimental programme included evaluating 12 column samples made of reactive powder concrete. Tested under (concentrically) stress and contrasted with the reference (6) reinforced regular concrete column samples were reinforced reactive powder concrete column samples made in the lab. Every column was strengthened with 4Ø6mm longitudinal reinforcement and Ø5mm bars have been utilised for transverse reinforcement (ties) with varying spacing, as indicated in Figure (3.8). The chosen dimensions were set for every column samples at (90 cm), and a square cross - sections of (10x10 cm). According to the fire temp levels, column samples have been classified into three groups. Every group included four reactive powder concrete columns, based on the spacing of the transverse reinforcement (ties) and concrete cover, as indicated in Table (3.13).

3.4.3 Column Specimens Identification

Each RPC column is marked by three symbols since the high number of column specimens examined in this study and to make it easier to compare these columns. The experimental work conducted on three different group each group exposure to specific burning degree (group one exposure to 200 degree centigrade; group two exposure to 400 degree centigrade and group three exposure to 600 degree centigrade). In each there are four samples each two has similar concrete cover either (15 mm and 30 mm as shown in figure 3.9) and one of them prepared without secondary reinforcement and the other one has tie spacing of 200 mm. Letters that stand in for the concrete kind are the initial symbol, where reactive powder concrete samples are identified by the letters (RM).

Table 3.12: Summary of Reactive Powder Concrete and Normal Concrete Column Test Specimens.

GROUP NO.	Variables				Constants			
	Fire Temp (°C)	Columns ID	Concrete Cover (C.C) (mm)	Transverse Reinforcement (Ties)	Cross Section Dimensions (mm)	Main Reinforcement	Volume Fraction of Steel Fiber Vf %	Fire Duration (hr.)
One	200	RM1	15	Without	100×100	4Ø6	2	1
		RM2		Ø5@200mm				
		RM3	30	Without				
		RM 4		Ø5@200mm				
Two	400	RM1	15	Without	100×100	4Ø6	2	1
		RM2		Ø5@200mm				
		RM3	30	Without				
		RM 4		Ø5@200mm				
Three	600	RM1	15	Without	100×100	4Ø6	2	1
		RM2		Ø5@200mm				
		RM3	30	Without				
		RM 4		Ø5@200mm				

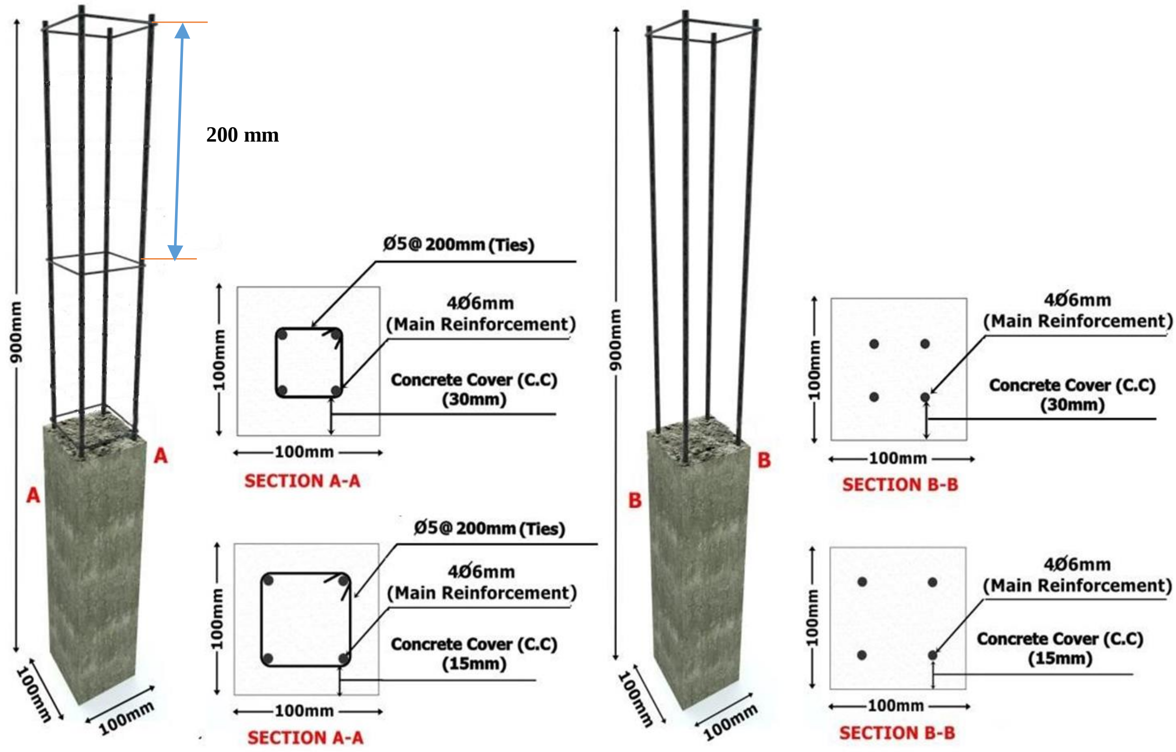


Figure 3.7: Column Samples Reinforcing Details with Column Dimensions.

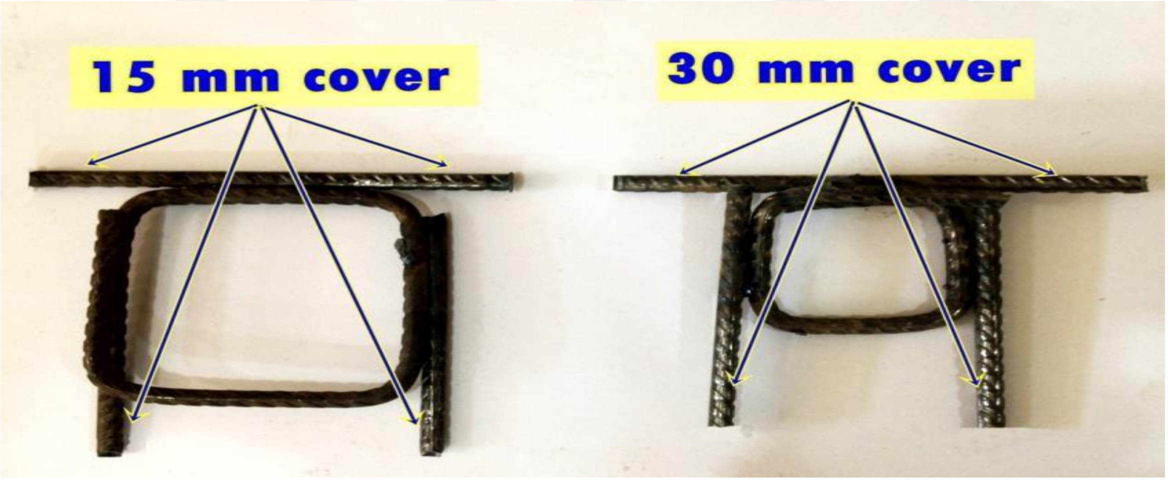


Figure 3.8: The Effect of Concrete Cover on Steel Reinforcing Ties.

3.5 MIXES PROCEDURES

Good and desirable concrete homogenous and effectiveness can be gained from an appropriate mixing process. The RPC mixing time is higher than in NSC because low w/cm ratio and high cementitious materials composition .This needs more time to make superplasticizer penetrates between cementititous molecules. The specimens mixes were made in a pan mixer of (0.09m3) for RPC while trial mixtures were conducted in a mixer (rotary one) with ($0.01m^3$) capacity. Before using the mix, all the residual concrete should be cleaned. The procedure of mixing which adopted in this work was suggested by Wille et al. [59] to products RPC in modest method short of augmented cure commands at the beginning of mixing procedure, the mixing of fume of silica and sand for 3 min then mixing cement and dry quantities for 2 min till a uniform color was gained. After that adding the Superplasticizer to water throughout the mixer rotation liquid of blending was put to the dry mix for additional 4 min. As a final point steel fibers were put throughout mixing by hand within 5 min, Throughout the research, the concrete mixing carried out at (25+- 2°C) temp. Such mixing procedure is schematized in Figure (3.10).

(A) Trial's Mixtures Mixer. (B) Samples and Columns Mixer.

Figure 3.9: The Mixers of This Project.

3.5.1 Specimens Cast and Cure

Steel molds were used for all kinds of samples and columns, the molds should be prepared before the pouring of each mixture as demonstrated in figure 3.11. This was done by suitable cleaning and good lubricating the internally faces softly by oil in order to avoid the adhesion with hardened concrete before casting.

Specimens cast in a short duration to reduce the variation in exposure situation, the steel reinforcement structure was put into the mold and the cover distance was provided for all structures.

Three cubes (5x5x5 cm) for compressive strength, three cylinders (100x20 cm) for splitting tensile strength, and three prisms (5x5x30 cm) for flexural strength were produced for every mixture to test the concrete's mechanical characteristics.

The heating remediation curing of RPC is one of the fundamentals for improving RPC that was previously mentioned (in chapter two), however this technique was not used in this research to gain the benefit of fabricating RPC with outstanding mechanical characteristics (compressive strength greater than 140 MPa) utilizing traditional curing technique without any extra provisions and also to predict the real-world site situations. Then, as indicated in Figures 3.12-3.13, samples were cured in a water tank at a temp of (23±2 degree centigrade), whereas column specimens were cured with saturated wet covers made of burlap.

Figure 3.10: Molds of Steel Used to Cast Samples of Columns.

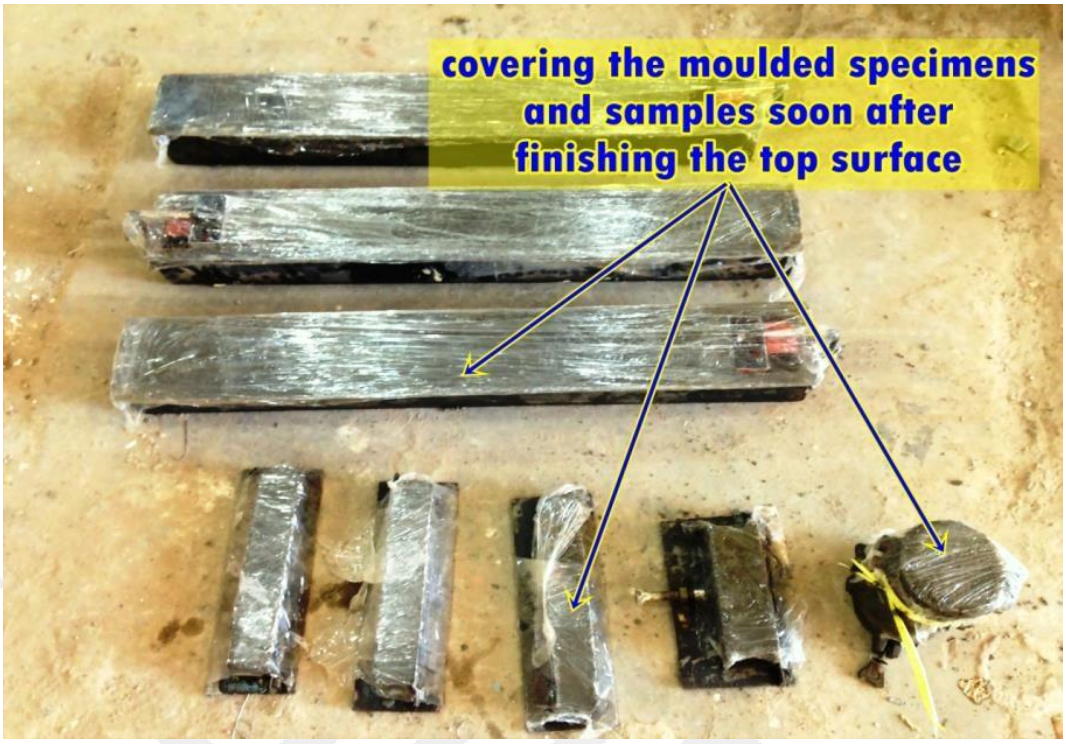


Figure 3.11: The Molded Specimens and Samples After Covering.

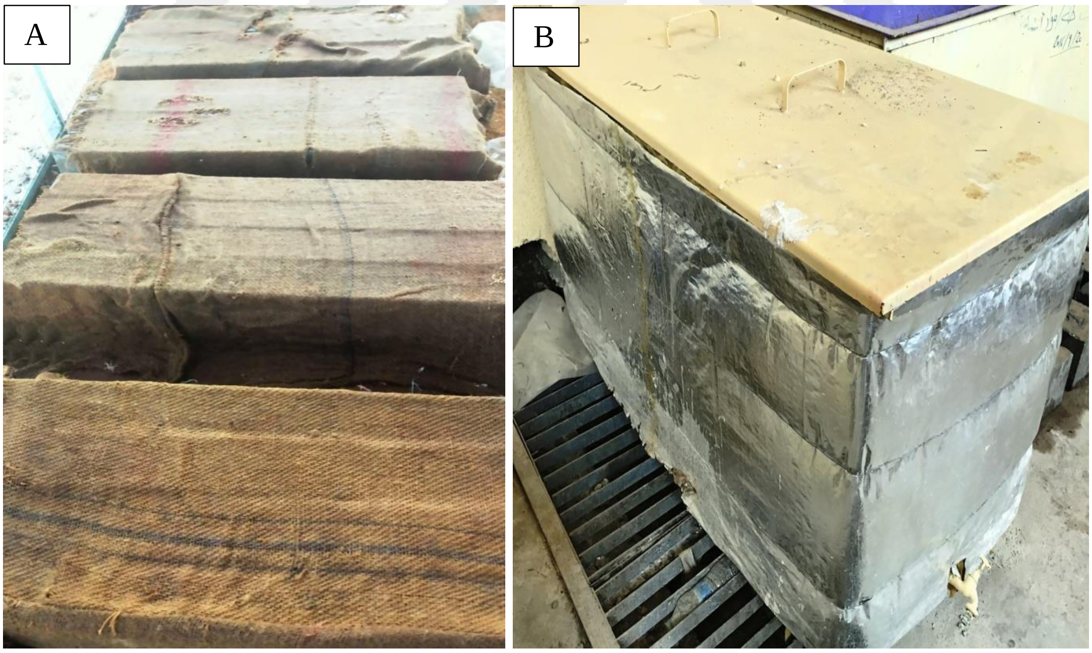


Figure 3.12: Curing Process for Column Samples and Specimens (A) Covering of Column Samples (B) Water Tank Used for Curing Samples with Burlap.

3.6 BURNING OF COLUMN SPECIMENS

Specimens were burned by utilizing fire flame stove, burning process comprises of the follow gear: (thermocouples (Digital one), Burning Network for methane, Brick stove, Electrical regulator gas controller, sensor for Temp, Gas connections and pipelines, Electrical network and source of Gas) as demonstrated in Figure 3.14.

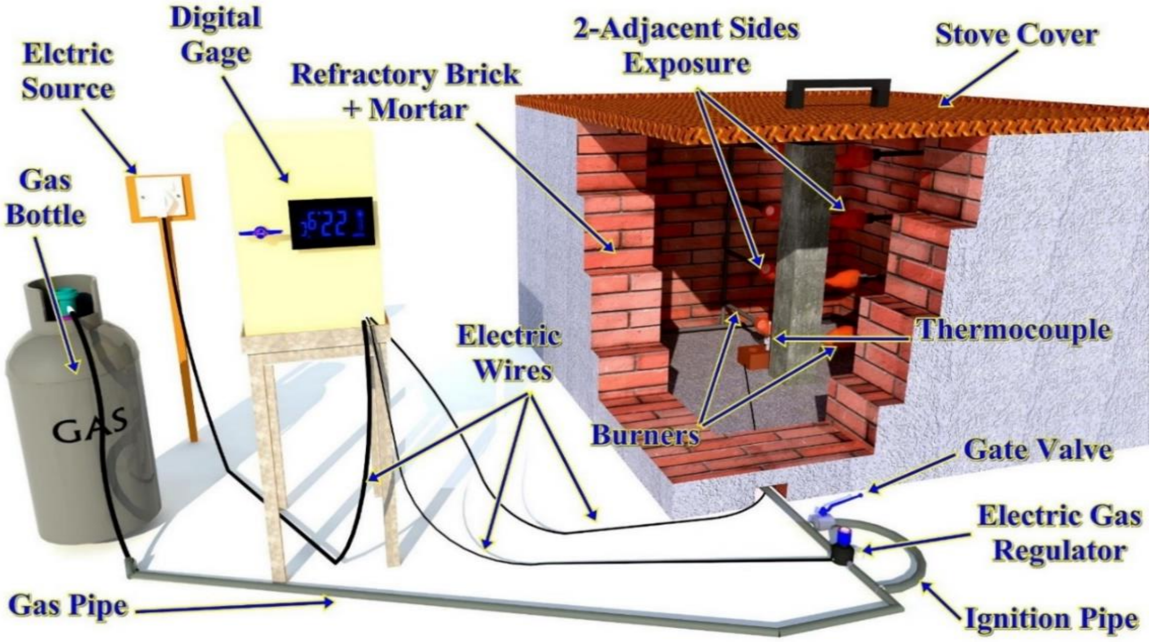


Figure 3.13: The Equipment of Stove

3.6.1 Stove of Brick

The stove was manmade with sizes (length=1m × width=70cm) and height=1.250 m and 250 mm thickness of wall in all sides, also small opening was made for supplying oxygen to the burners. The stove cover was made from 8 mm thickness insulator plate for keeping the temps displayed in Figure (3.15). The burners network involves of three burners for methane that systematized in one line at one exposing side and their distribution were along the column length without corbels, the burner of methane have been coupled in a pipeline together for controlling the discharge of gas and connected to gas bottle . The flame bars were proposed to simulate the heating situation in a real fire.

Figure 3.14: Specifics About the Stove and its Network of Burners' Methane.

3.6.2 Digital Thermocouple

Thermocouple is a temp sensor that has two wire legs manufactured from various metals, which are putting inside a metal tube (thermocouple cover). The legs cables are welded composed at one end to create an intersection where the temp is assessed by voltage generation resulting from temp change. Thermocouple linked by a thermal-insulated electrical wire to a thermometer (gage (digital) utilized in this research) to resist the elevated temp. throughout burning. Figure (3.16) display the thermocouple specifics and the digital indicator.

Figure 3.15: Specifics of Thermocouple and Digital Gage.

3.6.3 Regulator of Electric Gas and System of Ignition-Branding

Gas regulator system is an electronic regulator design to present the furnace burners with quite accurate and fast gas flow. The circuit electricity equals the pressure of gas injection to its specified temp level and can control the gas flow by opening or closing the door to maintain the temp at its set level. The regulator of gas electrically is linked to the digital gage to supply flowing of gas in accordance with the required temp, these connections enable the remaining fire flames in burners just like a system of ignition throughout the firing cycle. Explosion devices still burnt throughout the moment of locking gas to be prepared for reigniting when the temp degree drops below the necessary level (if necessary). Figure (3.17 and 3.18) demonstrates the regulator of electrical gas and the system of ignition burning with full details.

Figure 3.16: The Burning Processing Details and Stove.

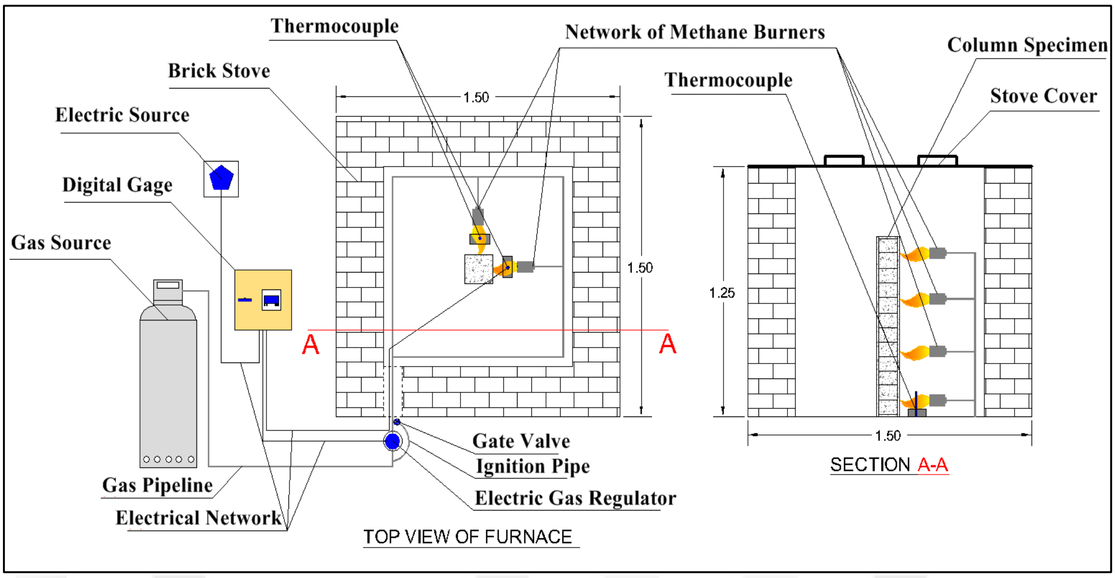


Figure 3.17: Side and Top Views for the Equipment and Stove of Burning.

3.6.4 Burning Process

The burning process is used after the completion of curing. The samples have been heated to the desired temp using direct flame from a network of methane burners within a brick stove. The following stages were used to perform the burning procedure:

a. Once the stove was ready and connected, the concrete samples were carefully handled, weighed, and put inside the stove.

b. With the same distance between every burners line, the concrete examples have been placed fair-faced to towards the methane burners.

c. After the burners were lit using an ignition instrument and the gas valve had been opened, the recorded temp was progressively raised.

d. Once the desired temp was achieved, the electric gas regulator kicked in, controlling the gas flow to maintain the target temp, which was monitored by a thermocouple that was put in direct contacting with the flame of fire.

e. Figure (3.19) show the desired temp and the subjected concrete surface temp were also evaluated by using an infrared ray thermometer at a distance of about one metre.

f. After the allotted burning time (60 minutes of exposure to fire) had passed, the gas valve was shut, and the samples have been promptly cooled.

Figure (3.20-3.21) depict the complete specifics of the burning procedure and burning furnace with all interconnections.

Figure 3.18: Infrared Ray Thermometer.

Figure 3.19: The Burning Process for Samples (Cube, Cylinder, Prism).

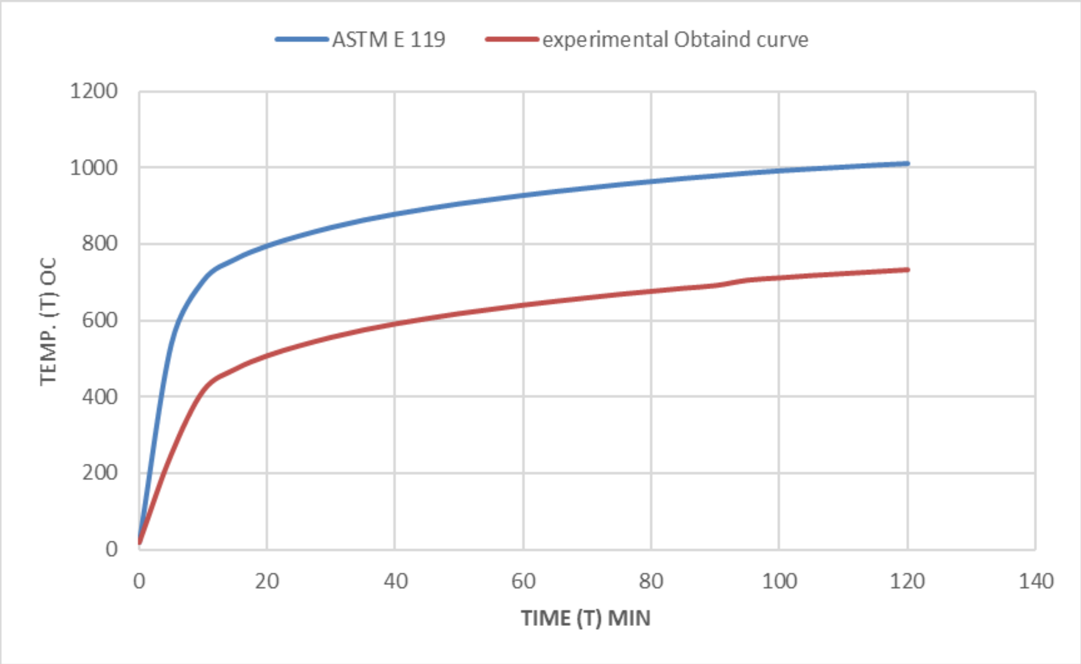


Figure 3.20: Experimental Time-Temp Curve.

3.7 CONTROL SPECIMENS TESTING

After choosing the combinations for the RPC column specimens, cylinders, cubes and casting prisms and examined at ages of (3, 7, 28 and 56 days)with various fiber kinds at temp of room and after flame fire of exposing (1) hour with the same methods and conditions of column burning. These testing consisted of cube strength against compression (fcu), modulus of rapture (fr) and strength against tension splitting (fsp). All the tests were done at Babylon University.

3.7.1 Compressive Strength Test

The compressive strength is amongst the most vital concrete engineering possessions of, which give an idea about the class of the concrete. 3-cubes of (5x5x5 cm) were cast for every mixture and burned in the same way as for column samples and with various duration of burning (1 hour of burning) to detect the compressive strength, and an obtaining mean magnitude of these cubes conferring to (ASTM C109/ C109M) [60]. The test of strength against compression was detected by cracking these cubes at (3, 7, 28 and 56 days) ages by means of a testing digital apparatus with a capability of (1,900,000 N), the loadings rate was used at (0.3 MPa/sec).

3.7.2 Strength under Splitting Tension

Strength under Splitting Tension of concrete had been consistent by (ASTM C496) [61] requirement. Three cylindrical concrete specimens (100x200 mm) had done for each mixes at (3, 7, 28 and 56 days), casting and those of age 28 days were burned in the same way for column samples and with various durations . Two bearing strips (3 mm plywood thickness, wide =2.5 cm and length=20 cm) were put below and above the sample in the testing machine (1900 kN capacity) as displayed in Figure (3.22).

The strength of splitting tensile (fsp) for sample is determined by the following Eq.:

$$f_{sp} = \frac{2p}{\pi \mathrm{DL}} \qquad (3.2)$$

f_{sp} : Strength under Splitting Tension (MPa).

P : Max practical load in splitting test (N).

D : Cylinder's Diameter (mm).

L : Cylinder's Length (mm).

3.7.3 Strength of Flexural Tensile

The concrete rupture's modulus was detected by experimenting 50×50×300mm prism for RPC, in compliance with (ASTM C78 / C78M) [62]. By using testing machine (1900 KN capacity) two point loading is subjected to each prism as displayed in Figure (3.22). The average rupture's modulus which sometimes called as strength of flexural-tensile is of 3 prisms for the every (3, 7, 28 and 56 days) days. Rupture's modulus (fr) can be calculate by the formula below:

$$f_r = \frac{PL}{bh^2} \qquad (3.3)$$

fr: Rupture's Modulus of, (MPa).

P: loading of failure, (N).

L: supports spaces, (mm).

b: Prisms’ Width, (mm).

h: Prisms’ Depth, (mm).

(A) Compression Strength

(B) Splitting Tensile Strength

(C) Flexural Strength

Figure 3.21: Compressive, Splitting Tensile and Flexural Strength Test.

3.8 INSTRUMENT AND TEST PROCEDURE

3.8.1 Instrumentations

Suitable devices were employed to notice the behavior of concrete columns structure in all stage, of load. In each load stage the related axial deformation, lateral deflection and concrete strain at mid height have been determined in addition to first crack load .The ultimately load was recorded and the tests continued up to failure. The instruments utilized in this research were :

a. The strains of concrete were recorded by a mechanical strain gage, which have an accuracy of 0.001mm. At mid-height if, column 5 of demec couples discs were utilized to observe the concrete strain at choosing loading's levels for every column specimen.

b. Dial gages of accuracy 0.01mm were utilized to identify the axially deformation and laterally deflection.

3.8.2 Testing Procedure

The column sample was prepared the day before the testing by cleaning the sample surface, and after that it was positioned for the test while being careful to keep it upright, and the dial gauges have been fastened in place. At each step of loading throughout testing, the major traits of the specimens' structural behaviour have been identified. Maximum load, mid-height lateral displacements, and axial deformation have all been recorded for every test.

A calibrated electro-hydraulic testing equipment with a max range capability of 2,500,000 N was used to test all of the column samples at the age of 60 days under increasing concentrical loads until failure.

Two dial gauges with a 2 cm capacity, 0.0001 cm per deviation precision, and a 5 cm max sensor length have been utilized to determine the mid-height lateral deflection and axial deformation. The dial gauges have been positioned at chest height on the piston of the electro-hydraulic testing equipment and along the vertical centre line of the column samples. Before applying the weight, every column's precise verticality was tested at both ends utilizing a spirit level, as illustrated in Figure (3.23). Small load increases have been applied, and readings of displacements against load were concurrently taken for every load increment using numerous HD video cameras connected to a computer that was monitoring these specifications until damage happened.

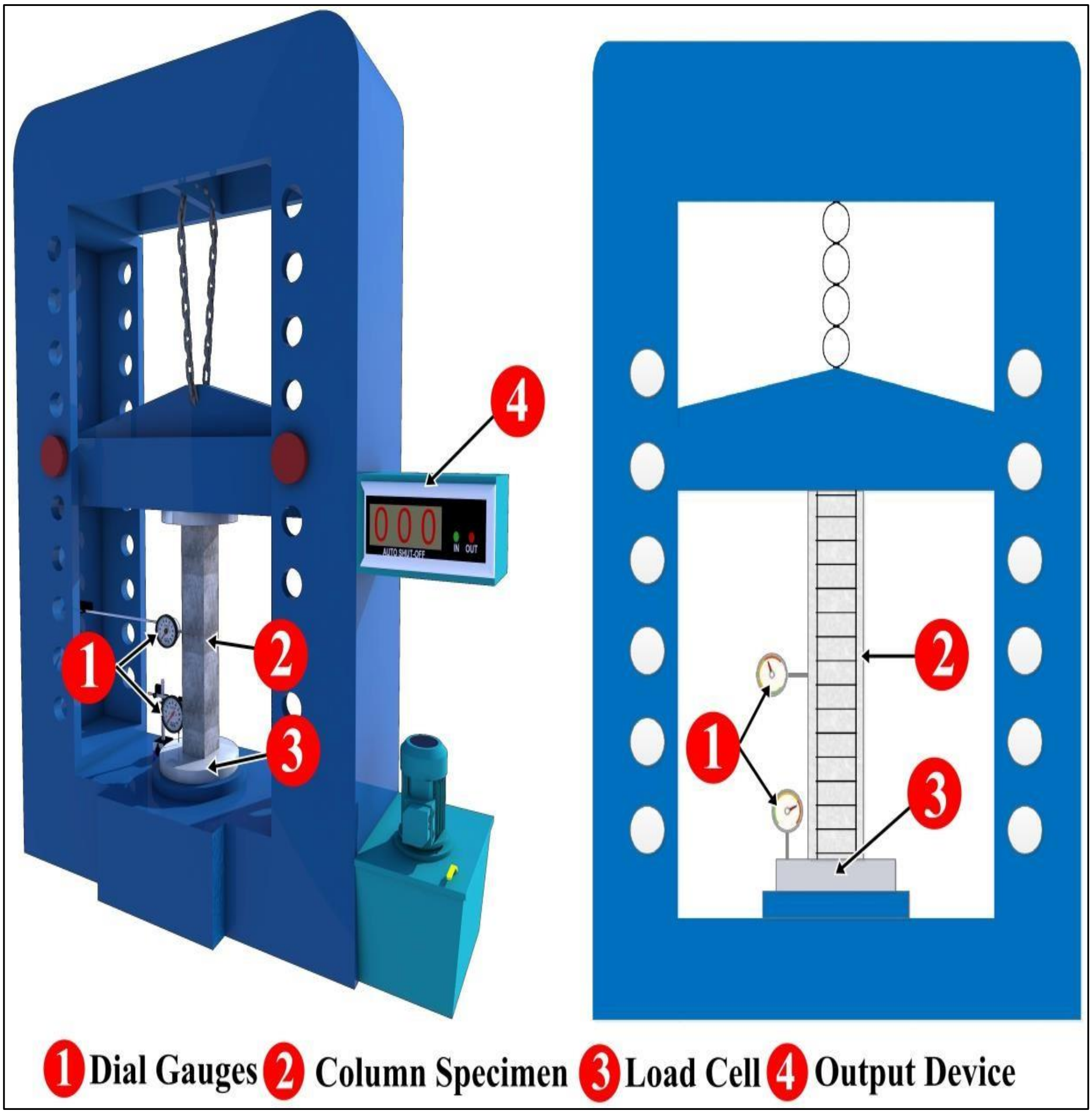


Figure 3.22: Electrohydraulic Machine for Columns Testing.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 INTRODUCTION

The findings of the experimental programme shown in chapter three are given and examined in this chapter. This chapter discusses the results of testing twelve concrete column specimens. To determine the importance of the taken into consideration experimental factors, the experimental findings were compared with one another. The ultimate load bearing capacity, failure behaviour, and the load displacement correlations for every loading increment were the test outcomes for the assessed experimental factors. To evaluate empirically the residual ductility and stiffness of concrete columns after being exposed to a real fire, ductility, stiffness, and energy absorption were computed and compared for the subject and non-subject RPC columns based on the predicted load-displacement relationships. The kind of concrete (RPC), transverse reinforcement spacing, concrete cover thickness, and flame temperature levels were taken into consideration as experimental factors.

The outcomes of the tests performed on the related control specimens to determine their mechanical characteristics are also included in this chapter. So as to examine and track the of the RPC behaviour under actual fire flame situations, several physical changes have also been documented. These adjustments included RPC's new look and colour.

4.2 MECHANICAL PROPERTIES OF HARDENED CONCRETE

Understanding the behaviour of concrete column specimens requires a thorough understanding of the mechanical characteristics of concrete. rupture modulus, splitting tensile strength, and compressive strength, are the mechanical parameters of hardened concrete that were investigated in this work. To determine the resistance and capabilities of RPC while exposed to fire, several qualities are examined. Identical to and lasting for the same amount of time, the RPC samples' burning process had been similarly to that of the column samples (1 hour).

4.2.1 Compressive Strength

The most frequent test on hardened concrete is the compression strength test. It is used to calculate the concrete's potential strength. Concrete is categorized according on its compressive strength in both local and international norms. The most important characteristic of RPC is its very high compressive strength. RPC cubes (50X50X50 mm) that have been produced utilizing RPC with 2percent micro steel fibr amount were used for the compressive strength (fcu) test. The cubes were evaluated for compressive strength at periods of 3, 7, 28, and 56 days after being subjected to fire flames at varied temps (200, 400, and 600) degree centigrade. The compressive strength of RPC is shown in Table 4.1 after exposure to various burning temps. To reduce the predicted error in every measured result, every magnitude in this Table is the mean magnitude of three cubes. Figure 4.1 demonstrates the compressive strength findings for various ages (3, 7, 28, and 56 days) and temps (200, 400, and 600) degree centigrade for reactive powder concrete. The compressive strength increased gradually with increasing the curing ages, but increasing burning temp lead to reduce the strength magnitude significantly from (83.1 MPa to 24.7 MPa) at 3 curing ages when rise temps from 200 to 600 degree centigrade.

Table 4.1: The Compressive Strengths Magnitude for RPC Specimens Before and After Burning.

Age (days)	**Compressive Strength $f$cu (MPa)**		
	Fire Temp (°C)		
	200	**400**	**600**
3	83.1	52.3	24.7
7	105.2	67.5	35.1
28	147.8	97.9	53.8
56	153.2	102.9	60.3

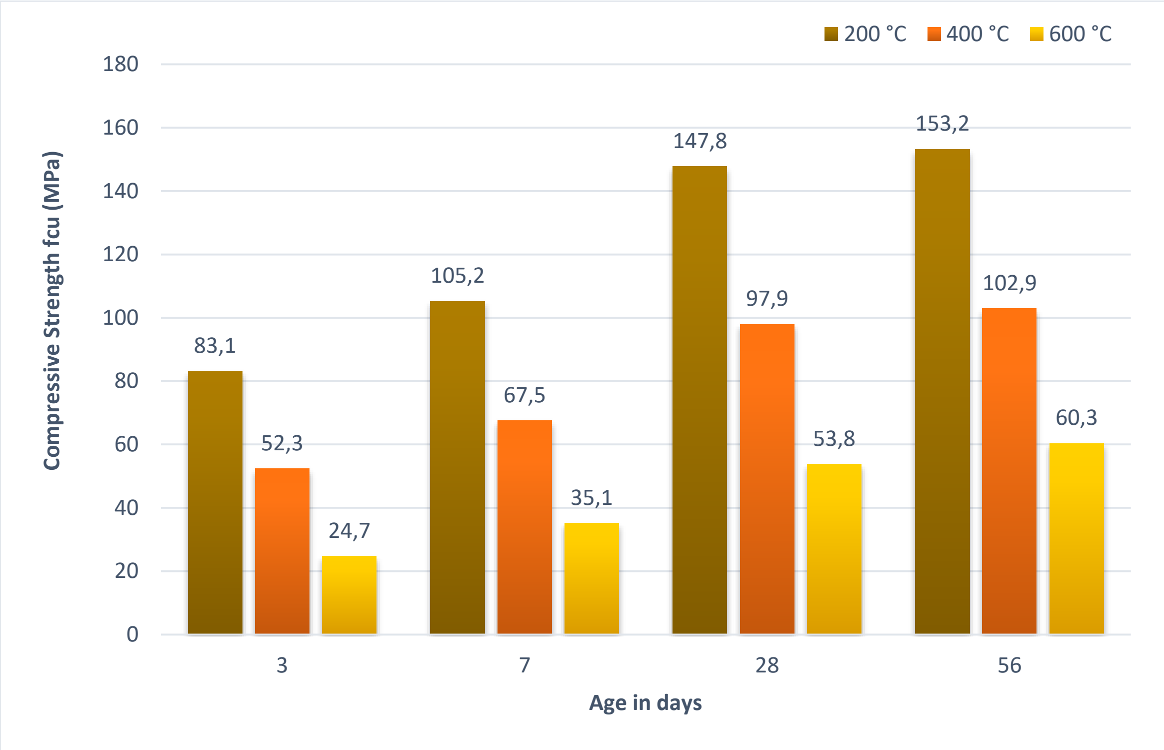


Figure 4.1: The Compressive Strength for RPC After Exposure to 200, 400 and 600 ^{O}C.

4.2.2 Splitting Tensile Strength

Table 4.2 provides a summary of the tensile strength (fsp) findings for the samples taken into account in this examination. Tensile strength controls the cracking behaviour and has an impact on the durability and stiffness of RPC, among other RPC features. A cylinder of 100 x 200 mm was used to test the splitting tensile strength at ages of 3, 7, 28, and 56 days. The cylinders were cast utilizing RPC that included 2percent micro steel fibre. Every test was carried out by three samples to calculate strength.

Figure 4.2 demonstrates the tensile strength findings for various ages (3, 7, 28, and 56 days) and temps (200, 400, and 600) degree centigrade for reactive powder concrete. The tensile strength increased gradually with increasing the curing ages as compressive strength magnitude, but increasing burning temp lead to reduce the strength magnitude significantly from (10.4 MPa to 3.6 MPa) at 3 curing ages when rise temps from 200 to 600 degree centigrade as shown in table 4.2.

Table 4.2: The Tensile Strengths Magnitude for RPC Specimens Before and After Burning.

Age (days)	Splitting Tensile Strength *fsp* (MPa)		
	Fire Temp (°C)		
	200	400	600
3	10.4	6.3	3.6
7	14.7	9.0	5.2
28	15.8	9.6	5.6
56	16.7	10.4	6.1

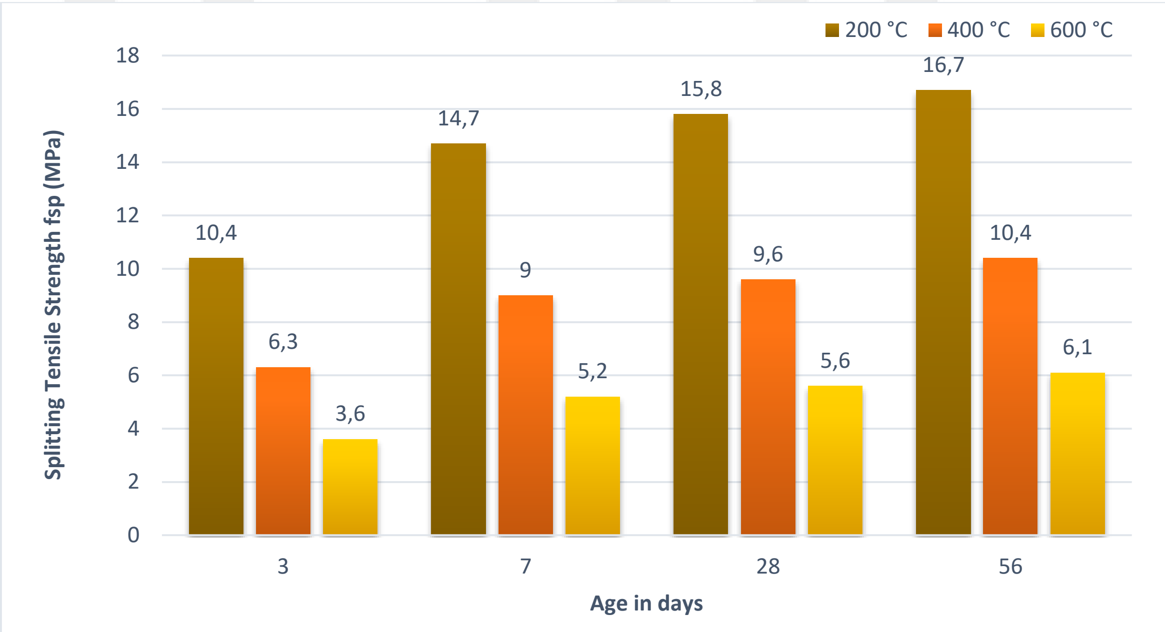


Figure 4.2: The Splitting Tensile Strength for RPC After Exposure to 200, 400 and 600 ^{O}C.

4.2.3 Flexural Strength (Modulus of Rupture)

The flexural strength was expressed by the modulus of rupture test. Each prism was put thru a two-point loading test while being simply supported. Table 4.3 shows the tested findings. To reduce the predicted error in each measured result, each number in this table is the mean magnitude of three prismatic specimens. Figure 4.3 demonstrates the flexural strength findings for various ages (3, 7, 28, and 56 days) and temps (200, 400, and 600) degree centigrade for reactive powder concrete. The flexural strength increased gradually with increasing the curing ages as compressive strength magnitude, but increasing burning temp lead to reduce the strength magnitude significantly from (35.7 MPa to 24.8 MPa) at 56 curing ages when rise temps from 200 to 600 degree centigrade as shown in table 4.3. However, at 400 degree centigrade most of flexural strength results are higher than the flexural strength at 200 and 600 degree centigrade.

Table 4.3: Test Magnitudes of Prisms Flexural Strength of RPC Samples Before and After Burning.

Age (days)	**Flexural Strength *fr* (MPa)**		
	Fire Temp (°C)		
	200	400	600
3	20.0	11.6	7.2
7	26.7	27.9	17.5
28	33.9	35.9	22.8
56	35.7	38.2	24.8

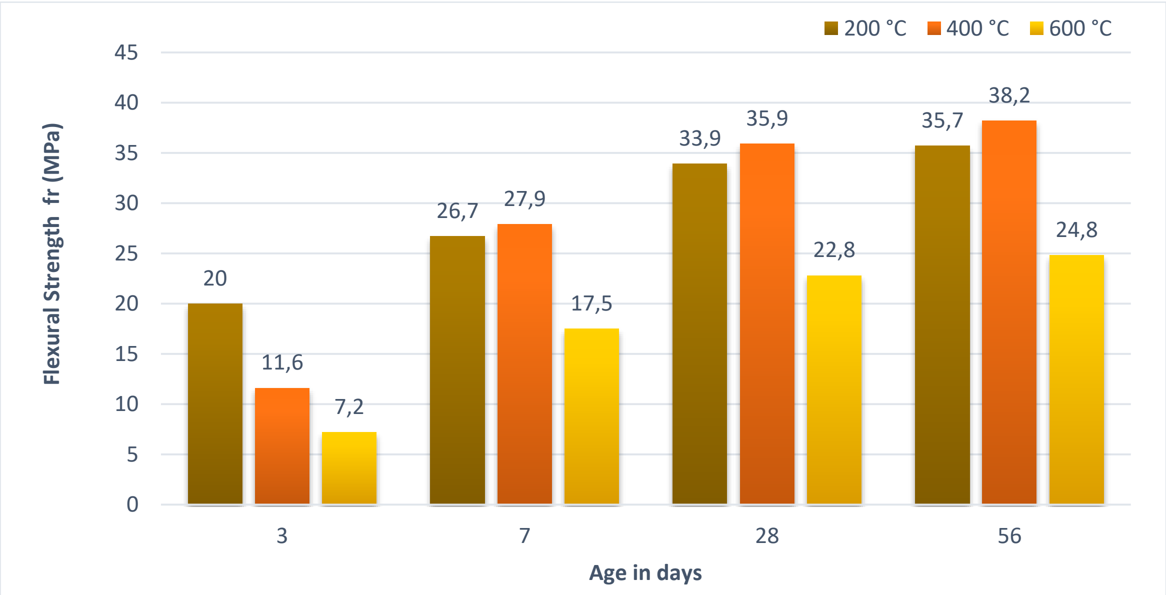


Figure 4.3: The Flexural Strength for RPC After Exposure to 200, 400 and 600 ^{O}C.

4.3 COLUMN BEHAVIOR UNDER VARIOUS BURNING TEMP

To evaluate the structural performance for the tested column samples the main structural characteristics observed and recorded throughout the test of each column specimens and at each stage of loading. The details of tests results of reinforced concrete columns that include the first crack load, the carrying loading capacity for samples, the percent of remaining carrying loading capacity of columns after subject to fire, the axial displacements determined for whole sample's height and approving side displacements at the sample's middle-height are given in Table (4.4).

Column behavior under various burning temps (200, 400 and 600) degree centigrade is demonstrated in Figure 4.4-4.7. Figure 8 and 9 demonstrate the relationship between axial displacement at ultimate load (mm) and load carrying capacity Pu (kN) for samples RM1 and RM2 with 15 mm concrete cover and RM3 and RM4 with 30mm concrete cover, respectively. In order to verifying the effect of using secondary reinforcement, where samples (RM1 and RM3) without reinforcement and samples (RM2 and RM4) with Ø5@200mm as a secondary reinforcement. Both figure 8 and 9 demonstrate a massive reduction in axial displacement when using Ø5@200mm for similar burning temps.

Table 4.4: Experimental Test Results of RPC and NSC Column Specimens.

Columns Symbol		Fire Temp (ºC)	Load Carrying Capacity Pu (kN)	Axial Displacement at Ultimate Load (mm)	Mid-Height Lateral Deformation at Ultimate Load (mm)
One	RM1	200	892	4.13	0.702
	RM2		975	4.57	0.777
	RM3		837	3.89	0.661
	RM 4		879	4.12	0.700
Two	RM1	400	646	4.01	0.681
	RM2		726	4.51	0.766
	RM3		603	3.74	0.635
	RM 4		659	4.07	0.692
Three	RM1	600	483	4.02	0.683
	RM2		675	6.14	1.041
	RM3		453	3.78	0.643
	RM 4		494	4.05	0.688

The load carrying capacity expressed the ultimate applied load that can be subjected to the tested column specimens, after which a decrease in machine reading occurred with a fast column deformation, which was termed as a failure. The behavior of columns tested at ambient temp were as considered a reference specimens for comparison to study the remaining loading capacity of columns after burning. Significant reduction in axial displacement after using secondary reinforcement, which compatible with improvement in loading carrying capacity as shown in figure 4.4. Also increasing the exposure temperature for similar column condition records reduction in column resistance against fire at the same increasing the concrete cover from 15 to 30mm lead to reduce the column displacement.

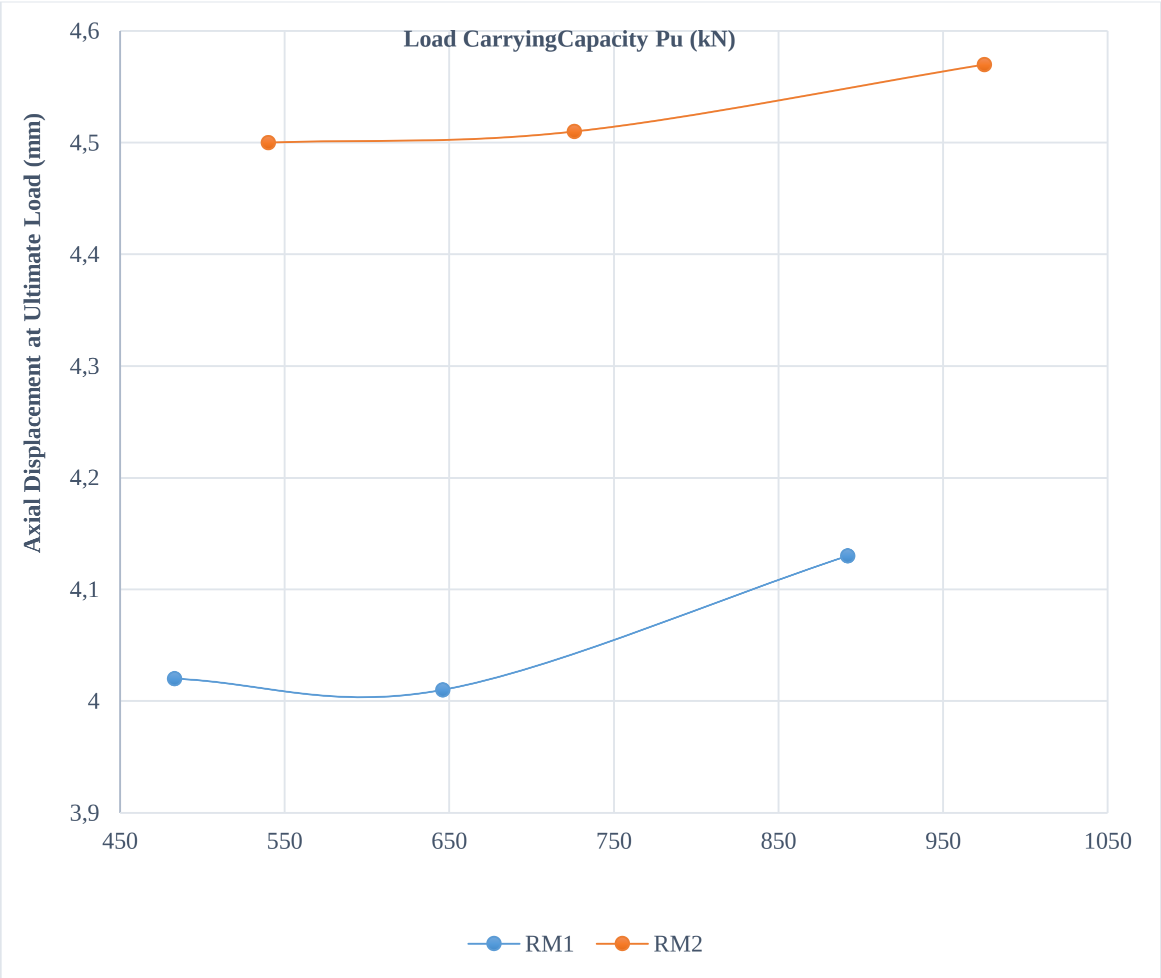


Figure 4.4: Reactive Powder Concrete with 15 mm Cover.

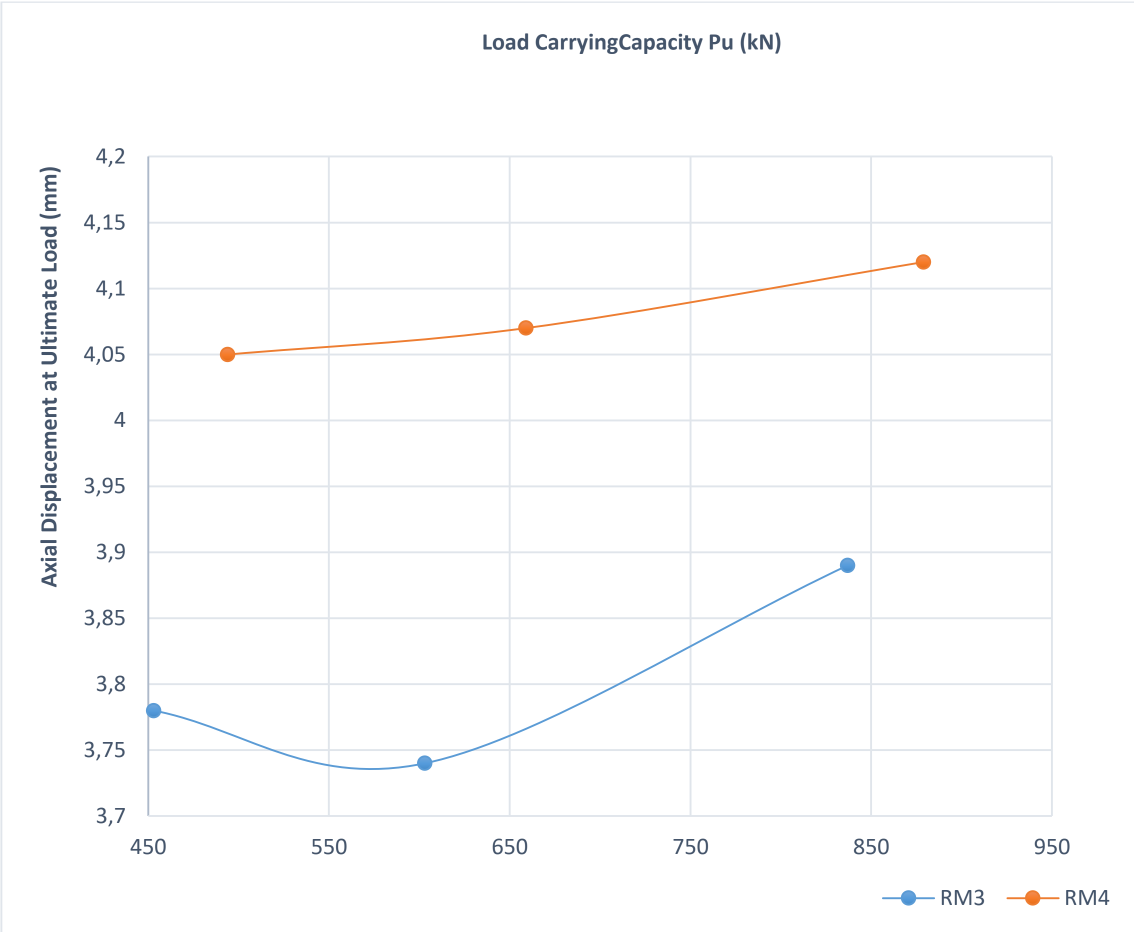


Figure 4.5: Reactive Powder Concrete with 30 mm Cover.

Figure 4.6 demonstrates the relationship between middle height deformation and burning temperature for all specified columns samples, for samples without secondary reinforcement (RM1 and RM3) increase temperature lead to reduce the lateral deformation, while in condition of presence secondary reinforcement (RM2 and RM4) increase the burning temperature from 200 to 600 degree centigrade lead to increase middle height deformation significantly, especially when using 15 mm concrete cover, while increasing the concrete cover to 30 mm lead to reduce changing in column deflection due to raising temperature.

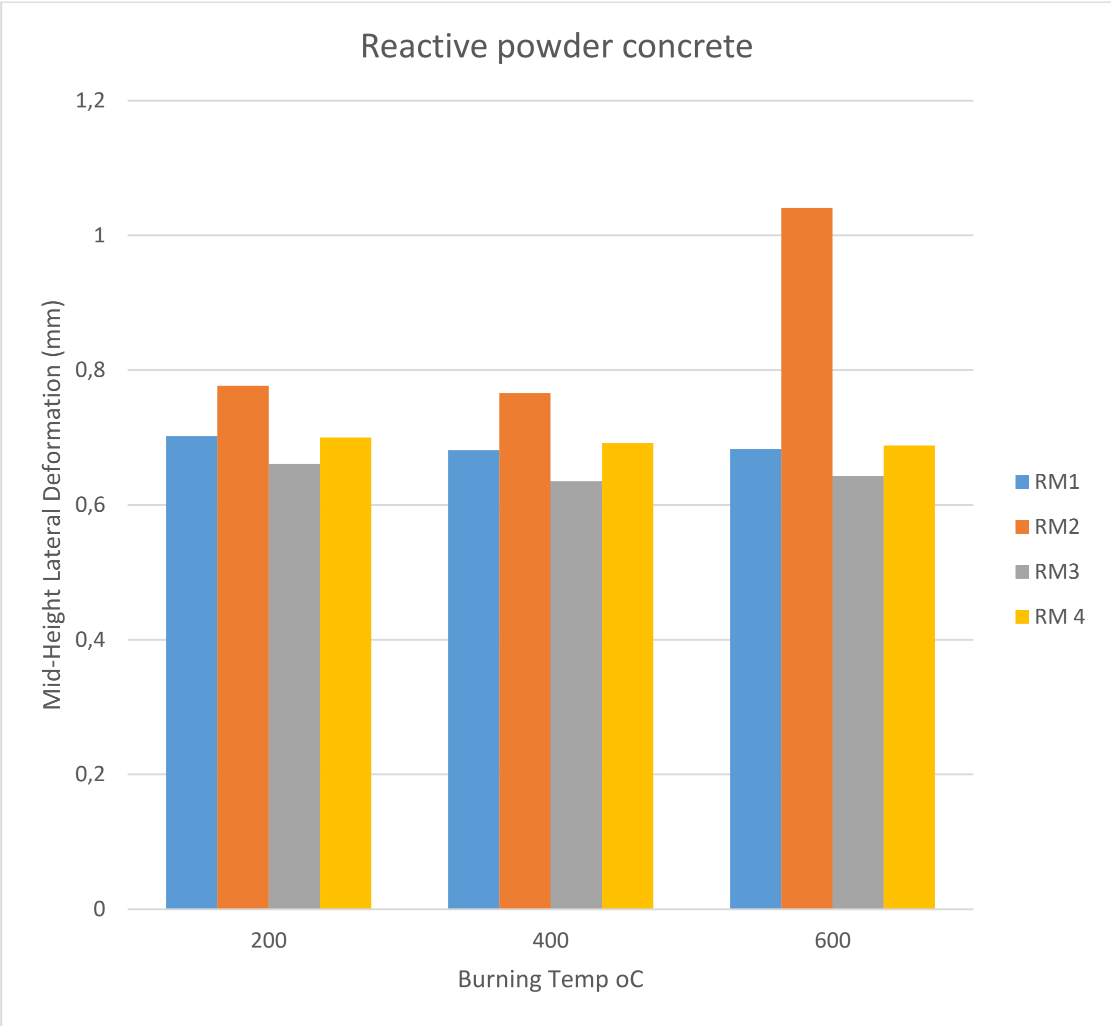


Figure 4.6: Mid-Height Deflection at Ultimate Loading for RPC.

5. NUMERICAL ANALYSIS

5.1 INTRODUCTION

This chapter, provide an assessment between the experiments and numeric investigations is obtainable to provide that modelling of the column is sufficient comprising: kind of elements, the characteristics of material, real constant and convergence investigation. This section consist of the tested columns' analysis that had been conducted in the fourth chapter and some significant investigation parameters by utilizing a nonlinearly finite-elements technique package ABAQUS/Standard 2018. An analyzing was conducted on tested concrete's columns by utilizing of analyzing of nonlinear finite element in the current investigation. The tested reference column As well column exposure to fire for 1 hour at one side were analyzed and compared with experimental findings.

5.2 FINITE ELEMENT MESH AND BOUNDARY CONDITIONS

Nine columns were modelling to study and unify the accuracy of F.E. modal thru comparison with experimental findings, as well as taking parametric study of the exposure to fire from all sides and their impact on the column. A main step in the modelling by finite element is a convergence investigation on model of the column to identify a suitable density of mesh. Convergence of findings is gained in condition of separating the structure into a satisfactory number of elements. This is essentially accomplished if the decrement in the dimension of mesh was an unimportant impact on the findings seeing that the complexity for the analyzing with the processing time used up. The columns of the similar material characteristics and loading were modeling with a decrease in the element dimension (increment the elements' number in every direction X, Y & Z) (50, 30, 25, 15and 10 mm) as displayed in figure (5.1). The axial displacement for all columns has been detected for the same applied load level. It can be concluded from convergence investigation displayed in Figure (5.2), the variance could be ignored in condition of the dimension's of mesh reduced from (25-20) mm. Consequently, (20) mm mesh size were implemented in this research for all the tested columns, which warranty a virtuous adjustment between the elements dimensions and the numerical stability solution.

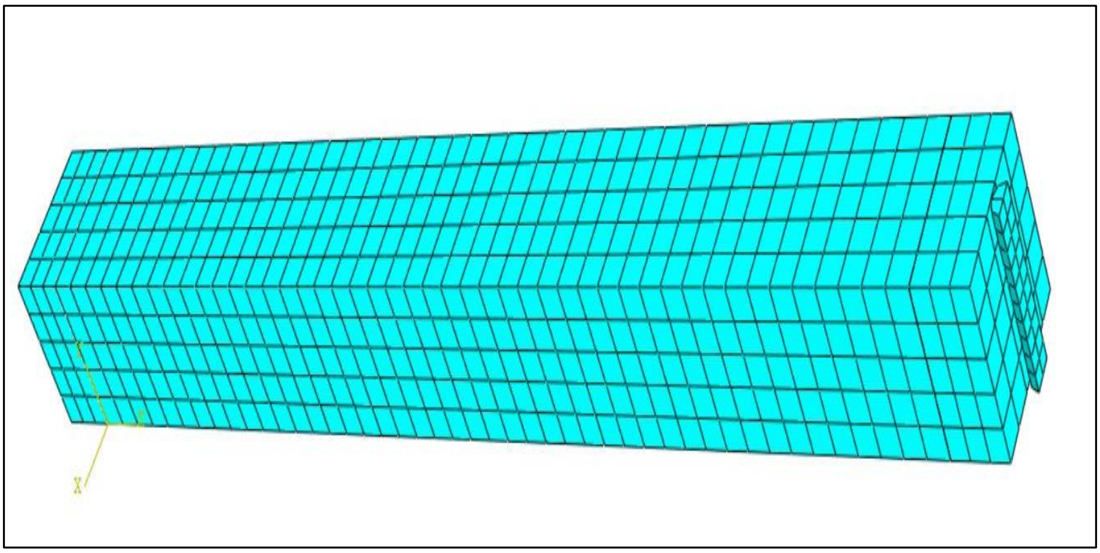


Figure 5.1: The Considered Meshes for the Columns.

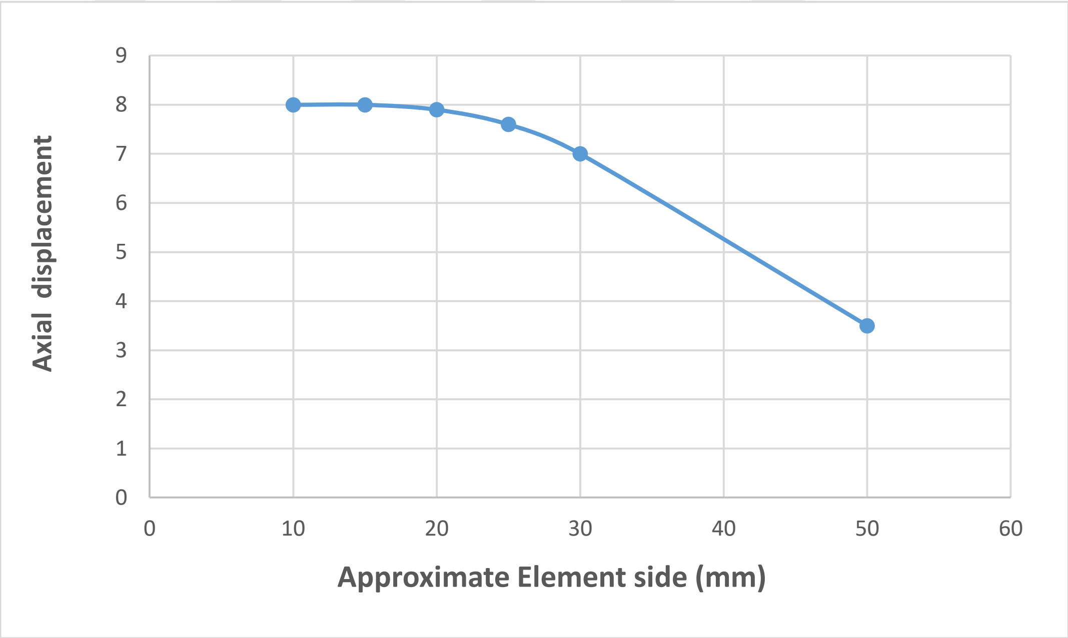


Figure 5.2: The Convergence Study.

5.3 MODELING OF COLUMN

5.3.1 Parts and Assembly

Figure (5.3) displays the components' assembly that was utilised to simulate these columns. The modelling of material characteristics for RPC and steel reinforcement should also be included.

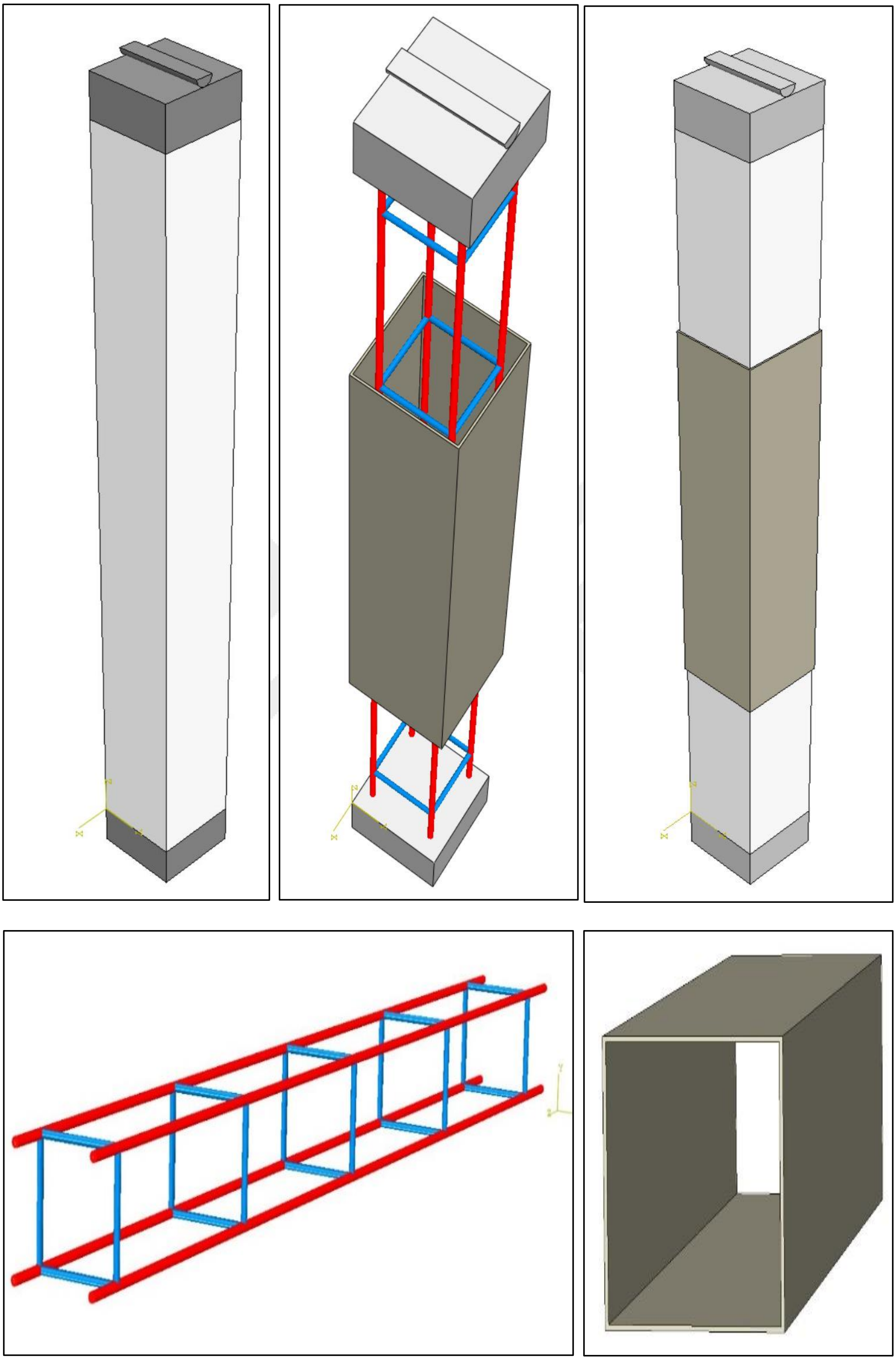


Figure 5.3: The Assembled Parts of Column.

5.3.2 Loading and Boundary Conditions

The mechanism of representing any column was done by joining the bottom by line hinge, the line hinge was restrained the displacement in all direction x,y&z-axes. In addition, at top surface (surface of load) half circle steel rod (rod of loading) it was tied to the plate of loading and loaded with a uniformly distributed load with a displacement freely is supposed in the y-axis directions (vertical shift). Figure (5.4) shows the conditions of boundary and applying load for the modeling column [63].

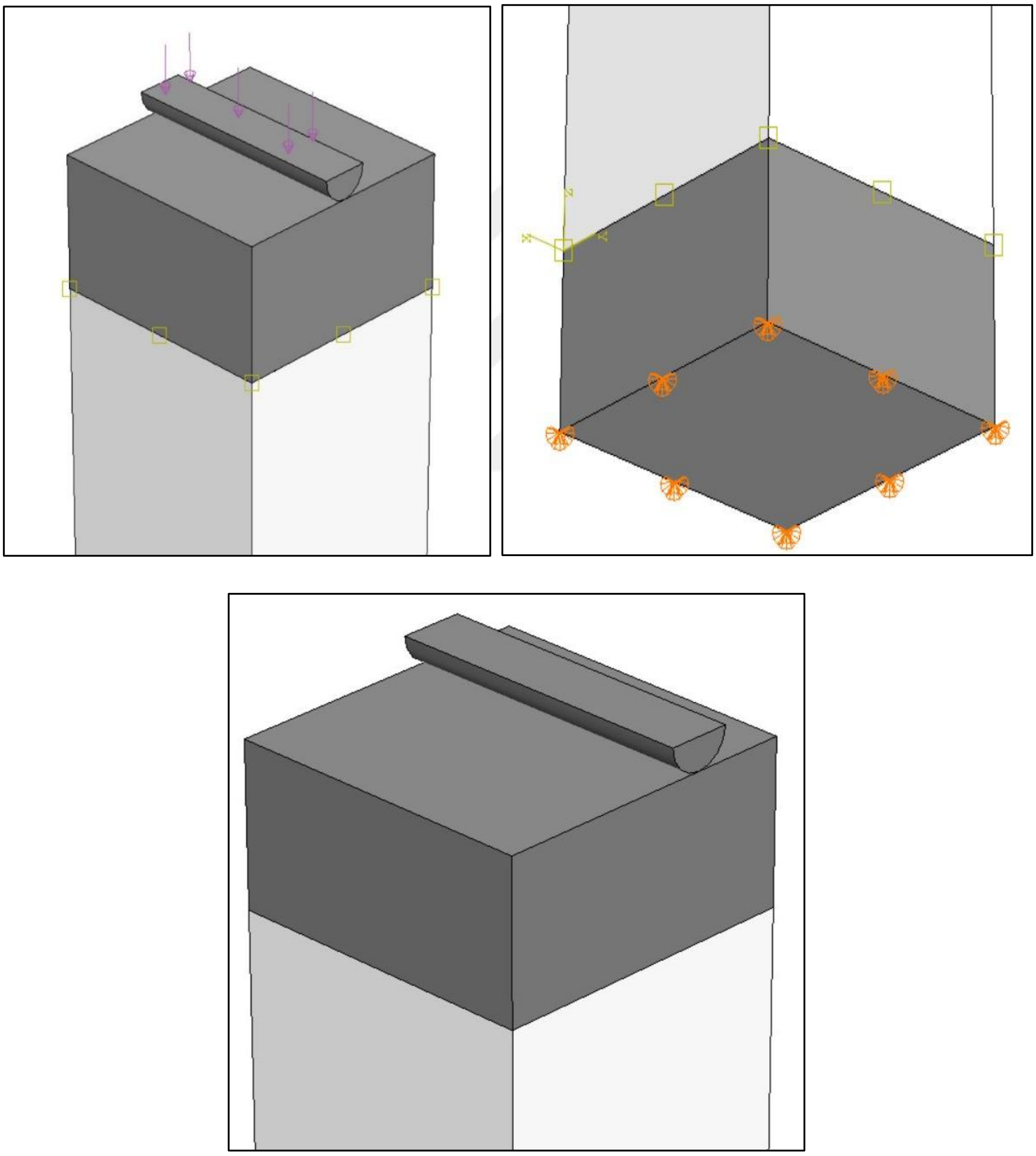


Figure 5.4: Applied Load and Boundary Conditions of Modeled Column.

5.4 STATIC ANALYSIS MODEL

In the control (unsubject) samples, the analyzing of the structure was achieved by utilizing just one step (general static analyzing step). Reference (control) RPC's columns were modelling utilizing 3D-solid elements in the concrete-modelling with eight node element of brick (C3D8). Although for reinforcing of steel, a space two nodes truss's element (T3D2) was utilized.

5.4.1 Coupled Temp-Displacement Analysis Model

The numerical model, suggested in this investigation, usages of two coupled steps for the analysis temperature displacement. The step number one was utilized for simulating the fire. Although the step number two was utilized to assess the response of structure (columns' of concrete) after exposing to flame of fire, with the similar conditions loading and boundary utilized in the control columns which demonstrated in the static model analyzing, Figure (5-4). The exposing of concrete's columns were modelling utilizing 3D elements solid in the concrete modelling with an eight nodes brick thermally-coupled, trilinear temperature and displacement (C3D8T), and for reinforcement, a 3D thermally coupled two-nodes element of truss (T3D2T). So as to investigate the impact of the fire-burning for fire duration (1 hours) on one side of column profile. The impact of fire simulation is conducted by utilizing a flux of heat, in every technique that the temperature was variant by utilizing a largeness. The largeness was utilized to the curve of fire temperature input and time to simulate the real fire utilized in the experimental program, Figure (5.5). At every intervals time, the analyzing is conducted thru two major procedures, called:

a. Establishing fire temperature because of exposing to fire.

b. Carrying out coupled analyzing for hydrothermal to estimate the distribution of fire temperatures history inside the column.

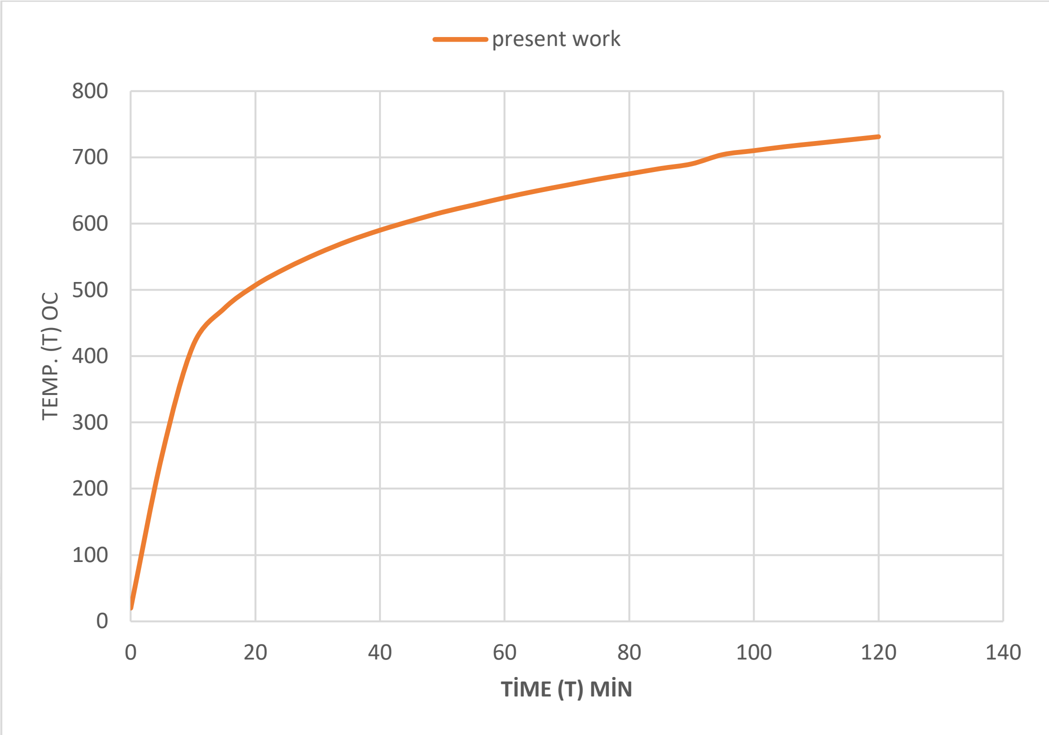


Figure 5.5: Time-Temp Curve.

5.5 FINITE ELEMENT ANALYSIS FINDINGS AND DISCUSSION

5.5.1 Analytical Findings of Subject to Fire Flame Columns

Experimentally, columns were subject to fire from one side for a period 1-hour. An assessment between the ultimate loads, axial displacement, and lateral displacement of the tested column samples that subject to fire flame with numerical magnitudes from finite element analysis. The comparison between subject columns gave the impression that the findings columns from numerical analysis were stiffer than the experimental columns load-displacement relationships of columns subject to fire.

5.5.2 Parametrical Investigation

The key objective of the current part is to study the influence of the most significant factor on the behavior of RPC columns.

According to the location of the column in the building and the case of exposure to fire flame (direction of the subject to fire). A case where the column was in the middle of the room space was studied in the numerical analysis.

5.6 UNSTRENGTHED RPC

5.6.1 15 mm Cover

The temp distribution of subject columns after full time of burning and the temp depth with time are shown in figures (5.6-5.11) for reactive powder concrete with 15mm concrete cover. From these figures, the increase in temp of burning cause a serious problem in the column edges and increase in temp toward the core of columns leading to most damage in RC column thus reduced the capacity of subject columns. At the same time applying eccentrically loads cause column Bucking failure before the failure that happened due to burning.

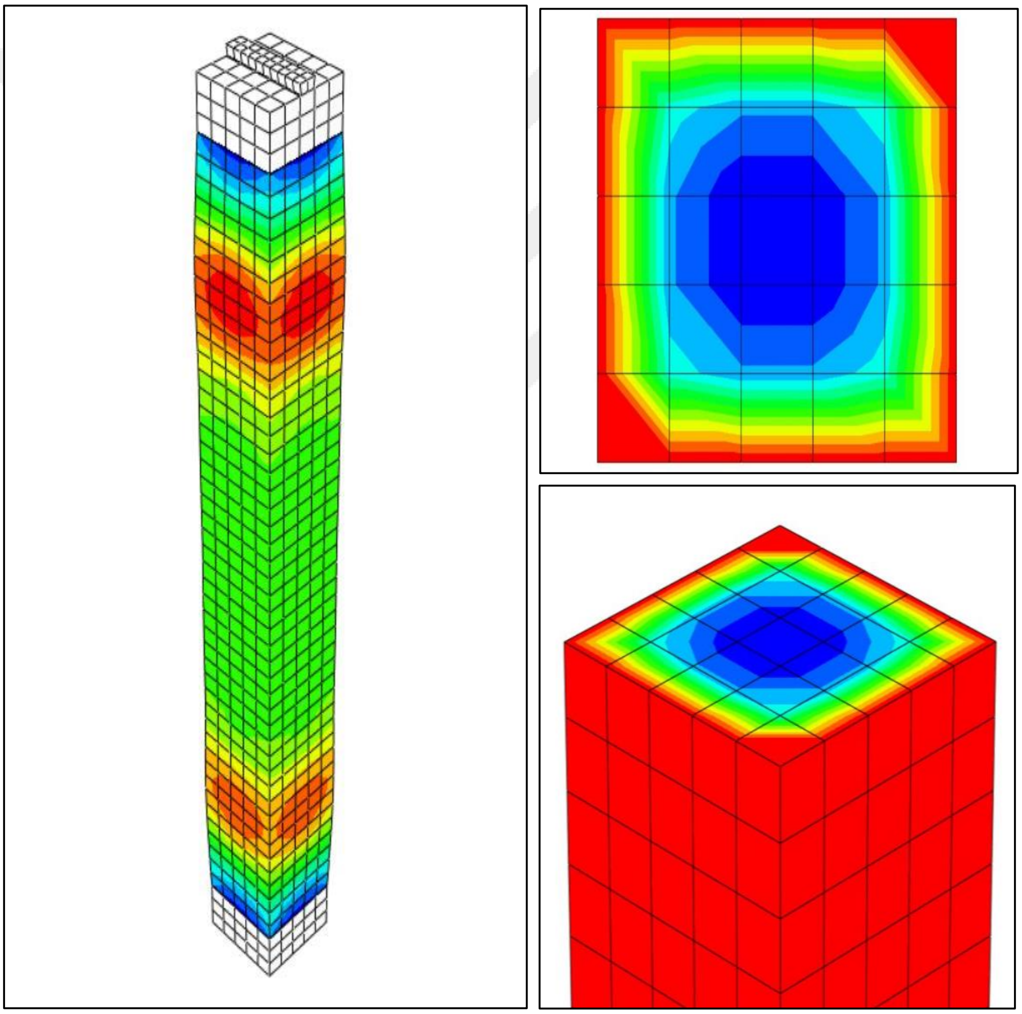


Figure 5.6: Plastic Strain Distribution with Axial Load at 200 ^{O}c.

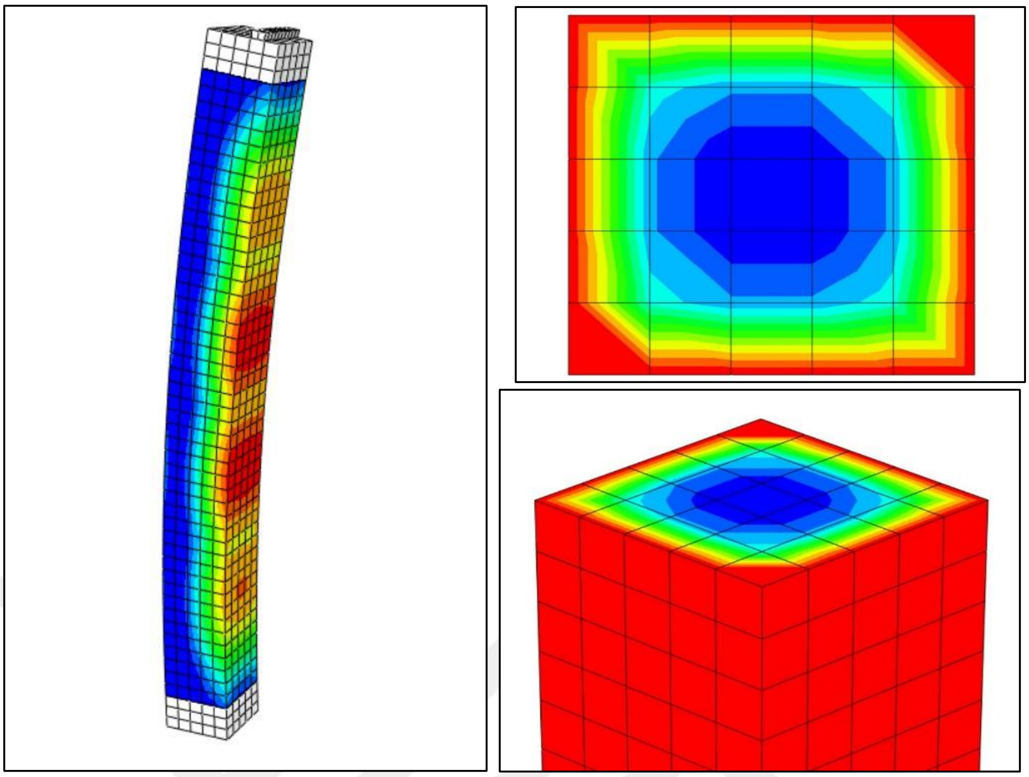


Figure 5.7: Plastic Strain Distribution with 20 mm Eccentric Load at 200 ^{O}c.

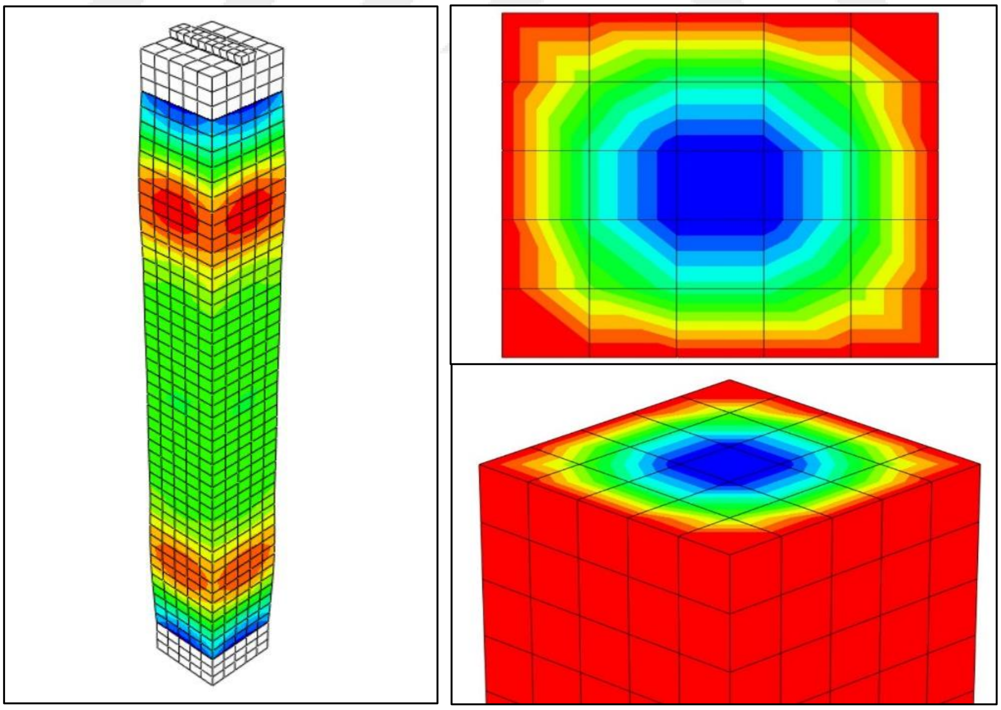


Figure 5.8: Plastic Strain Distribution with Axial Load at 400 ^{O}c.

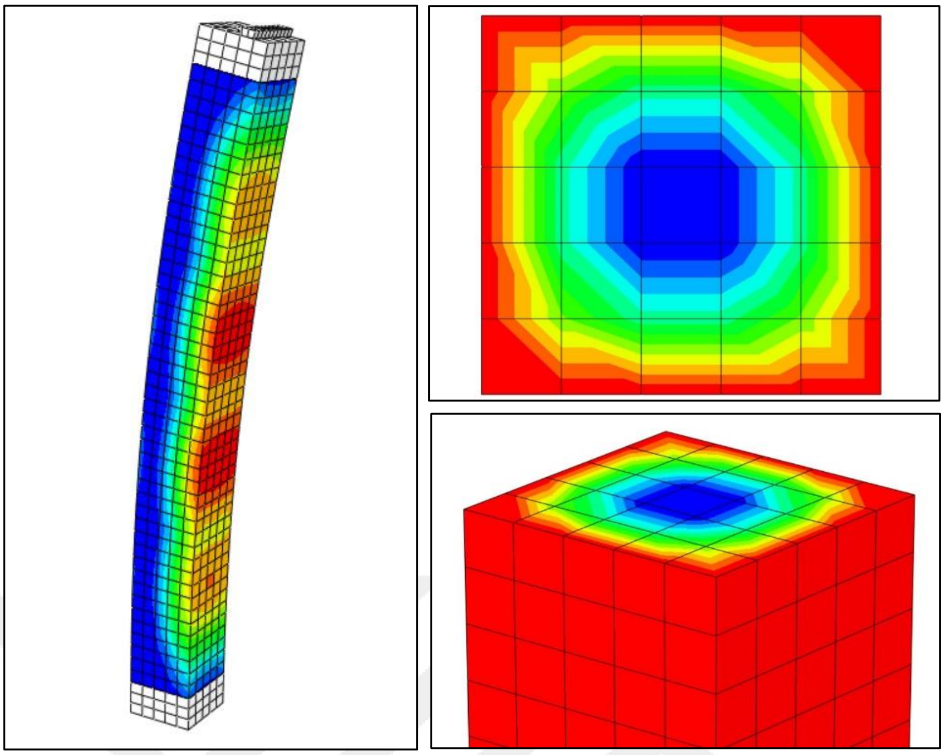


Figure 5.9: Plastic Strain Distribution with 20 mm Eccentric Load at 400 ^{O}c.

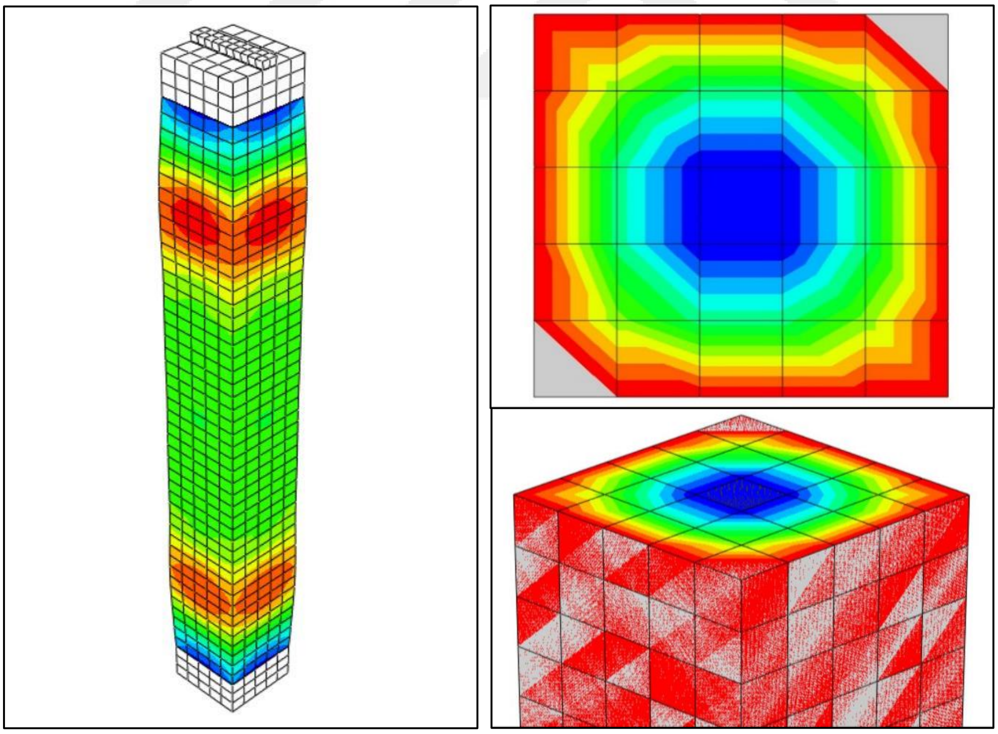


Figure 5.10: Plastic Strain Distribution for Axial Load at 600 ^{O}c.

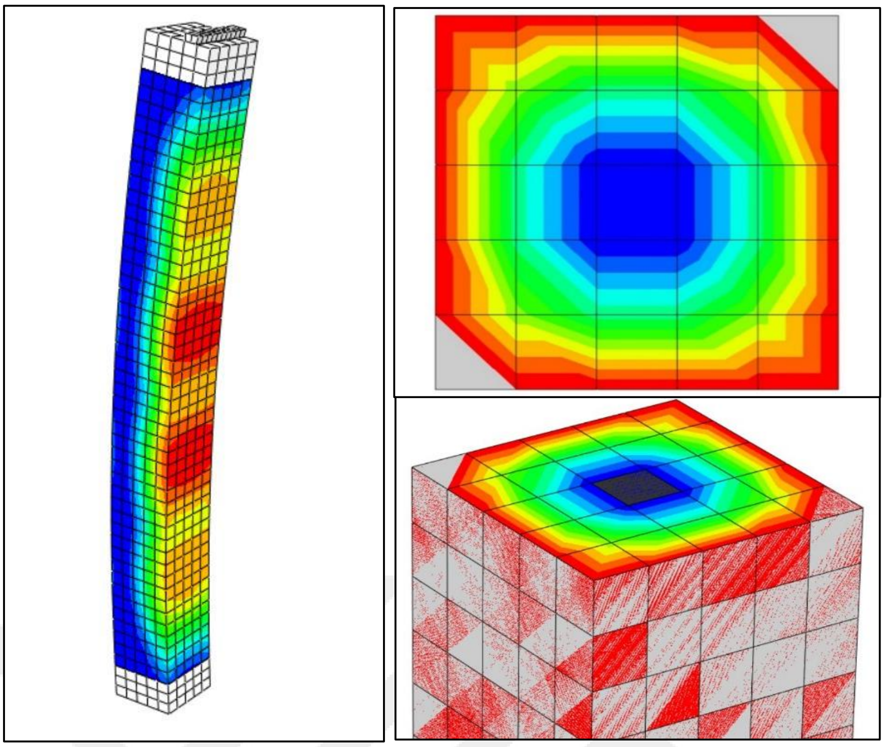


Figure 5.11: Plastic Strain Distribution for 20 mm Eccentric Load at 600 ^{O}c.

5.6.2 30 mm Cover

The temp distribution of subject columns after full time of burning and the temp depth with time are shown in figures (5.12-5.17) for reactive powder concrete with 30 mm concrete cover. From these figures, the increase in temp of burning cause a serious problem in the column edges and increase in temp toward the core of columns leading to most damage in RC column thus reduced the capacity of subject columns. At the same time applying eccentrically loads cause column bucking failure before the failure that happened due to burning. Increasing the concrete cover from 15 to 30mm records insignificant burning effect due to increasing the cover as well as 1 hour burning is considered not very effective on concrete because 15 mm concrete cover can stand 60 minute safely according to American slandered. Therefore, using 30mm cover considered very safe and may not change the column strength.

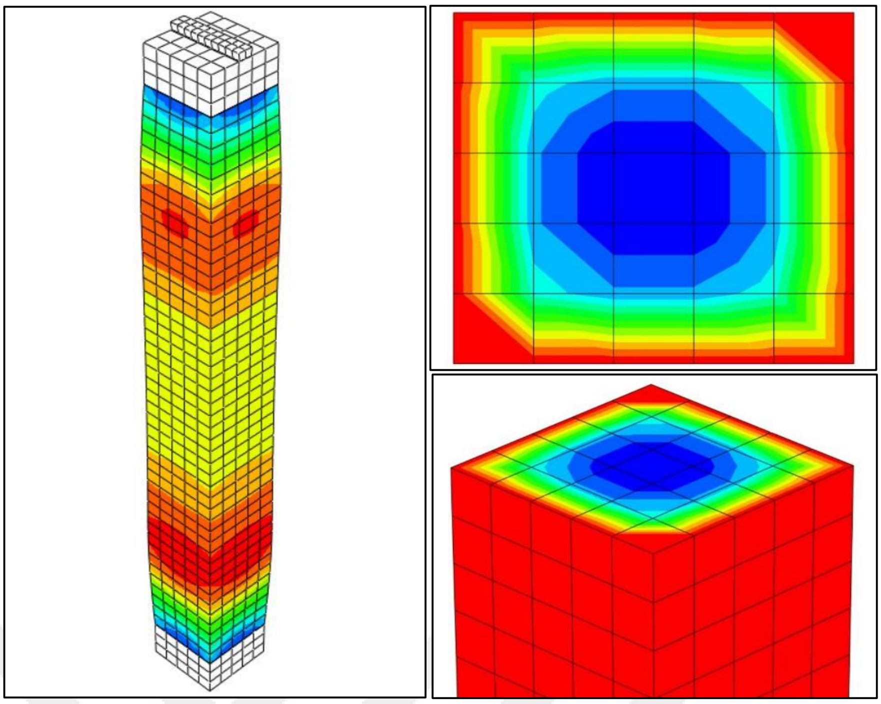


Figure 5.12: Plastic Strain Distribution for Axial Load at 200 ^{O}c.

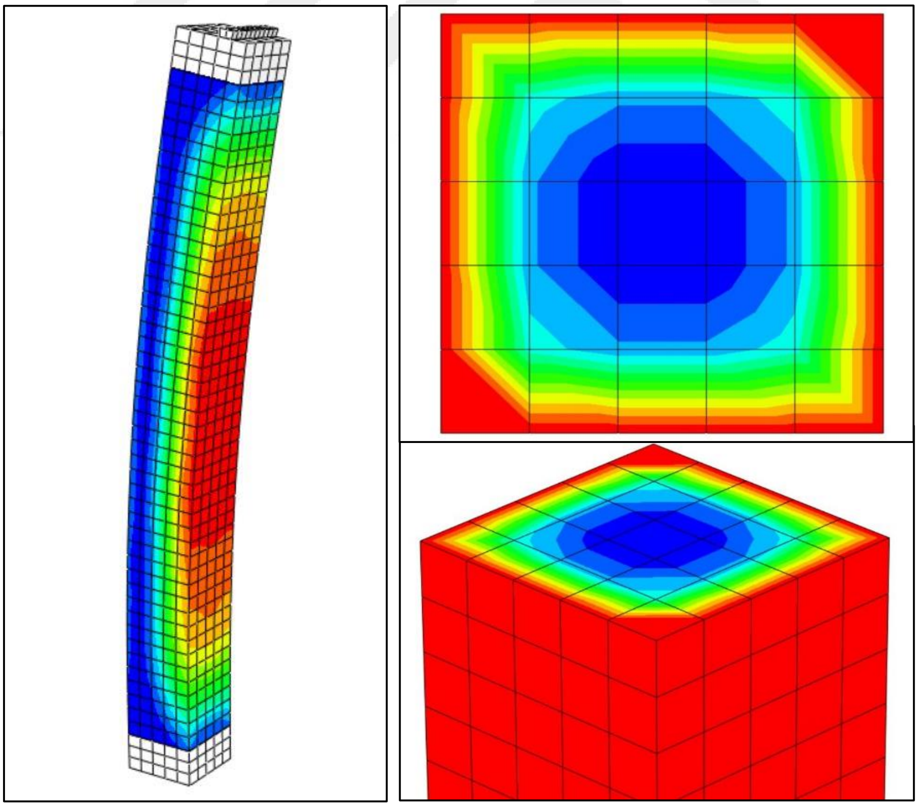


Figure 5.13: Plastic Strain Distribution for 20 mm Eccentric Load at 200 ^{O}c.

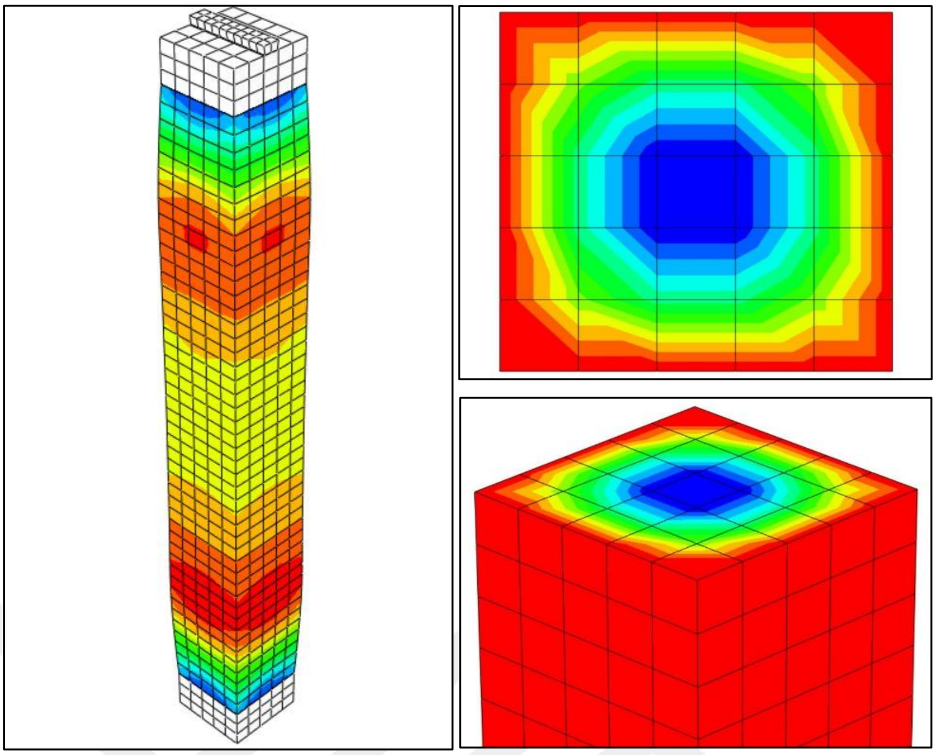


Figure 5.14: Plastic Strain Distribution for Axial Load at 400 ^{O}c.

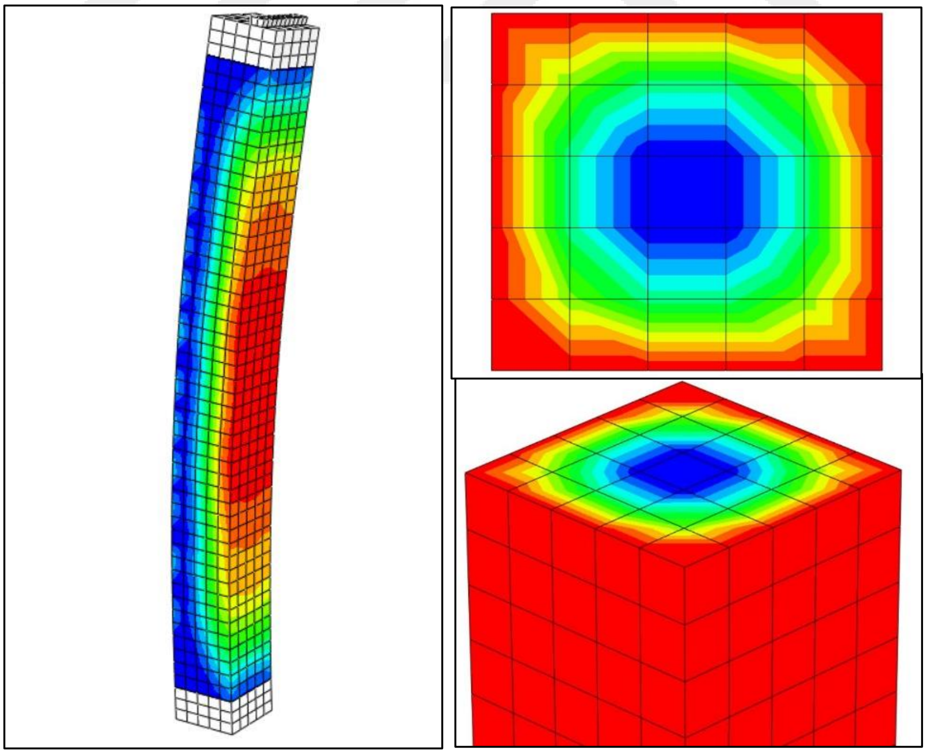


Figure 5.15: Plastic Strain Distribution for 20 mm Eccentric Load At 400 ^{O}c.

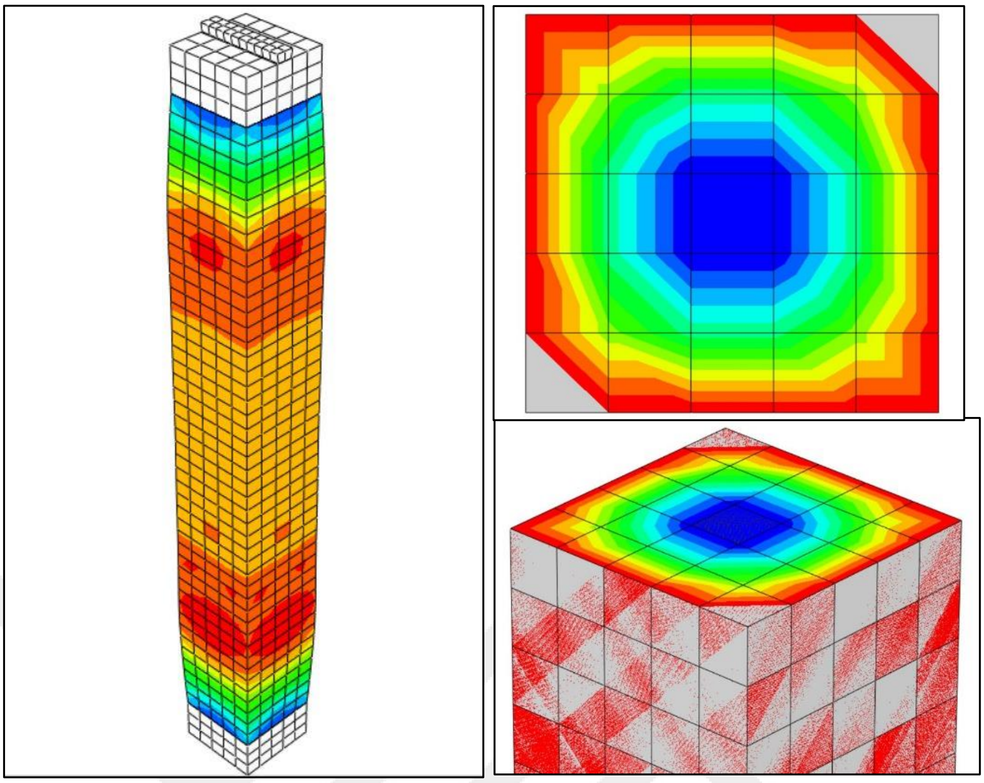


Figure 5.16: Plastic Strain Distribution for Axial Load at 600 ^{O}c.

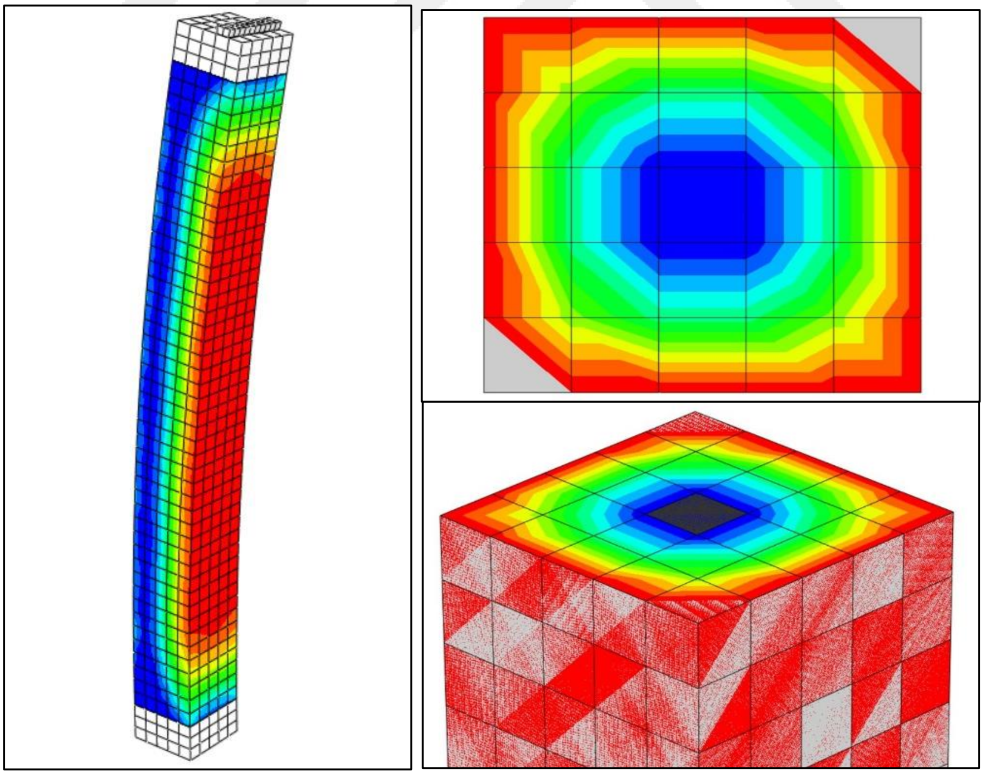


Figure 5.17: Plastic Strain Distribution for 20 mm Eccentric Load at 600 ^{o}C.

5.7 STRENGTHENED RPC

5.7.1 15 mm Cover

The temp distribution of subject columns after full time of burning and the temp depth with time are shown in figures (5.18-5.23) for reactive powder concrete with 15 mm concrete cover along with strengthening the column by steel plate. From these figures, the increase in temp of burning cause a serious problem in the column edges and increase in temp toward the core of columns leading to most damage in RC column thus reduced the capacity of subject columns. At the same time applying eccentrically loads cause column bucking failure before the failure that happened due to burning.

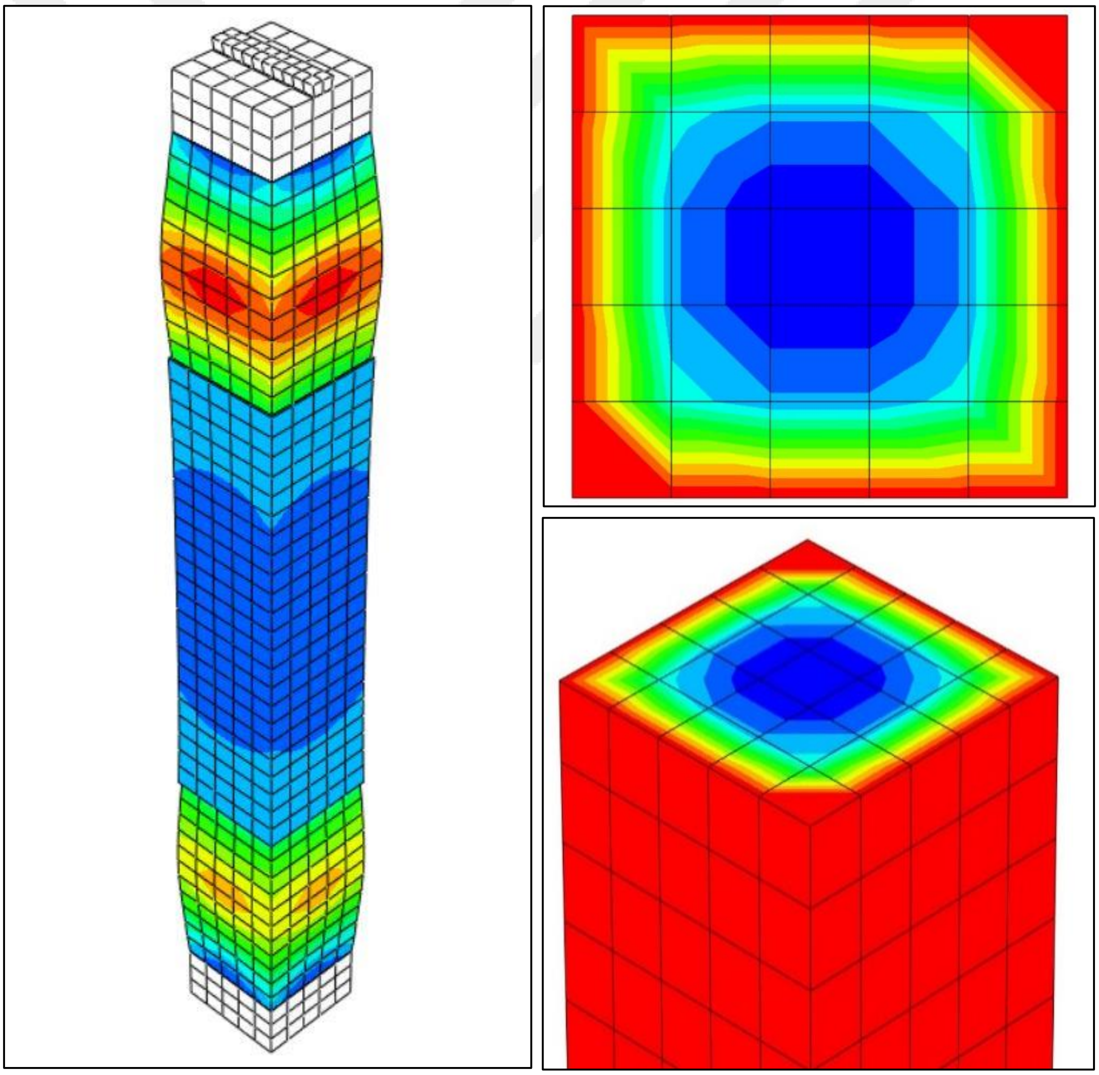


Figure 5.18: Plastic Strain Distribution for Axial Load at 200 ^{O}c.

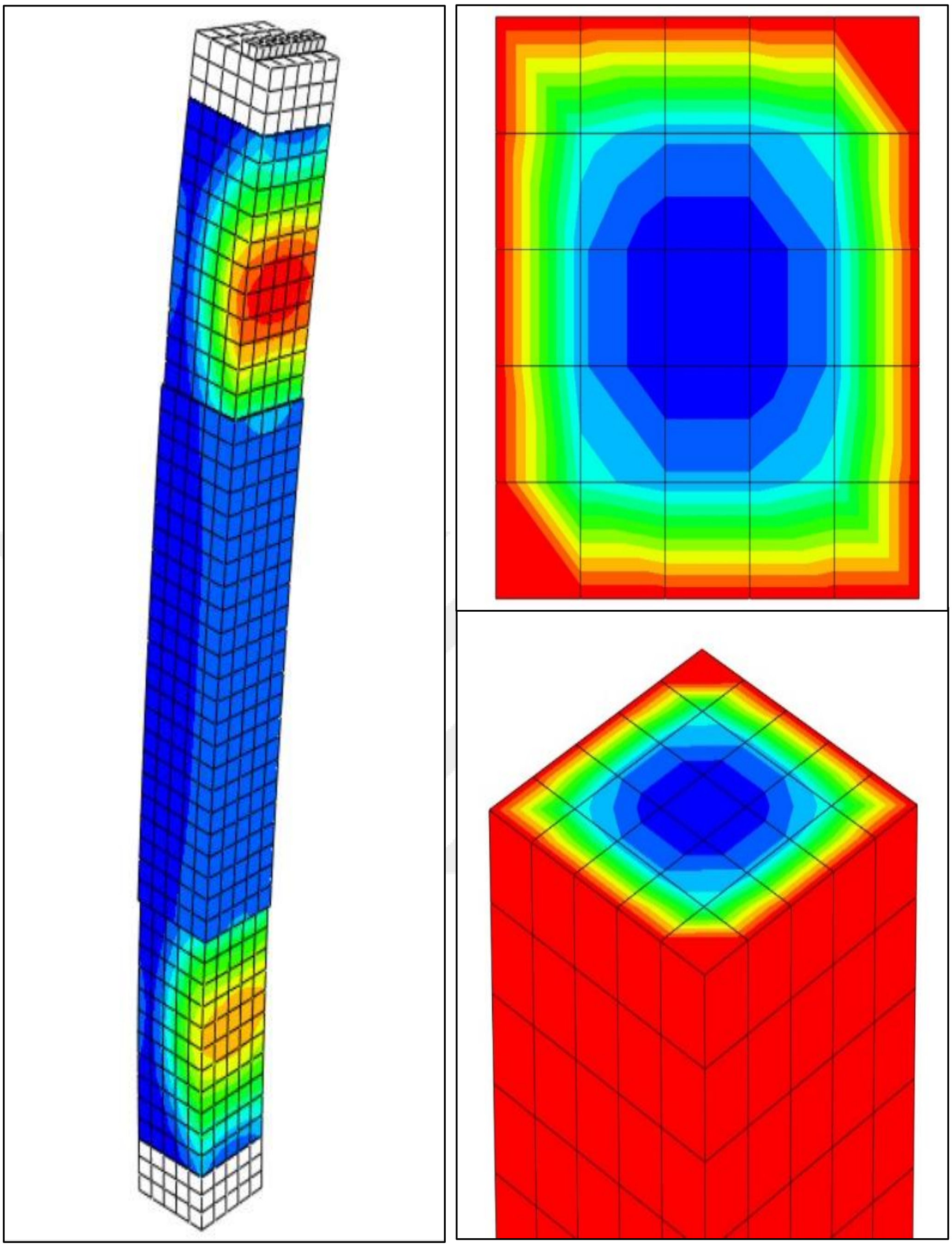


Figure 5.19: Plastic Strain Distribution for 20 mm Eccentric Load at 200 ^{O}c.

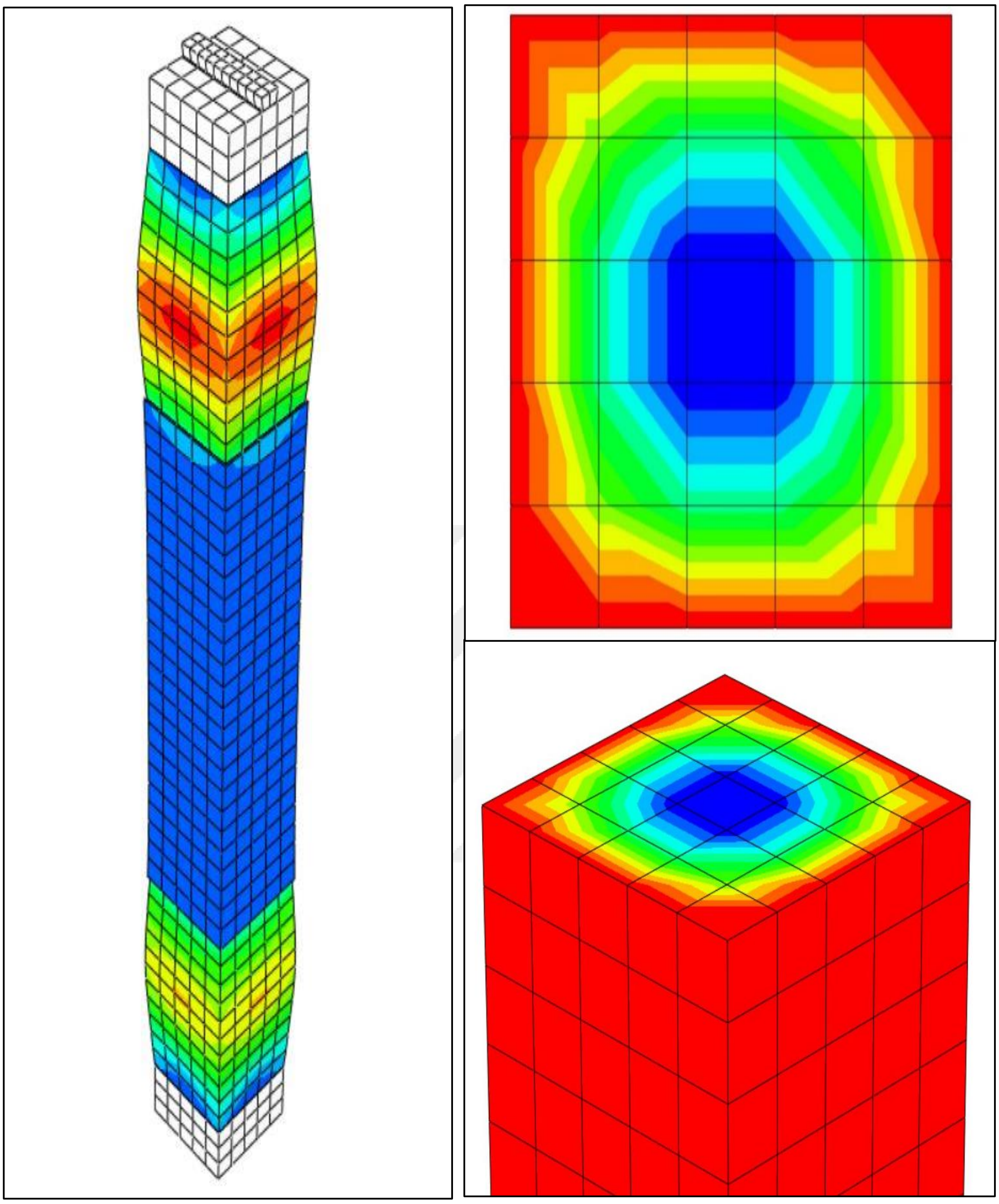


Figure 5.20: Plastic Strain Distribution for Axial Load at 400 ^{O}c.

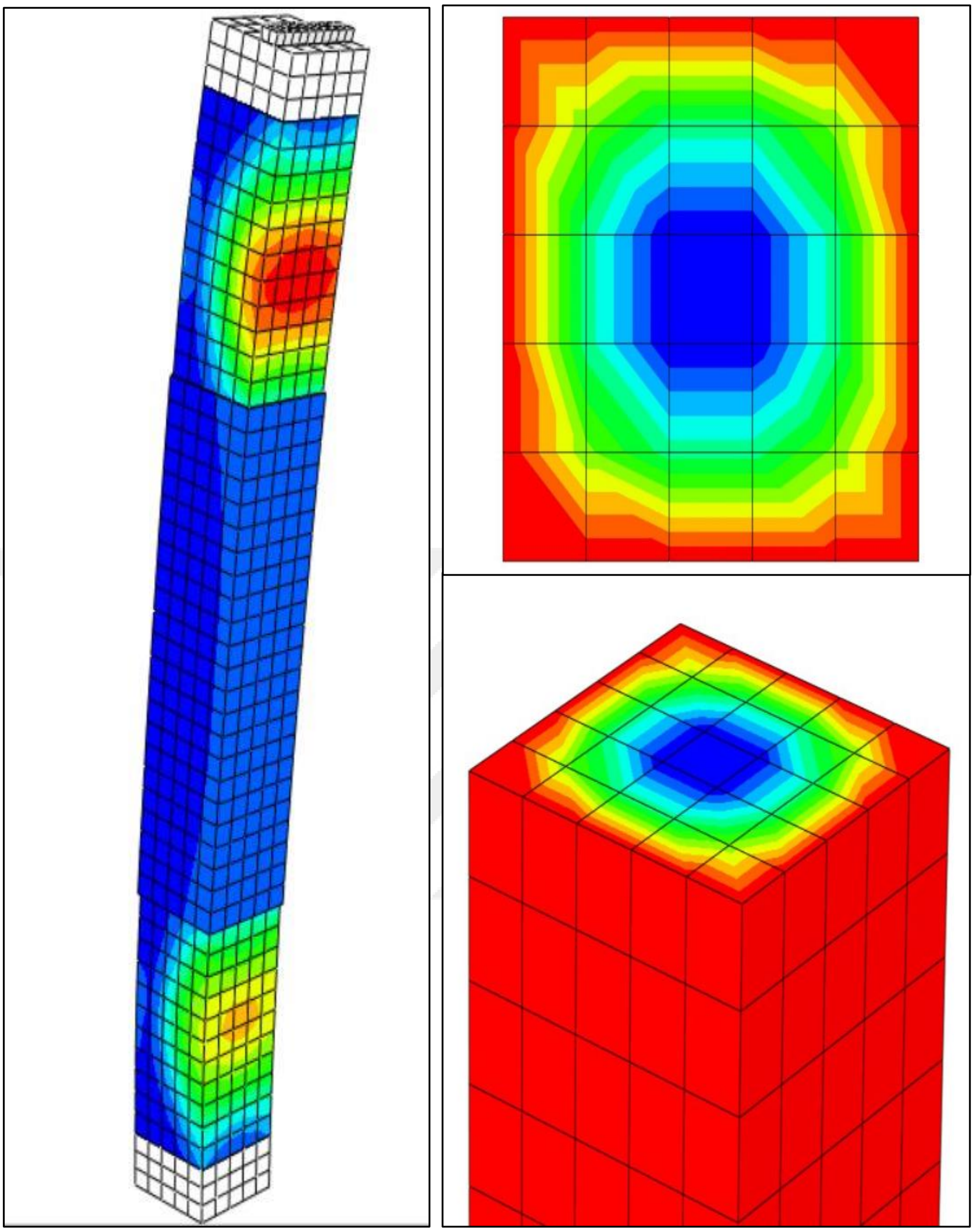


Figure 5.21: Plastic Strain Distribution for 20 mm Eccentric Load at 400 ^{o}C.

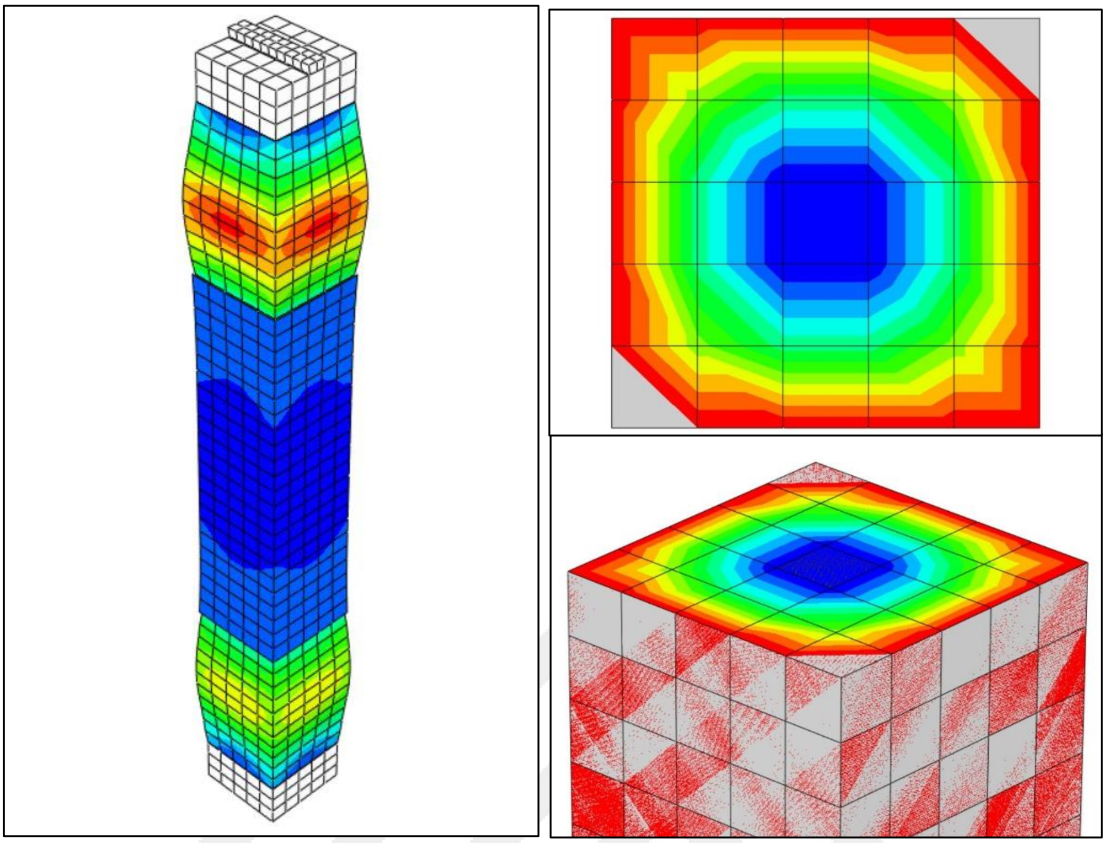


Figure 5.22: Plastic Strain Distribution for Axial Load at 600 ^{O}C.

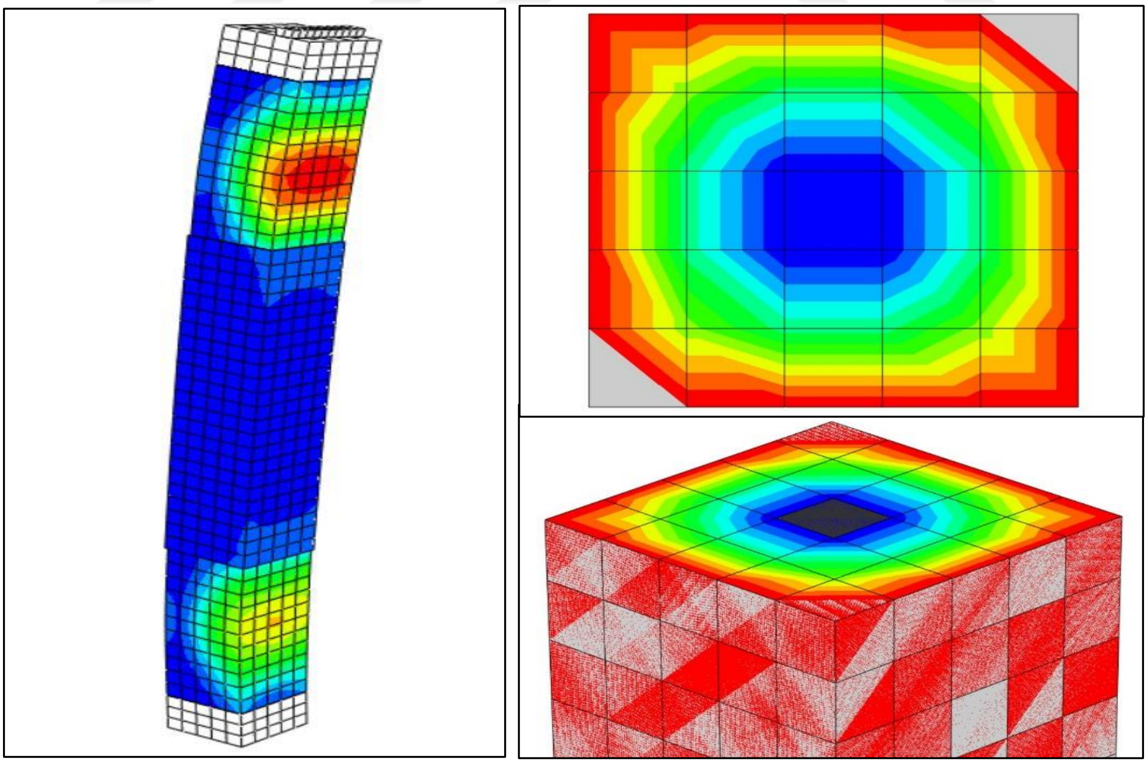


Figure 5.23: Plastic Strain Distribution for 20 mm Eccentric Load aT 600 ^{O}C.

5.7.2 30 mm Cover

The temp distribution of subject columns after full time of burning and the temp depth with time are shown in figures (5.24-5.29) for reactive powder concrete with 30 mm concrete cover along with strengthening the column by steel plate. From these figures, the increase in temp of burning cause a serious problem in the column edges and increase in temp toward the core of columns leading to most damage in RC column thus reduced the capacity of subject columns. At the same time applying eccentrically loads cause column bucking failure before the failure that happened due to burning.

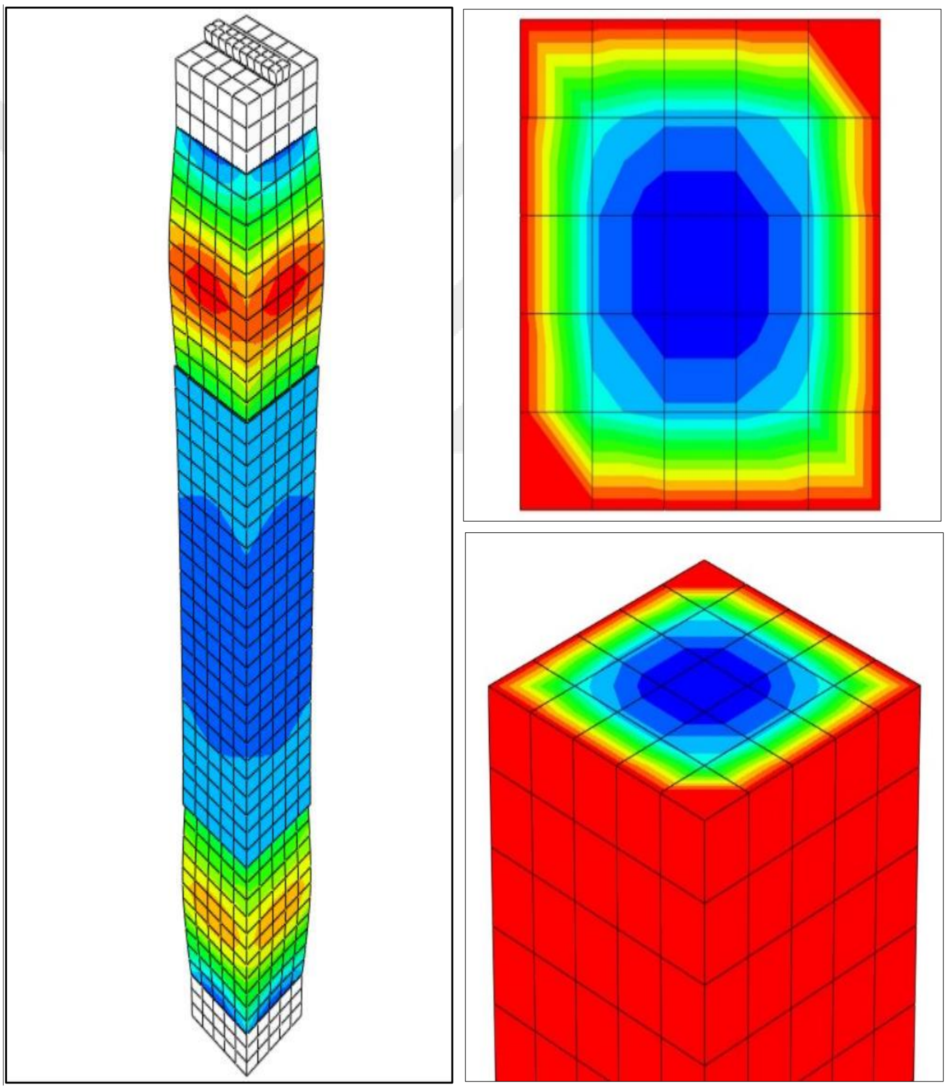


Figure 5.24: Plastic Strain Distribution for RPC Strengthen-Concrete with Axial Load at 200 ^{O}c.

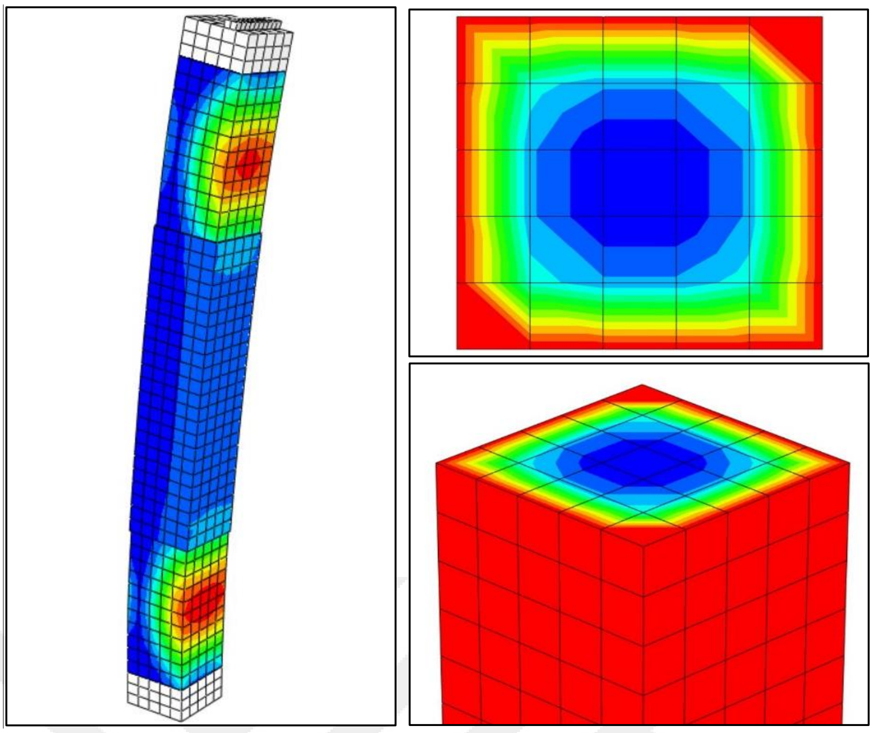


Figure 5.25: Plastic Strain Distribution for Strengthen-RPC with 20 mm Eccentric Load at 200 ºC.

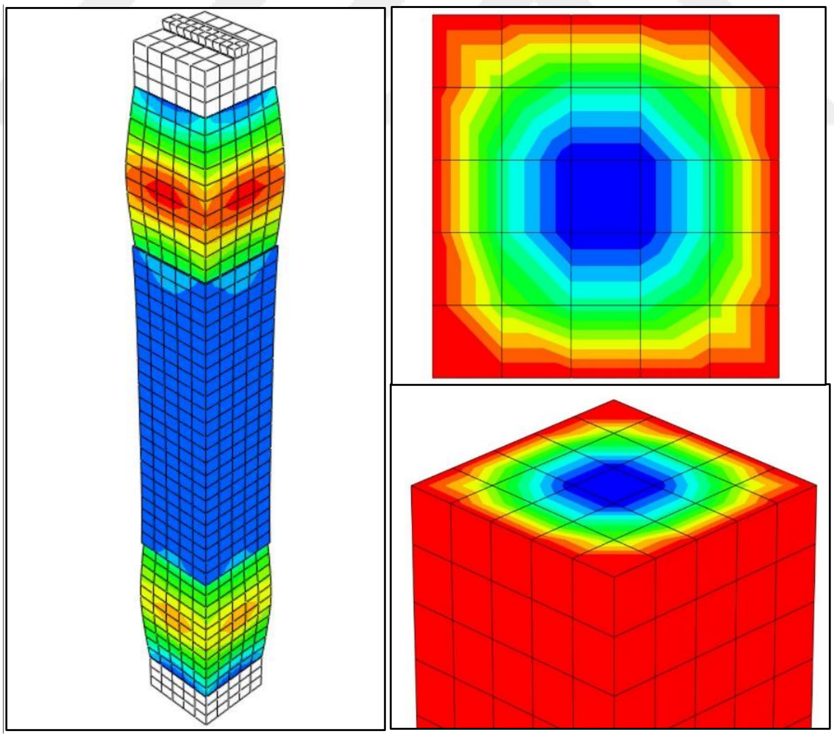


Figure 5.26: RPC Strengthen-Concrete with Axial Load at 400 ºC.

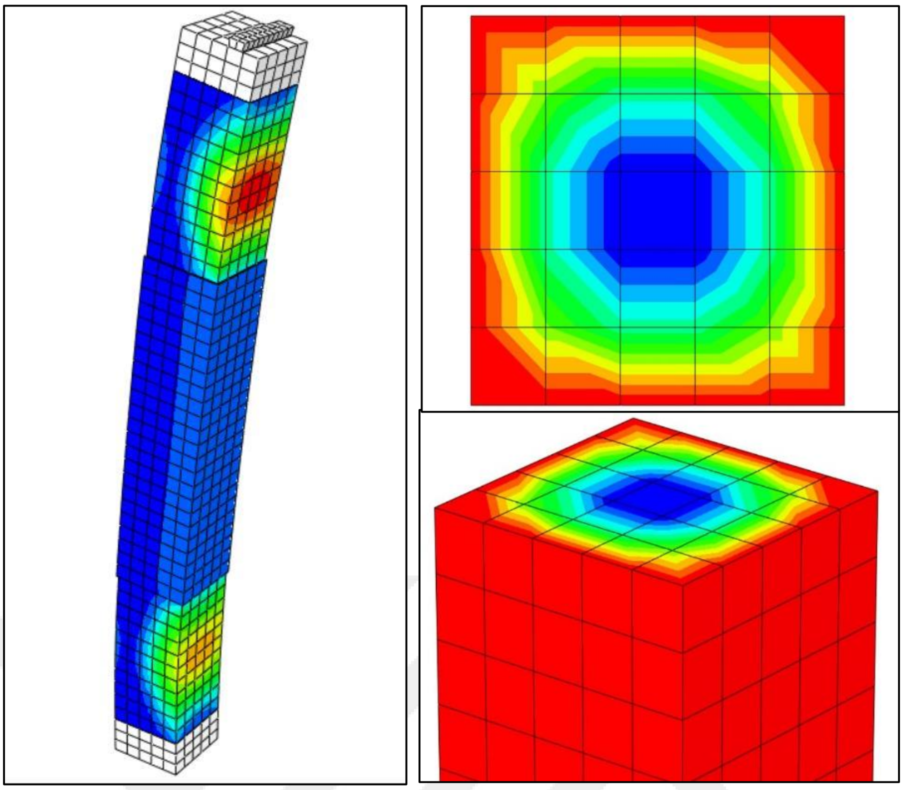


Figure 5.27: Strengthen- RPC with 20 mm Eccentric Load at 400 ºC.

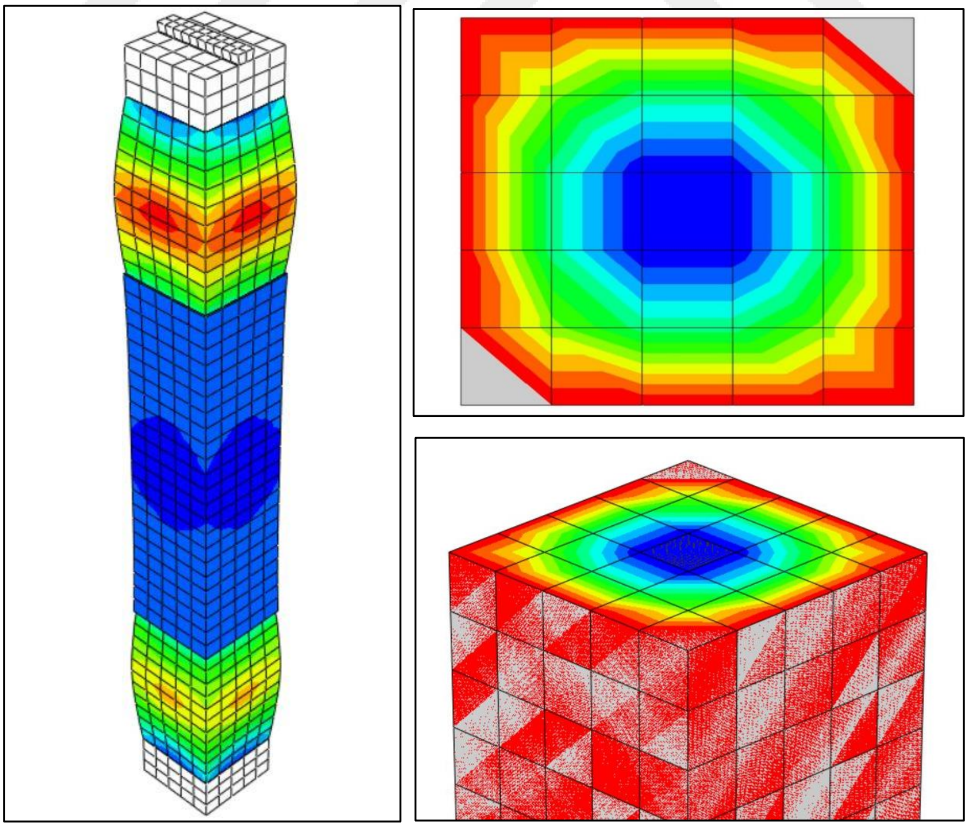


Figure 5.28: Strengthen- RPC with Axial Load at 600 ºC.

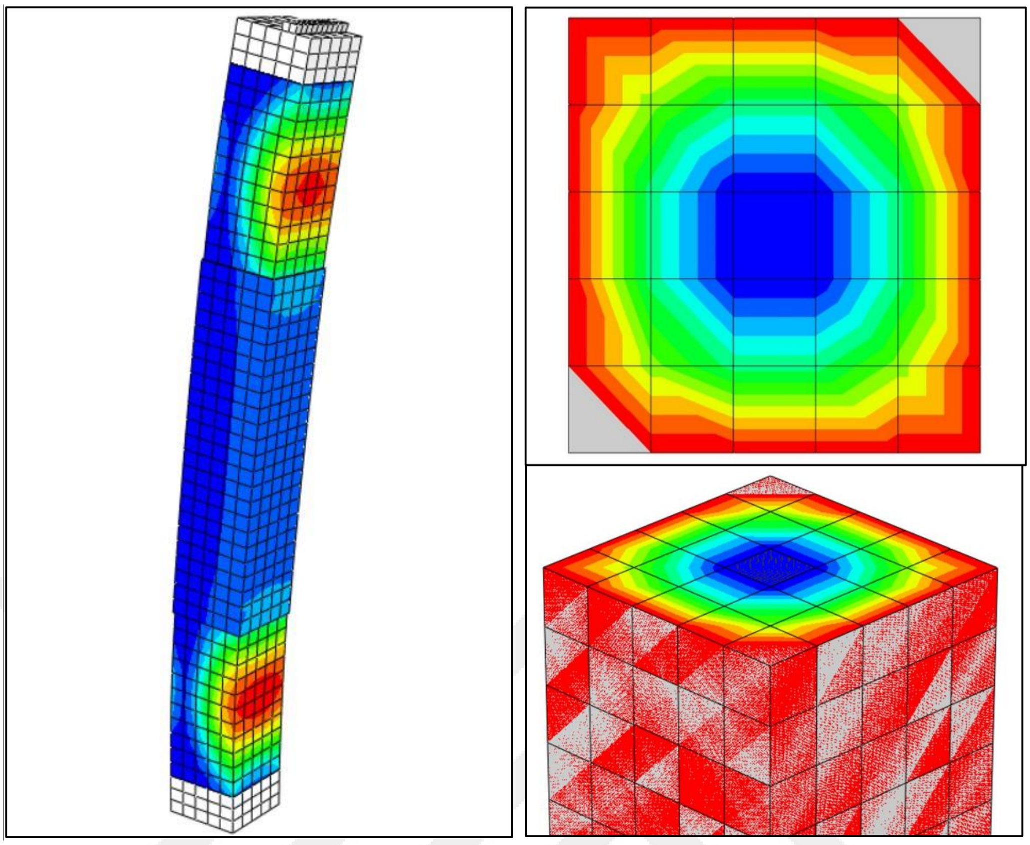


Figure 5.29: Strengthen-RPC with 20 mm Eccentric Load at 600 ^{o}C.

5.8 LOAD-DEFLECTION CURVE

5.8.1 15 mm Cover

An association between the ultimate loads, axial displacement, and lateral displacement of the tested column samples with numerical magnitudes from FEA for concrete column with 1.5 cm concrete cover. In Figure (5.30 to 5.32) finite element findings of displacement are compared axial an uniaxial load at different burning temperatures. In most cases uniaxial with 20mm eccentricity records lower loads carrying capacity and axial displacement comparison with axial applied load.

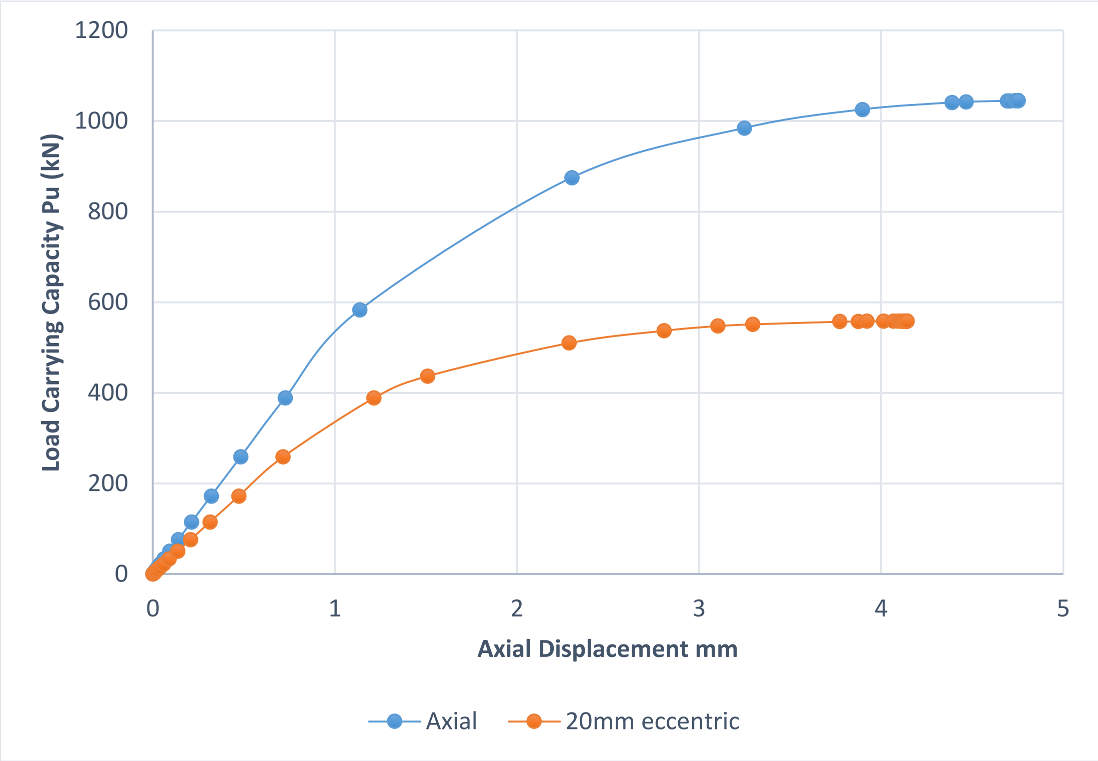


Figure 5.30: Load-Deflection for Unstrengthen-RPC with Axial and Uniaxial Loads at 200 ^{O}C.

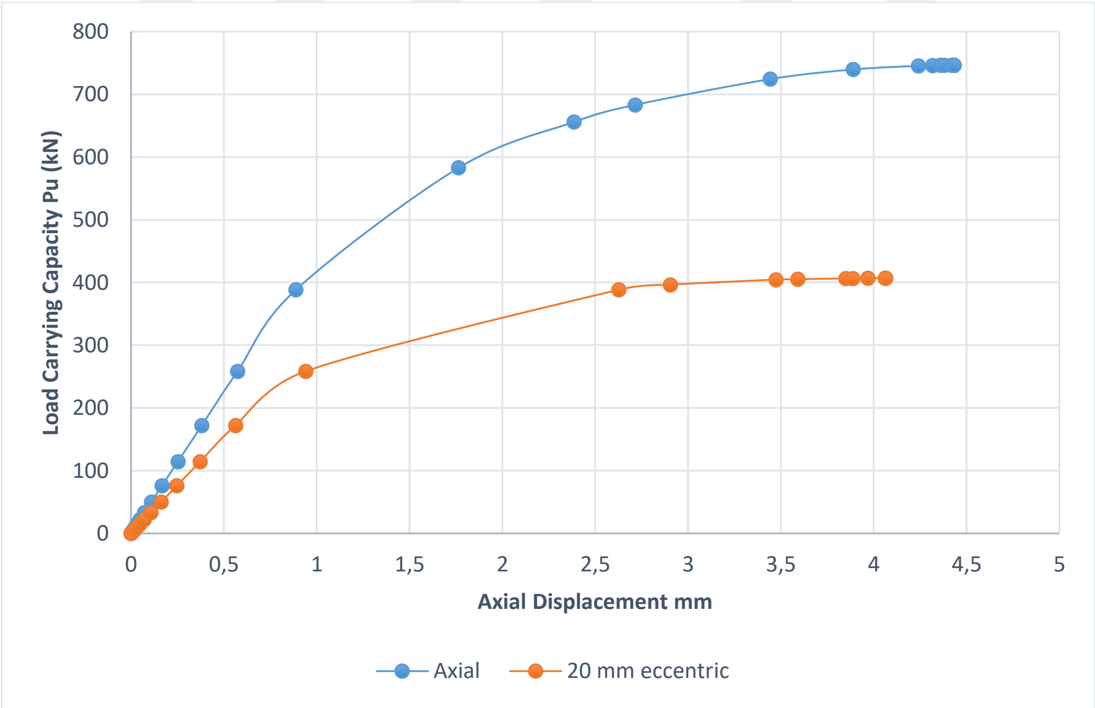


Figure 5.31: Load-Deflection for Unstrengthen-RPC with Axial and Uniaxial Loads at 400 ºC.

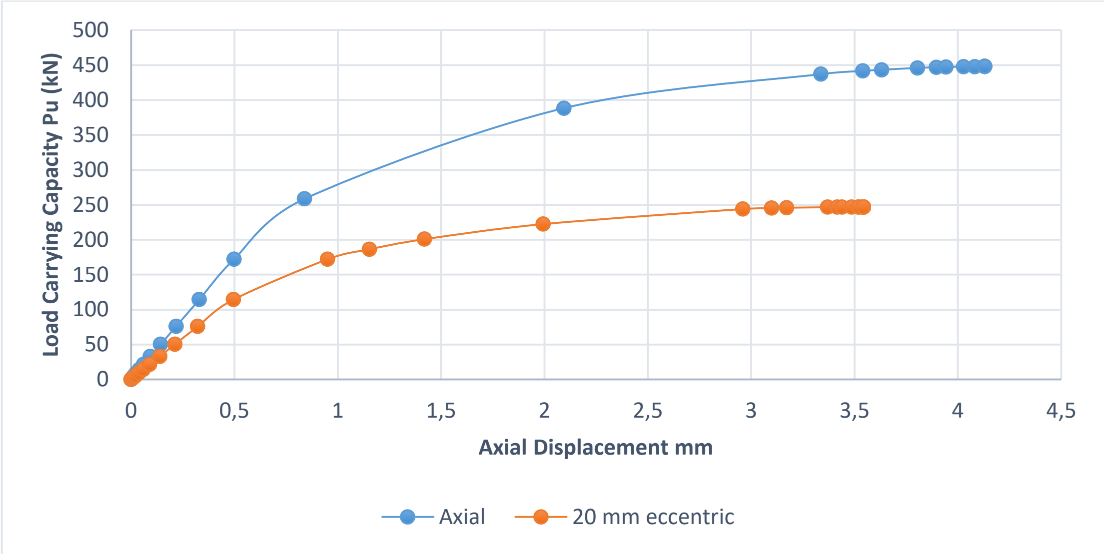


Figure 5.32: Load-Deflection for Unstrengthen-RPC with Axial and Uniaxial Loads at 600 ºC.

An assessment between the ultimate loads, axial displacement, and lateral displacement of the tested column samples with numerical magnitudes from FEA for concrete column with 15 mm concrete cover strengthening by steel plate. In Figure (5.33 to 5.35) finite element findings of displacement are compared axial an uniaxial load at different burning temperatures. In most cases uniaxial with 20mm eccentricity records lower loads carrying capacity and axial displacement comparison with axial applied load. Increasing temperature with strengthening column show no significant increase in the loading carrying capacity.

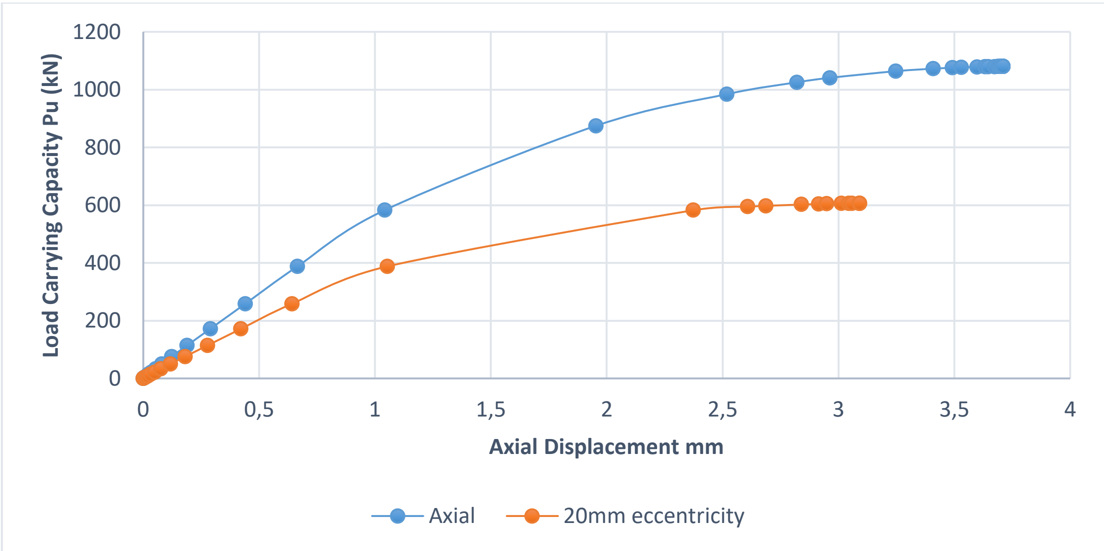


Figure 5.33: Load-Deflection for Strengthen-RPC with Axial and Uniaxial Loads at 200 ºC.

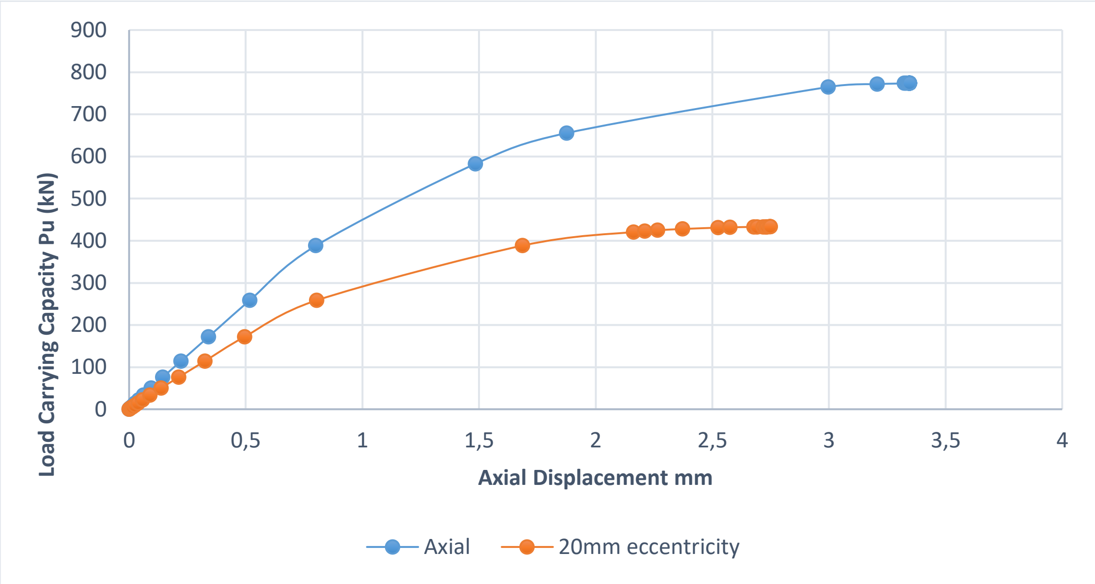


Figure 5.34: Load-Deflection for Strengthen-RPC with Axial and Uniaxial Loads at 400 ºC.

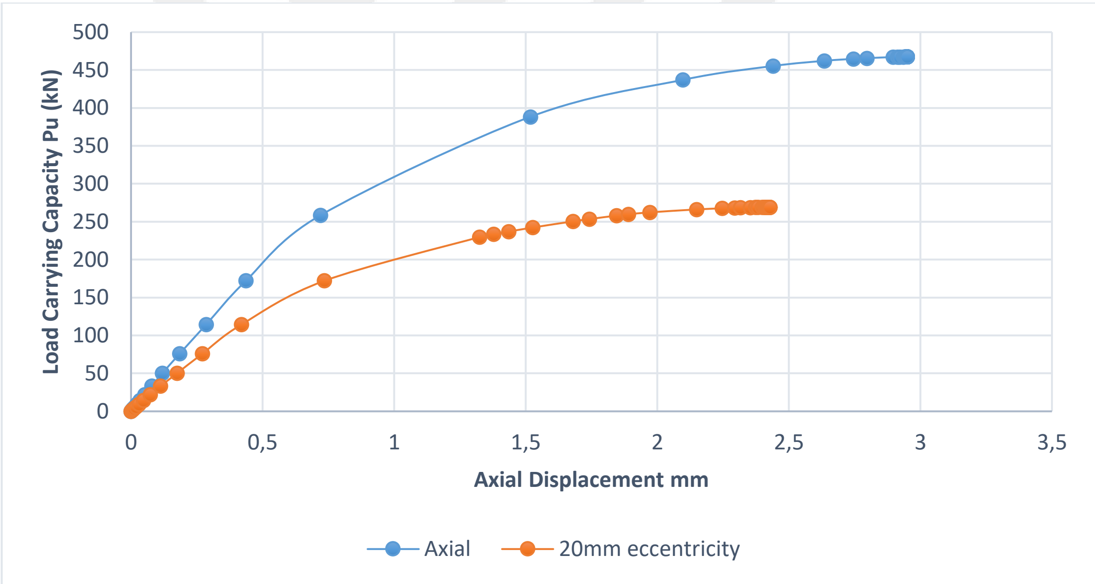


Figure 5.35: Load-Deflection for Strengthen-RPC with Axial and Uniaxial Loads at 600 ºC.

5.8.2 30 mm Cover

An assessment between the ultimate loads, axial displacement, and lateral displacement of the tested column samples with numerical magnitudes from FEA for concrete column with 1.5 cm concrete cover. In Figure (5.36 to 5.38) finite element findings of displacement are compared axial an uniaxial load at different burning temperatures. In most cases uniaxial with 20mm eccentricity records lower loads carrying capacity and axial displacement comparison with axial applied load.

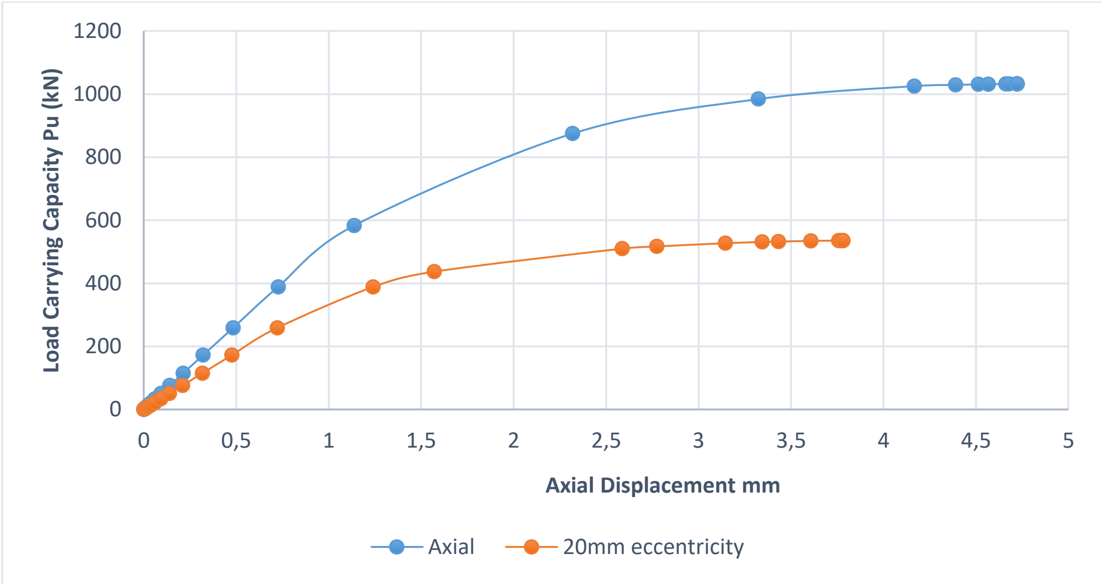


Figure 5.36: Load-Deflection for Unstrengthen-RPC with Axial and Uniaxial Loads at 200 ºC.

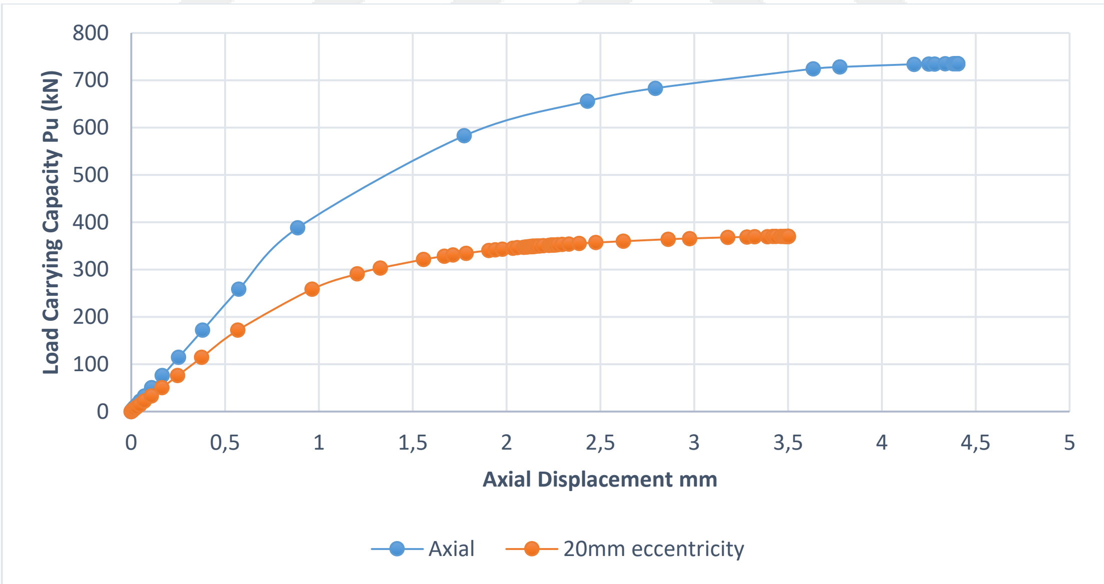


Figure 5.37: Load-Deflection for Unstrengthen-RPC with Axial and Uniaxial Loads at 400 ºC.

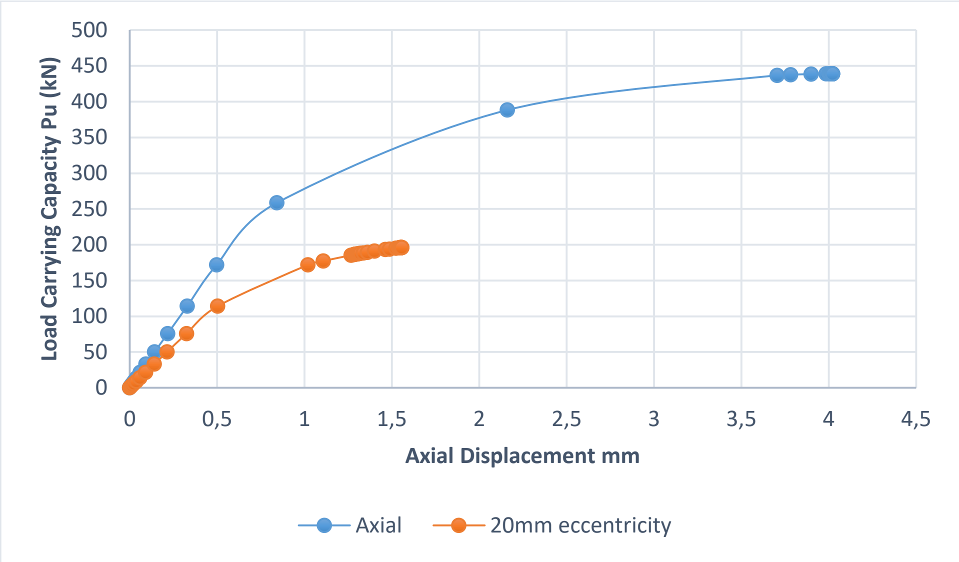


Figure 5.38: Load-Deflection for Unstrengthen-RPC with Axial and Uniaxial Loads at 600 ºC.

An assessment between the ultimate loads, axial displacement, and lateral displacement of the tested column samples with numerical magnitudes from FEA for concrete column with 3 cm concrete cover strengthening by steel plate. In Figure (5.39 to 5.41) finite element findings of displacement are compared axial an uniaxial load at different burning temperatures. In most cases uniaxial with 20mm eccentricity records lower loads carrying capacity and axial displacement comparison with axial applied load. Increasing temperature with strengthening column show no significant increase in the loading carrying capacity.

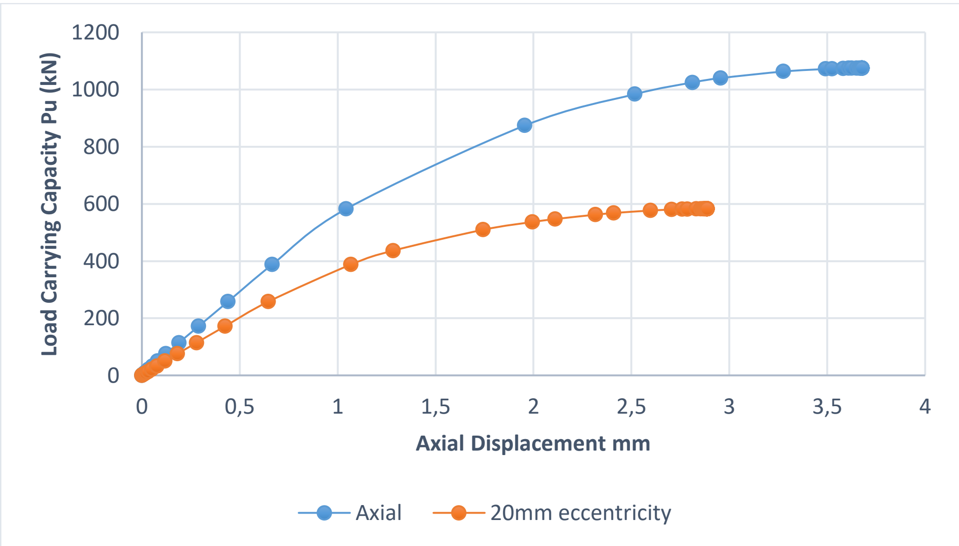


Figure 5.39: Load-Deflection for Strengthen-RPC with Axial and Uniaxial Loads at 200 ºC.

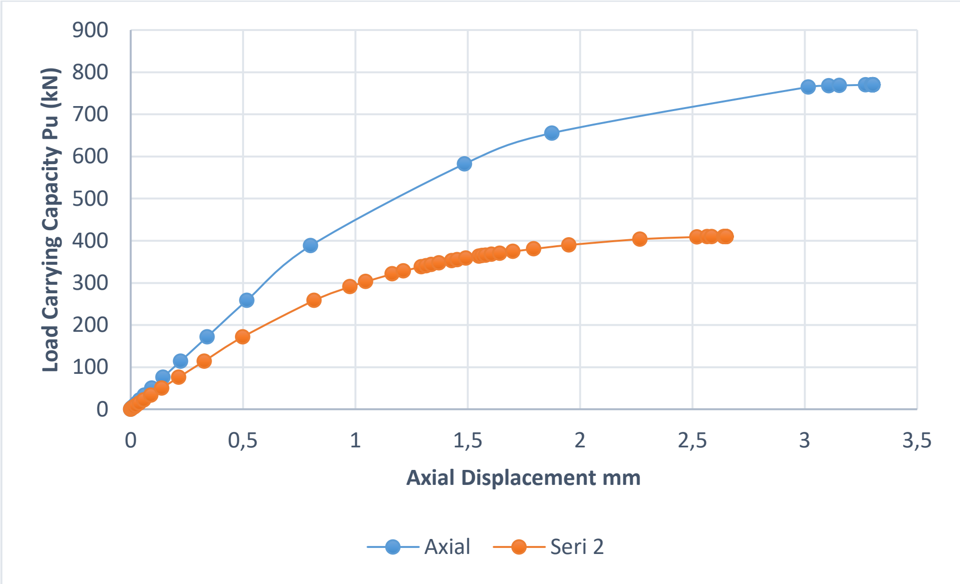


Figure 5.40: Load-Deflection for Strengthen-RPC with Axial and Uniaxial Loads at 400 ºC.

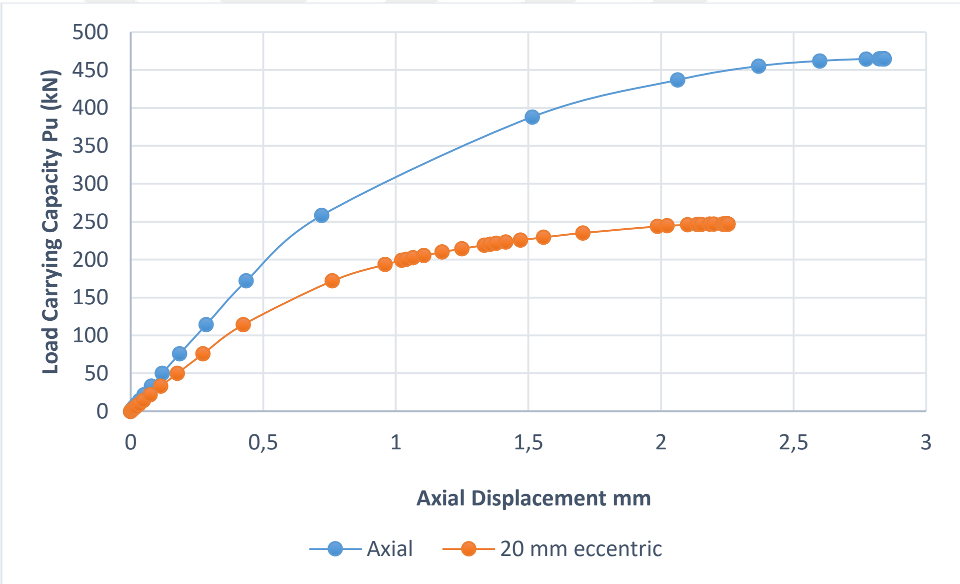


Figure 5.41: Load-Deflection for Strengthen-RPC with Axial and Uniaxial Loads at 600 ºC.

6. CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

This thesis' main objective is to investigate how reinforced-RPC columns behave in fire situations and to examine the many aspects of a reinforced-concrete column that influence how well it performs in a fire. The creation of a numerical model to aid in future research on reinforced RPC structures during fire exposures seems to be a secondary purpose of the thesis. According to the variables that were investigated in this research, a number of different findings about the column specimens' (structural performance) response to an actual fire were derived, and these findings may be summed up as follows:

a. The obtained findings show that increasing burning temps from 200 to 600 lead to reduce the compressive, tensile and flexural strength for reactive powder concrete.

b. After subject to fire at (400 and 600 degree centigrade), the mechanical characteristics of RPC were reduced, although at earlier ages than at later ages.

c. The elasticity modulus of RPC decreased more significantly than the other mechanical parameters after subject to fire at (400 and 600 degree centigrade).

d. The tensile strength increased gradually with increasing the curing ages as compressive strength magnitude, but increasing burning temp lead to reduce the strength magnitude significantly from (10.4 MPa to 3.6 MPa) at 3 curing ages when rise temps from 200 to 600 degree centigrade.

e. However, at 400 degree centigrade most of flexural strength findings are higher than the flexural strength at 200 and 600 degree centigrade.

f. Also, increase concrete cover from 15 to 30mm lead to enhance the concrete column against firing and using secondary reinforcement for similar concrete cover lead to increase the concrete resistance against fire significantly.

g. For RPC column samples, the impact of the secondary reinforcement on the load-carrying capacity has been somewhat less effective. For RPC column with concrete cover (C.C.) of (15 and 30 mm), the load bearing capacity was enhanced by 19 and 16.5 percent, respectively.

6.2 RECOMMENDATION

As a finding of the study on the influence of fire subject on hybrid reactive powder columns and also so as to finish major components of this research, the following suggestions for future investigations might well be taken into account as a possible outcome of the research:

a. So as to more accurately simulate the actual subject to fire within the concrete structure, additional research on the impact of various fire scenarios based on the position of the column is required. For instance, in the case of a corner column, the evaluation needs to take into account the impact of biaxial bending with two adjoining fire subject sides.

b. There should be more research to investigate the influence that increasing the dimensions of RPC column specimens has on the structural behavior of RPC columns when they are subjected to the effects of fire impact.

c. An investigation of the impact that a change in the proportion of longitudinal reinforcement has on the structural behavior of RPC columns when they are subjected to heat and flame.

d. Research into the effects of varying the thickness of the concrete cover on columns made of conventional concrete in order to determine how columns react when subjected to fire after such alterations have been made.

e. Research into the required remediation of the columns (with hybrid fibers) after burning, which involves removing the concrete cover and pouring a combination in order to test the resistance of the columns after they have been burned.

f. More theoretical and experimental research is needed to examine how various fire exposure situations affect thin RPC columns, where a potentially dangerous condition might develop owing to the eccentricity brought on by unequal spalling.

g. More research is needed to determine how the size of RPC column samples affect the way they behave structurally when exposed to fire flames.

h. Looking at how altering the main reinforcing bars proportion (ρ) affects the structural behaviour of RPC columns subjected to flame.

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