



**EXPERIMENTAL INVESTIGATION OF CONCRETE WITH GLASS FIBER  
EXPOSED TO FIRE**

**MSc. THESIS**

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**HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA**

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**EXPERIMENTAL INVESTIGATION OF CONCRETE WITH GLASS FIBER  
EXPOSED TO FIRE**

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**A THESIS SUBMITTED TO THE INSTITUTE OF TECHNOLOGY,  
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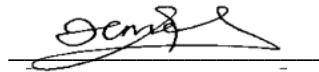
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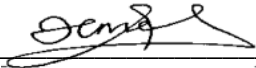
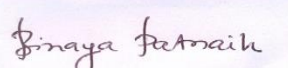
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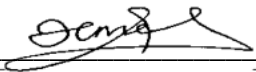
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## LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
CA	Coarse Aggregate
CN	Control no fire
C	Control
E-GFRC	Electrical glass fiber reinforced concrete
FA	Fine Aggregate
F	Fire
GFRC	Glass fiber reinforced concrete
FRC	Fiber reinforced concrete
ISO	International Organization for Standardization
OPC	Ordinary Portland cement
RC	Reinforced Concrete

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## ABSTRACT

This research intention is to investigate the compressive, tensile as well as flexural strength of concrete that mixed with E-glass fiber and then exposed to fire under different magnitude of temperature for different durations. A total of 192 specimens were cast; including 129 for compression strength test and the rest 63 for split tensile strength test with the concrete grade C25/30 with the percentage of glass fiber 0%, 0.09%, 0.18%, 0.27% and 0.36% by weight of concrete. Also, 6 beams with and without E-glass fiber, cast to investigating flexural strength of concrete. The furnace temperature adjusted for 150<sup>0</sup>C, 300<sup>0</sup>C, 450<sup>0</sup>C and 600<sup>0</sup>C for 2 and 4 hours of firing time.

From the result, adding glass fiber in concrete improves the compressive and tensile strength of conventional concrete as well as concrete which is exposed to fire at different level of temperature and firing hour. However, the workability of concrete decreases as the addition of E-glass fiber in concrete mix increase.

The optimum percentage of fiber for the concrete grade considered in this study for compressive strength is 0.18% and for tensile strength is 0.27%. At optimum point, the compressive strength has increased by 29.7% and the tensile strength by 31.5% from plain concrete. For flexural strength, percentage of glass fiber 0.27% has shown a great result on failure load and has a great impact on load vs deformation. It makes the failure of concrete more ductile than it used to be. For lower temperature 150<sup>0</sup>C with 2hr, at the optimum percentage of glass fiber, the compressive strength increased by 35.2% and the tensile strength by 39.8%. Whereas for higher temperature 600<sup>0</sup>C with 4hr, at the optimum percentage of glass fiber, the compressive strength increased by 78.4% and the tensile strength by 84.8%.

Time vs Temperature of furnace used for this study has similarity to the ISO standard curve. However, somehow the equation of this ISO standard curve is changed to meet the curve for this specific furnace. Spalling, cracking, weight loss and color change was observed during fire exposure. It is commonly observed that adding of glass fiber has shown a greater effect on resisting fire damage on concrete.

**Key Words:** Concrete, Glass fiber, fiber reinforced concrete, fire exposure, furnace time vs temperature curve, firing hour, firing temperature

## CHAPTER 1- INTRODUCTION

### 1.1. Background

Concrete is combination of aggregate bonded together with a fluid cement that hardens over time. (Alwyn, D.Jasper, Selva, Anand, & Prince, 2018). Although one of the benefits of concrete from other building materials is having a characteristic of fire resistant, it should designed for fire effects. (David, P, S, & Mahmoud, 2008). Even though concrete is inflammable material, there will be a change in its chemical, physical and mechanical properties once it subjected to high temperature. (Alwyn, D.Jasper, Selva, Anand, & Prince, 2018).

One of the most damaging environmental effects for reinforced concrete structures is exposure to high temperatures during a fire. (Alwyn, D.Jasper, Selva, Anand, & Prince, 2018). Even though the increase in temperature causes a decrease the strength and modulus of elasticity for concrete and steel reinforcement, structural elements still should able to withstand dead and live loads without collapse. (David, P, S, & Mahmoud, 2008)

A fire could occur from cooking equipment, electrical distribution systems, heating equipment, intentional or smoking. Fires behave differently; some burn slowly and evenly; others are extremely hot, burning fiercely and quickly. Different fires have different colored flames. Some fires start easily; others do not. Once it occurs it might rise and cause damage. Not only causes damage to the building but also risks human life by quickly spread, while releasing a toxic gas that leads to suffocation and death unless it is not control soon.

Fire temperatures up to 80<sup>0</sup>C have little effect on properties of concrete this is because concrete will maintain its compressive strength until a critical temperature is reached. However, above 80<sup>0</sup>C, cement paste undergoes shrinkage due to dehydration, aggregates expand due to temperature rise that results in overall expansion of concrete then cracks, and spalling will occurs, this leads to reduction of strength, stiffness and potential damage at the end. Mostly the reduction of compressive strength of concrete is heating it above about 300<sup>0</sup>C; the reduction is approximately linear with temperature, with all strength, being effectively lost at about 600<sup>0</sup>C.

The performance of concrete at any temperature depends on the properties of the cement, the aggregates, and the bond between them. The type of aggregates used, mix design, moisture condition and age are factors that govern the behavior of concrete under extreme

exposure of fire. Good materials should be selected in order to have a better strength, which can withstand fires with high temperature. In order to decrease the spreading of fire throughout the structures it is advisable to use concrete materials that can extinguish fire and will not spread it through the building in addition to that some fibers can be used in order to strengthen the concrete mix.

Fibers are small pieces of reinforcing materials possessing certain characteristics and properties. They enhance flexural and tensile strength and as a binder that could combine Portland cement in bonding with cement matrices. They increase the structural integrity of concrete.

Adding of fiber is expected to improve the durability and mechanical properties of concrete. It is proven that synthetic fibers helped to improve the post peak ductility performance, pre-crack, tensile strength; impact strength and they reduce the shrinkage cracks. It is expected that the addition of fibers will improve the tensile strength and fracture toughness of concrete at elevated temperature (Alwyn, D.Jasper, Selva, Anand, & Prince, 2018). Among many fiber types, the best fire resisting and low thermal fibers are glass fibers, Moreover, glass fiber can increase ductility and toughness of concrete.

Glass Fibers is a material made from extremely fine fibers of glass. It is lightweight, extremely strong and brittle material. Its bulk strength and weight properties are also very satisfactory when compared to metals, and it can easily be formed using molding processes. They possess high strength-to-weight ratios; have low thermal properties, which it can protect up to 315<sup>0</sup>C temperature. Therefore, in this research in order to have good performance in fire exposure concrete is mixed with one of the best fibers, which is glass fiber.

From a mechanical point of view, glass fibers are able to retain a considerable portion of their mechanical properties at elevated temperature; the softening and melting temperatures of E-glass fibers have been reported to be 830<sup>0</sup>C and 1070<sup>0</sup>C respectively. (T.Morgado, J.R.Correia, N.Silvestre, & F.A.Branco, 2018)

## **1.2.Problem of the statement**

In Ethiopia there is a lack of giving attention on design philosophy of fire resistance in structures, most construction are design and constructed without considering the effect of fire exposure and there is a gap in experimentally checking the performance of concrete regarding to fire. As the country is now introducing high-rise buildings and congested constructions, fire design can no longer be taken for granted.

Even if concrete is good thermal conducting material relative to others, it has its own weakness. When temperature of fire is rise cement paste undergoes shrinkage due to dehydration, aggregates expand due to temperature rise that results in overall expansion of concrete then cracks, and spalling will occurs, this leads to reduction of strength, stiffness and finally this leads to potential damage at the end.

Another weakness of concrete is that it is weak in tension and it is brittle in nature, it will crack with the increase of tensile forces. This cracks will propagates in the concrete when the applied load is increased. So in order to make concrete capable of carrying tensile forces fibers added. The addition of fiber will not only increase the tensile strength of concrete but also it can fill the cracks that occur during the exposure of fire.

## **1.3.Objective**

**General objective:** The main objective is to investigate experimentally the performance of concrete with glass fiber when exposed to fire.

**Specific objective:**

- ✓ To find the optimum percentage of glass fiber for compressive, tensile and flexural strength of concrete mixed with E-glass fiber
- ✓ To compare the behavior of plain concrete with E-GFRC exposed to fire under different magnitude temperature for different durations.
- ✓ To generate time vs temperature curve for different magnitude temperature and compare it with Euro-code's time vs temperature curve.
- ✓ To investigate the weight loss, color change, occurring of spalling and cracks of concrete after exposed to fire

#### **1.4. Research question**

1. What is the optimum amount of E-glass fiber in concrete to get the maximum compressive strength, tensile as well as flexural strength?
2. Does the adding of E-glass fiber has great impact on the strength of concrete, which has been exposed to fire at different firing hour?
3. How time-temperature curve is going to be generated and what is its relation to Euro-code's time –temperature curve?
4. At what temperature level color change and occurring of spalling and cracks observed. In addition, what will be the weight of concrete after it has been exposed to fire?

#### **1.5. Scope of study**

The scope of this research is assessing the performance of the concrete with glass fibers under the exposure of fire for different magnitude of temperature with different durations. There is less availability of measuring gages for local fire in our country and it is very difficult to maintain the temperature of local fire, so that using of furnace for firing of concrete is advisable for this research because it is very easy to control the temperature.

The mix design for this study is according to ACI 211.1-91. Since C25/30 is commonly used for most construction in Ethiopia, it is found better to use this concrete grade. One of benefit of glass fibers is increasing tensile strength of concrete and also it is useful for filling cracks, these cracks could be developed from higher exposer of fire so in order to fill these cracks and to increase the tensile strength of the concrete glass fibers are used.

After curing the specimens with and without glass fibers for 28 days, they all inserted in furnace so that the concrete can exposed to fire. Then they have been exposed to fire for different magnitude of temperature with different duration. After that, they cool down for 24 hours just simply using natural air-cooling system. Then, the performance of plain concrete and GFRC is checked with comparison. In addition, the physical appearance of the concrete is observed and evaluated. Finally, the time vs temperature of the furnace is plotted for every temperature taken.

## CHAPTER 2-LITERATURE REVIEW

### 2.1. Definition

Concrete is a composite material composed of aggregate, sand and gravel, chemically bonded together by hydrated Portland cement. It is a mixture of cement paste and aggregate, each of which has an essentially linear and brittle stress-strain relationship in compression. Concrete is strong in compression but weak in tension. (G.MacGREGOR & K.WIGHT, 2012)

### 2.2. Fiber reinforced concrete (FRC)

Fiber reinforced concrete is a composite material essentially consisting of concrete reinforced by random placement of short, discontinuous and discrete fine fibers of specific geometry (Bassam, 2005). When cracks develop whenever loads, restrained shrinkage or temperature changes give rise to tensile stress in excess of the tensile strength of the concrete. (G.MacGREGOR & K.WIGHT, 2012). Fiber in concrete contributes the prevention of crack propagation and the effect depends on the mechanical properties of fiber. (Isamu, Koji, Tetsuo, & Koji)

Since earliest times, fibers have been used to reinforce brittle materials. (ACICommitte544, 2002) Depending on fiber type and fiber content, enhancement may include in varying degrees improvements in tensile or flexural strength, ductility, toughness or energy absorption capability, impact resistance, and fatigue resistance, resistance to cracking, fire resistance permeability and durability. (Colin, 2010)

#### 2.2.1. Types of fibers

Based on (ACICommitte544, 2002), There are numerous fiber type available for commercial and experimental use, some of them are listed below

##### 1) NFRC-Natural Fiber Reinforced Concrete.

Fiber-reinforced composites made with naturally occurring fiber such as straw and horsehair. Some of naturally available fibers are akwara, bamboo, coconut, flax, jute, sisal, sugarcane bagasse and wood. Modern technology has made it possible to extract fibers economically from various plants, such as jute and bamboo to use in cement composites. (Parveen & Mohit, 2017).

According to (ACICommitte544, 2002) they are divided as unprocessed natural fibers and processed natural fibers. The problem to use these fibers is there is a tendency to disintegrate in an alkaline environment (Parveen & Mohit, 2017).



Figure 2.1- Natural Fiber. (Parveen & Mohit, 2017)

## 2) SNFRC-Synthetic Fiber Reinforced Concrete

Synthetic fibers resulting from research and development in the petrochemical and textile industries (ACICommitte544, 2002). They are the result of extensive by scientists to improve on naturally occurring animal and plant fibers. They are being used to improve the performance of concrete. These fibers are more durable; they can be used to improve the strength of hardened concrete and are used for crack control in semi-hardened concrete. Synthetic fibers helps to improve pump ability and keep concrete from spalling during impacts. They also prevent cracking as these do not expand in heat and contract in cold. (Parveen & Mohit, 2017) Some of the synthetic fibers based on (ACICommitte544, 2002) are - Acrylic, Aramid, Carbon, Nylon and polyester.

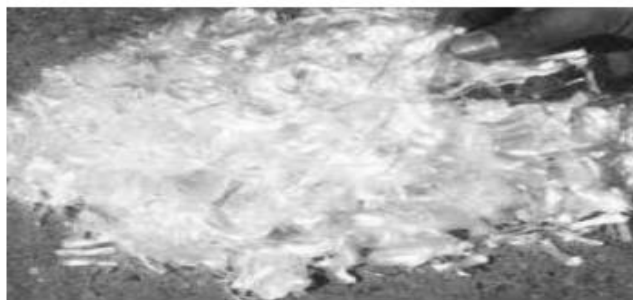


Figure 2.2- Synthetic Fibers. (Parveen & Mohit, 2017)

## 3) SFRC-Steel Fiber Reinforced Concrete

Steel Fiber are most commonly used fibers, these are cheaper and easier to use a form of rebar reinforced concrete. Rebar reinforced concrete uses steel bars that laid within the

liquid cement, which requires a great deal of prep work but make for much strong concrete. (Parveen & Mohit, 2017).

In general SFRC mixes contain higher cement contents and higher ratios of fine to coarse aggregate than do ordinary concretes and so the mix design procedures the apply to conventional concrete may not be entirely applicable to SFRC (Parveen & Mohit, 2017)



Figure 2.3- Steel Fiber (Parveen & Mohit, 2017)

#### 4) GRFC-Glass Fiber Reinforced Concrete

Glass fiber is a recent introduction in making fiber concrete. They help insulate the concrete in addition to making it stronger. They also help prevent the concrete from cracking due to thermal stress. In addition, glass fiber does not interfere with radio signals as the steel fiber reinforcement does. (Parveen & Mohit, 2017)



Figure 2.4- Glass Fiber (Parveen & Mohit, 2017)

### 2.2.2. Glass fiber

#### 2.2.2.1. General definition of glass fiber

Glass fiber-reinforce the concrete by using fiberglass, much like found in fiberglass insulation. The glass fiber helps insulate the concrete in addition making it stronger. Glass

fiber also helps prevent the concrete from cracking over time due to mechanical or thermal stress. In addition, glass fiber will not burn or support combustion. It retains approximately 25% of its initial strength at 540<sup>0</sup>C. According to (Antonio, 1993) Glass fibers are formed by extruding molten glass through an orifice that is usually 0.79-3.18 mm in diameter, followed by drawing to a fine diameter of 3-20 $\mu$ m.

#### 2.2.2.2. Types of glass fiber

1. *A-glass* - It is transparent, easily formed and most suitable for window glass. Used where electrical resistivity of E-glass is not needed, poor resistance to heat (500<sup>0</sup>C-600<sup>0</sup>C). Used for windows, containers, light bulbs, tableware.
2. *C-glass* – Chemical glass- Corrosive resistant glass made with calcium borosilicate with high boron oxide content, improved durability, making it preferred composition for applications requiring corrosion resistance. Used acid corrosive environments and for glass staple fibers possesses.
3. *D-glass* Low dielectric constant glass made with borosilicate's. Used in electrical applications.
4. *E-glass* Used in glass-reinforced plastics as general purpose fibers where strength and high electrical resistivity are required.
5. *ECR-glass*-Modified E-glass with higher acid corrosion resistance. Have superior long-term resistance to strain crack corrosion in acid conditions. Used where strength, electrical conductivity and acid corrosion resistance is needed.
6. *AR-glass* –Used in Portland cement substrates and concrete
7. *R-glass* – A reinforcement glass made with calcium aluminosilicates used where higher strength and acid corrosion resistance is needed.
8. *S-glass* – High strength glass made with magnesium aluminosilicates. Used where high strength, high stiffness, extreme temperature resistance, and corrosive resistance is needed
9. *S-2 glass* – Glass similar to , S-glass, but with somewhat improved properties S-2 is a brand name originally created by Owens-Corning but spun off in 1998 and is now a registered trademark of AGY Holdings Corp.

### 2.3. Definition of “Fire” and “A fire”

There is a fundamental difference between fire and a fire. “Fire” involves combustion, which is found in furnaces and boilers in the form of controlled combustion. Fire experts master a

controlled combustion that corresponds to the scenario defined by predetermined thermal program. These are found in the glass industry, ceramics industry and other industries, as well as in test laboratories, all places where fires are produced in furnaces or test chambers, where smoke is channeled so as not to inconvenience operators. (Jean-Francois, 2007)

“A fire” involves uncontrolled combustion; it then assumes such size that it can cause a fire. The fire experts that are firefighters in turn have to try to master an uncontrolled combustion, which corresponds to a scenario strewn with unforeseen aspects, with human lives that have to be saved, who also have to save, intervene, and so on. (Jean-Francois, 2007)

### 2.3.1. How fire occur

For fire to occur three elements must be present; Oxygen (21% volume in air), combustible materials and a heat source. Together, they make up what it is convenient to call the fire triangle. The first two elements will only start the process of combustion when the inflammation temperature is reached. The combustion of carbon produces carbon dioxide  $\text{CO}_2$  and, if there is a lack of oxygen, it produces the well-known gas  $\text{CO}$ , which is highly dangerous to man. (Annelies, 2011)

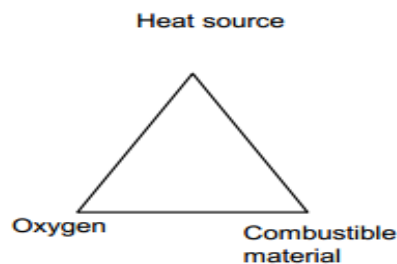


Figure 2.5. Fire -triangle. (Jean-Francois, 2007).

A fire involves a development phase in which the temperature increases, then a decline phase in which this temperature drops. A heat source causes a fire to start in quantity of materials. The first gases and smoke appear. In a closed environment, under the action of increasing heat, the smoke rises to the ceiling in a plume. At this point, it spreads radially along the ceiling until it reaches a wall and continues downwards where it stagnates in an upper layer beneath the ceiling. (Jean-Francois, 2007).

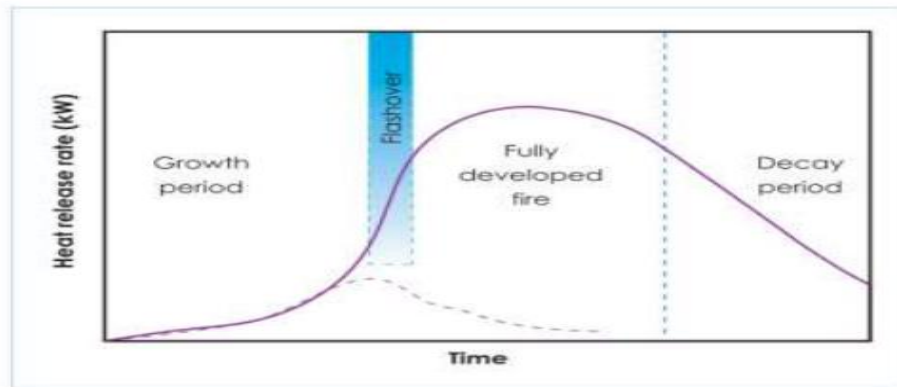


Figure 2.6. Fire Growth

According to (Annelies, 2011) the different stage of fires in rooms are ignition, growth, flashover, fully developed fire and decay.

### 2.3.2. Development of a fire-flashover.

The definition of flashover is the transition from a localized fire to combustion of all exposed combustible surfaces in a room. Thus, it is not possible for flashover to occur in an open unenclosed space since, by definition, it can only occur in an enclosed compartment. Furthermore, it may be pointed out that the term flashover describes a transition rather than a precise event. (Annelies, 2011)

In general, the room contains a cool lower layer composed of ambient air, gas and warm upper layer (two-zone model). A temperature in the order of  $200^{\circ}\text{C}$  causes windows to break, creating a sudden influx of fresh oxygen that gives the fire a new lease of life. The upper layer moves closer to the floor because it increases in volume because of being fed by plumes of smoke.

During the development of a fire, there may be a time when the temperature of the gaseous mixture of the upper layer is so high that it causes any combustible element in the compartment to ignite. This phenomenon is known as flashover. It generally corresponds to a temperature of  $500^{\circ}\text{C}$  to  $600^{\circ}\text{C}$ . The extremely rapid rise in temperatures in the compartment and the increase in the release of heat cause the smoke to stirred up where the layers mix (single-zone model). The fire is then said to be “fully developed”. (Jean-Francois, 2007)

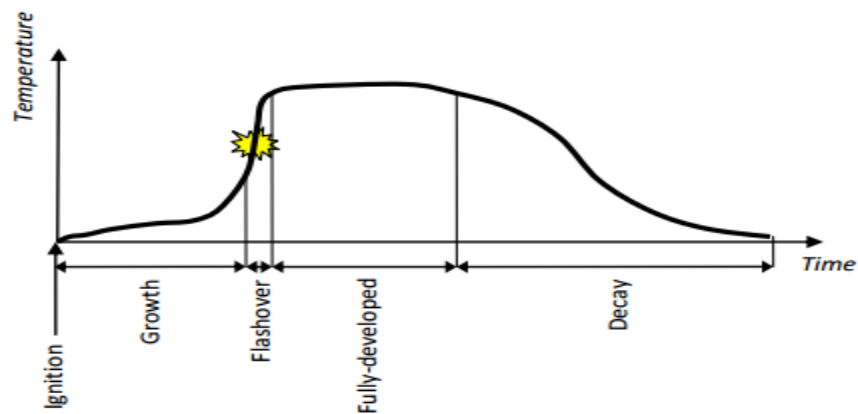


Figure 2.7. Flash over. (Annelies, 2011)

### 2.3.3. Concrete performance in Fire

Concrete structures are frequently exposed to fire for example building and tunnels. The nature of the fire varies not only from fire to fire depending upon the fire load (fuel) but also from the geometric configuration and the availability of oxygen. (Gabriel, 2008)

Concrete is not homogeneous material, consisting of sand, cement and aggregates. Each of these components has different reaction to thermal exposures in itself and behavior of composite system in fire cannot easily defined. (Fletcher, Stephen, Jose, Richard, & Asif, 2007) There are a number of physical and chemical changes, which occur in concrete subjected to heat. Some of these are reversible during cooling but others are non-reversible and may significantly weaken the concrete structure after fire. (Ian, Audun, Neil, & Stephen)

Concrete is non-combustible and emits no toxic fumes. As concrete is a good insulator, the temperature of the concrete will usually be much less than the flame temperature. As its temperature rises, concrete progressively loses moisture and gradually loses strength. The loss of strength is greatest at concrete temperatures above 450<sup>0</sup>C -500<sup>0</sup>C (the exact temperature depends on the aggregate type). Wet or moist concrete can spall in fire, due to the buildup of steam pressure within the concrete, leading separation and loss of the surface layer.

#### 2.3.3.1. How fire affects concrete structures

Concrete contains liquid water, this begins to vaporize if the temperature exceeds 100<sup>0</sup>C, usually causing a build-up of pressure within the concrete. In practice, the boiling temperature range tends to extend from 100<sup>0</sup>C to about 140<sup>0</sup>C due to the pressure effects. Beyond the moisture plateau, when the temperature reaches about 400<sup>0</sup>C, the calcium

hydroxide in the cement will begin to dehydrate, generating more water vapor and bringing about a significant reduction in the physical strength of the material. (Fletcher, Stephen, Jose, Richard, & Asif, 2007)

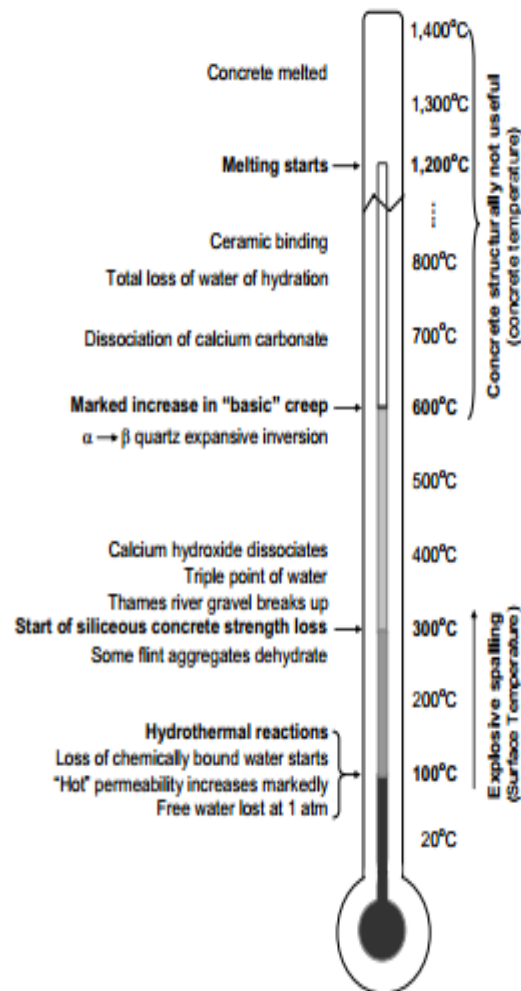


Figure 2.8. Effect of temperature on concrete (Gabriel, 2008)

As figure 2.8 shows, temperature up to 100°C has no effect on concrete. At 100°C, there will be a loss of chemical bound and then water will start vaporization due to the hydrothermal reactions. In between 100°C-300°C, there will be explosive spalling because of the temperature rise on the surface of concrete. At 300°C, siliceous concrete strength will start to loss and some fine aggregates dehydrates. When the temperature rise to 400°C Calcium hydroxide detaches triple point of water and river, gravel breaks up. At 600°C concrete, will lose its strength so that after this point of temperature concrete will not be useful structurally.

At 800<sup>0</sup>C, there is a total loss of water of hydration. At 1200<sup>0</sup>C melting of concrete will starts and finally the concrete will fully melted at 1400<sup>0</sup>C (Gabriel, 2008)

### *2.3.3.2.Effect of fire on concrete components*

Concert contains both cement and aggregate elements, and these may react to heating in variety of way (Ian, Audun, Neil, & Stephen). It is evident that the insufficient choice of construction material can significantly affect the degree of fire safety whose purpose is to save occupant lives and adjacent buildings as well as to protect lives of emergency services and building integrity. (Josef & Alena, 2017)

#### *A. Coarse aggregate under fire*

The type of coarse aggregate used can change in concrete properties due to high temperature (David, P, S, & Mahmoud, 2008). It is evident that aggregate type can affect both magnitude and direction of thermal expansion, and most concrete expand when heated. (Luke, 2003)

Aggregate used in concrete classified into three types (David, P, S, & Mahmoud, 2008): Carbonate, siliceous and lightweight.

- Carbonate aggregate include limestone and dolomite.
- Siliceous aggregates include materials consisting of silica and include granite and sand stone.
- Lightweight aggregates are usually, manufactured by heating shale, slate or clay.

Changes may occur in aggregate at higher temperatures. For example, quartz-based aggregates increases in volume due to mineral transformation at about 575<sup>0</sup>C while lime stone aggregates will begin to decompose at about 800<sup>0</sup>c.Differential expansion between aggregate and cement matrix may cause cracking and spalling. (Fietcher, Stephen, Jose, Richard, & Asif, 2007)

#### *B. Cement paste under fire*

The heating of concrete makes its aggregate volume grow, and at the same time, it causes the contraction of the cement paste that surrounds it. As a result, the cement paste-aggregate bond is the weakest point in heated cementitious material. Largely, damage to concrete is caused by cracking, which occurs arising due to mismatched thermal strains between the coarse aggregates and the matrix. (I.Hager, 2013)

#### **2.3.4. Properties of fibers under higher temperature**

- 1) Aramid fibers- Have a high thermal stability, but oxidation limits their use above 150<sup>0</sup>C
- 2) Carbon fibers-They show negligible strength loss up to temperatures of 2000<sup>0</sup>C.
- 3) Glass fibers-Will not oxidize but tends to soften at temperatures in the range of 800<sup>0</sup>C to 1000<sup>0</sup>C (Luke, 2003)

Plastic fiber can provide the additional pore so that plastic fiber is melted by fire heating . It can soften the stem pressure, and can prevent the collapse. (Isamu, Koji, Tetsuo, & Koji)

#### **2.3.5. Fire safety**

##### *A. Fire Endurance of structures*

Fire endurance is a measure of the elapsed time during which a material or assembly continues to exhibit fire resistance under specified conditions of test and performance. (ACIcommittee216, 1994).Fire endurance expressed in terms of minimum allowable times to reach specified failure criteria. The prescribed time to failure is chosen based on a number of factors, such as the building size and occupancy. In addition since it is a function of load, member type and dimensions, fire intensity and the materials also considered as factors for time to failure. (Luke, 2003)

When examining the fire endurance of reinforced concrete members, it is essential to consider the three basic types of members: beam, slabs and columns. Each member type has specific requirements in terms of the applicable failure criteria and the required time to reach said criteria. For instance, columns which are primary load bearing members in a structure, tend to have the highest required fire rating (up to 4 hours) whereas slabs, the failure of which would likely be more localized have comparatively low fire rating (as low as 1 or 2 hours). (Luke, 2003)

If bottom side of slab is subjected to fire, the strength of concrete and the reinforcing steel will decrease as the temperature increase. However, it can take up to three hours for the heat to penetrate through the concrete cover to the steel reinforcement. As the strength of steel reinforcement decreases the moment-capacity of the slab decreases. When the moment capacity of the slab is reduced to the magnitude of the moment caused by the applied load, flexural collapse will occur. It is important to point out that duration of fire until the

reinforcing steel reaches the critical strength depends on the protection to the reinforcement provided by the concrete cover. (David, P, S, & Mahmoud, 2008)

### *B. Fire resistance*

Fire resistance is the property of material or assembly to withstand fire or to give protection from it. (ACIcommittee216, 1994) . Fire resistance can be defined as the ability of structural elements to withstand fire. This include the ability of restrain a fire or to continue to perform a given structural function or both. (David, P, S, & Mahmoud, 2008)

According to (Vigneshwaran & Vimalrajan, 2015) Fire resistance of concrete structure is determined by three factors

- Capacity of the concrete itself to withstand heat
- Subsequent action of water without losing strength, without cracking or spalling
- The coefficient of thermal expansion

### *C. Fire resistance rating*

It can be called fire rating, fire resistance classification or hourly rating. Based on fire endurance, resistance rating is assigned by different building codes for various constructions and occupancies and usually given in half-hour increments. (ACIcommittee216, 1994)

The fire resistance of column, beams, walls and slabs must prevent the spread of the fire and the collapse of the structure to allow the extinguishing operations to pass off smoothly without the firefighters being exposed to excessive risks. (Jean-Francois, 2007)

Since 90% of all fatalities in fires occur as the result of smoke and toxic gases, it is particularly important for evacuation routes to be provided, with floors and staircases remaining free of smoke and properly illuminated. Smoke and fire doors should shut off floors and protect staircase. The distance from any room to a staircase should not be greater than about 30m. Staircases must be design to withstand a fire for 90 minutes. In all cases, two evacuation routes must be provide. Up to height of about 20m, fire brigade ladders may be consider to provide a second escape route. (Karl, Giuseppe, Kurt, Angelika, & Konrad, 2010)

## **2.4. Design Fires and Time-Temperature graph**

The first stage in a structural fire engineering design is to define the appropriate fire design scenario. This will typically involve a consideration of a fire in various compartments within a building to establish the most suitable cases for design purpose. The choice of the design fire scenario will dictate the choice of design fire to be use. A determination of the thermal actions to be use in subsequent structural analysis can be achieved either through a prescriptive approach, which relies on data from standard test methods or from a consideration of the physical parameters specific to a particular building. (T.Lennon, D.B.Moore, Y.C.Wang, & C.G.Bailey, 2007)

### **2.4.1. Nominal Time-Temperature curves**

The conduct of fire tests of materials and construction shall be control by the standard time vs temperature curve. Fuel flow data may be useful for a furnace heat balance analysis for measuring the effect of furnace or control changes, and for comparing the performance of assemblies of different properties in the fire endurance test. (ASTM, E119)

The time-temperatures curve used in fire resistance tests is called the standard fire (Long, Therese, John, & Morgan, 2010). The simplest way of representing a fire is to use nominal curves giving the evolution of the temperature of the gases as a function of time. (Jean-Francois, 2007). Once the time temperature relationship is determined, using a standard curve the effect of the rise in temperature on the structure can be determined (David, P, S, & Mahmoud, 2008)

Nominal or standard fire curves provide a simple means of assessing building materials and components against a common set of performance criteria subjected to closely define thermal and mechanical loading under prescribed loading and support conditions. (T.Lennon, D.B.Moore, Y.C.Wang, & C.G.Bailey, 2007)

#### *2.4.1.1.Types of the nominal time-temperature curves*

The nominal curves according to (Eurocode1991-1-2, 2002) are

##### *1. Standard ISO temperature- time curve*

The standard fire curve has been use effectively for many years to determine the relative performance of construction materials. The temperature- time relationship described below

$$\theta_g = 20 + 345 \log(8t + 1)$$

Where

$\theta_g$  is the gas temperature in the fire compartment ( $^{\circ}\text{C}$ )

T is the time (min)

For ISO curve, it is easy to remember that, after 1/4hr, the ambient temperature reaches around  $745^{\circ}\text{C}$  and continues to increase by around  $100^{\circ}\text{C}$  each time the time is double. In this equation, the two phases that occur during a fire can easily be identify: the flashover period in which there is a very rapid increase in temperature to around  $800^{\circ}\text{C}$ , then the period when the fire is fully developed. (Jean-Francois, 2007)

### 2. *External Fire curve*

The external fire curve used for structural members in façade external to the main structure. The external fire curve is given by:

$$\theta_g = 660(1 - 0.687e^{-0.37t} - 0.313e^{-3.8t}) + 20$$

This curve developed in the 1970's by the petrol company Mobil shows a very rapid increase in temperature with a temperature of  $900^{\circ}\text{C}$  in the first 5 minutes and a plateau at  $1100^{\circ}\text{C}$ . (Jean-Francois, 2007)

### 3. *Hydrocarbon curve*

In situations where petrochemicals or plastics form a significant part of the overall fire load. The temperatures rise is very rapid due to the much higher calorific values of these materials. Therefore, for such situations an alternative temperature- time curve has been develop of the form

$$\theta_g = 1080(1 - 0.325e^{-0.167t} - 0.675e^{-2.5t}) + 20$$

This curve is more severe and it have been perfected more recently following the wave of major fires in tunnels, which revealed that more severe fire scenarios had to be considered. (Jean-Francois, 2007)

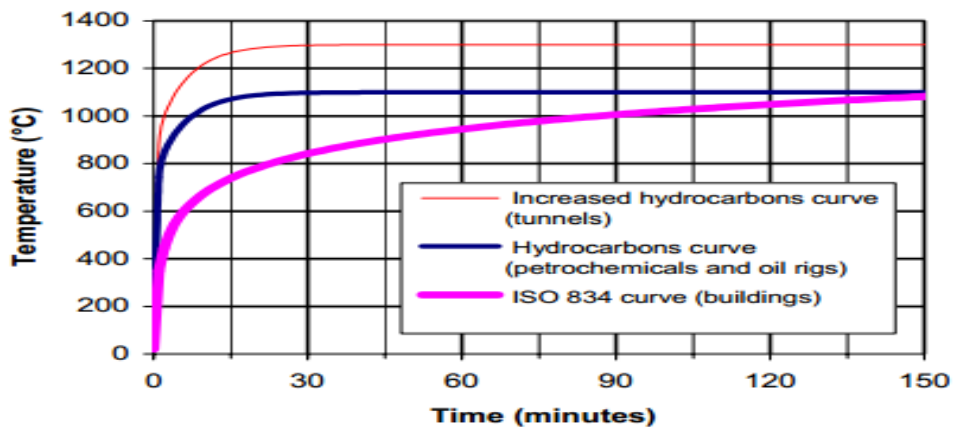


Figure 2.9. Comparison of Nominal Time-temperature curve (Jean-Francois, 2007)  
 The three nominal curves defined in the Euro codes are illustrate in figure 2.9 together with a typical natural fire exposure consisting of an ignition phase, a growth phase, a steady-state phase and decay phase.

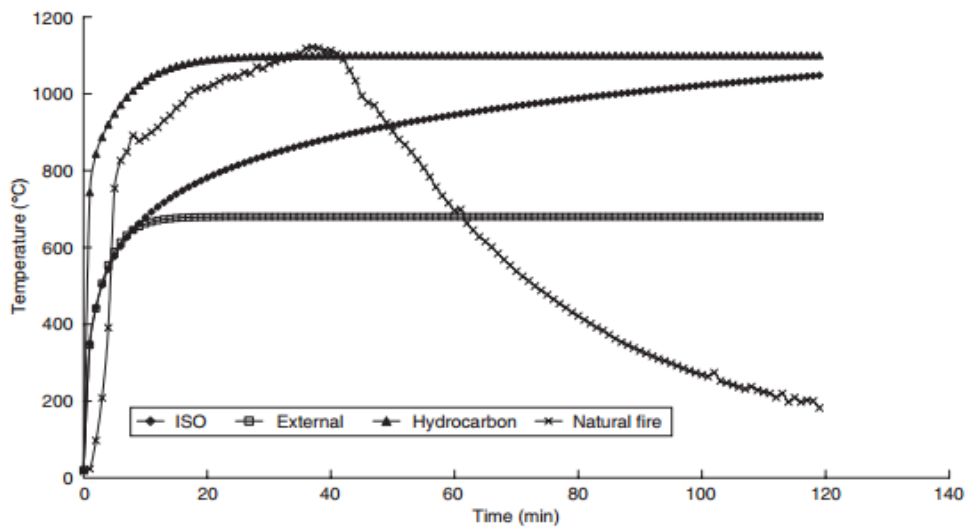


Figure 2.10. Comparison of natural fire curve with Nominal fire curves (T.Lennon, D.B.Moore, Y.C.Wang, & C.G.Bailey, 2007)  
 Concrete elements can easily withstand an ISO fire of 1 hour. A greater resistance can easily obtained, which is anything but the case with unprotected metal elements. After 10 to 15 minutes, steel reaches 500°C to 600°C and its resistance declines rapidly. Boards and paints are available which insulate steel, but poor site execution and reported degradation of these materials can have dramatic consequences. (Jean-Francois, 2007)

#### 2.4.1.2. Equivalent time of fire exposure

EN1991-1-2 includes a method for determining the appropriate fire resistance period for design based on consideration of the physical characteristics of the fire compartment. This is effectively a halfway house between the nominal curve so familiar to many and the behavior of realistic fire compartment. The method relates the severity of real fire in a real compartment to an equivalent period of exposure in standard test furnace. The relevant input parameters are the amount of fire load, the compartment size (floor area and height), the thermal properties of compartment linings and the ventilation conditions. The formulation in the Euro code based on fire load density related to floor area is:

$$t_{c,d} = (q_{f,d} * k_b * w_t) * k_c$$

Where:

$t_{c,d}$  is the equivalent time of fire exposure for design(min)

$q_{f,d}$  is the design fire load density (MJ/m<sup>2</sup>)

$k_b$  is a conversion factor dependent on thermal properties of linings

$w_t$  is the ventilation factor and

$k_c$  is a correction factor dependent on material

For protected steel and reinforced concrete  $k_c=1$

Where no detailed assessment of the thermal properties is made the factored  $k_c = 0.09$

The ventilation factor is:

$$w_t = \left(\frac{6}{H}\right)^{0.3} * [0.62 + 90(0.4 - \alpha_v)^4]$$

In the absence of horizontal openings (roof lights) in the compartment;

Where

H is the height of the fire compartment (m); and

$\alpha_v = A_v/A_f$  , Where:  $A_v$  and  $A_f$  are the ventilation and floor area respectively (m<sup>2</sup>)

The verification is then that the fire resistance of the member is greater than the time equivalent value. The concept of time equivalence illustrated in the following figure with respect to achieve an identical temperature in a standard furnace test.

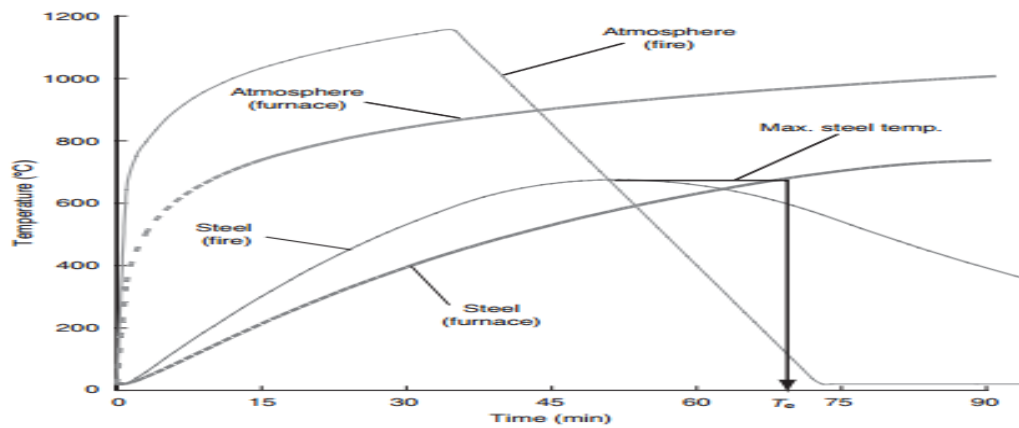


Figure 2.11. Concept of time equivalent (T.Lennon, D.B.Moore, Y.C.Wang, & C.G.Bailey, 2007)

#### 2.4.2. Furnace Temperatures

The temperature fixed by the curve shall be the average temperature from not fewer than nine thermocouples for floor, roof, wall or partition and not fewer than eight thermocouples for structural column. (ASTM, E119)

Based on (ASTM, E119) time-temperature curve for furnace is plotted using by recording cumulative flow of gas or fuel to the furnace burners at 10min, 20 min, 30 min and every 30 min thereafter or more frequently. Total gas consumed during the total test period is also to be determined. A recording flow meter has advantages over periodic readings on an instantaneous or totalizing flow meter. Select a measuring and recording system to provide flow rate readings accurate to  $\pm 5\%$ .

#### 2.5. Material specific characteristics

Concrete and fire have a complex interaction, due to the composition of concrete and the extreme thermal conditions often found in fire. Concrete is far from being a homogenous material, consisting of a composite of cement gel, aggregate and frequently, steel or other reinforcement. Each of these components has a different reaction to thermal exposures in itself, and the behavior of the composite system in fire is not easy to define or model. Furthermore. The low thermal conductivity of concrete precludes the use of the lumped parameter simplification commonly adopted in thermal analysis of metal structures such as steel, where thermal gradients within the solid are ignored. It is common for design codes to bypass the complexities of temperature distribution by simply specifying a certain depth of concrete cover to the reinforcement bars in a composite structure, providing an insulating effect upon the steel. (Fletcher, Stephen, Jose, Richard, & Asif, 2007)

Most permeable concrete contain a certain amount of liquid water. This begins to vapor if the temperature exceeds 100<sup>0</sup>C in which usually causing a building-up of pressure within concrete. In practice, the boiling temperature range tends to extend from 100<sup>0</sup>C to about 140<sup>0</sup>C due to pressure affects. Beyond the moisture, when temperatures reaches about 400<sup>0</sup>C, calcium hydroxide in cement will begin to dehydrate, generating more water vapor and bringing significant reduction in physical strength of material. (Fletcher, Stephen, Jose, Richard, & Asif, 2007)

Even if concrete can endure high temperature and fires, it does not mean that fire as well as temperatures does not affect the concrete. Characteristics such as color, compressive strength, elasticity, concrete density and surface appearance are affected by high temperature. (Aka, Usman, Ummar, Birnin, & Samuel, 2013)

#### **2.5.1. Weight loss**

300mm x 150 mm cylinders were casted using steel molds and consolidated with vibrating table. They heated in furnace after they were cure after 28 days. The maximum temperature attend was 986<sup>0</sup>C. The specimens were expose to heat for 30minute, 60minute and 90 minute. After heating, the specimens kept in room temperature for one day to attain room temperature. They were test for weight loss. Results shows that the weight loss will increase when the level of temperature is increased. (Alwyn, D.Jasper, Selva, Anand, & Prince, 2018)

#### **2.5.2. Color change**

At temperatures of 300<sup>0</sup>C to 600<sup>0</sup>C, color of concrete changes to pink or red. For temperatures ranging from 600<sup>0</sup>C to 900<sup>0</sup>C, the colure becomes whitish gray and for temperature ranging from 900<sup>0</sup>C to 1000<sup>0</sup>C, the color becomes buff. (Alwyn, D.Jasper, Selva, Anand, & Prince, 2018)

#### **2.5.3. Spalling and Cracking**

Spalling is the forceful or non-forceful breaking off layers or pieces of concrete from the surface of structural element when it exposed to high and rapidly rising temperature as experienced in fires. (Annelies, 2011). It is one of the most complex but poorly understood behavioral characteristics in reaction of concrete, to high temperature or fire is phenomena exposure spalling. This process often assumed to occur only at high temperatures, yet it has been observe in early stages of fire and at temperatures as low as 200<sup>0</sup>C. It has impact decreasing on physical strength of the cross-section of concrete to support the imposed loading. (Fletcher, Stephen, Jose, Richard, & Asif, 2007)

### *2.5.3.1.Types of spalling*

Based on (Annelies, 2011) it is identified that there are four different types of spalling

- Aggregate spalling- crater formed spalling producing a popping sound
- Surface spalling- disc shaped violent flaking, especially in pressure stressed walls, producing a cracking sound.
- Corner spalling- fire seen as violent, by later researchers described as non-violent
- Explosive spalling- very violent spalling with a loud bang

Spalling is exceptional to concrete and can be governing factor in determining the fire resistance of RC structural member. Spalling can occur soon after exposure to rapid heating and can be accompanied by forceful explosions or it may happen during later stage of fire when concrete has become so weak after heating such that, when cracks develop, pieces of concrete fall off from the surface of concrete member. Extensive spalling exposes deeper layers of concrete to fire temperatures, thereby increasing the rate of transmission, of heat to the inner layers of the member, including the reinforcement. (Annelies, 2011)

## **2.6. Mechanical and deformation properties of concrete under exposure of fire**

### **2.6.1. Mechanical properties**

This property determine the extent of strength loss and stiffness deterioration of member. The mechanical properties that determine the fire performance of RC members are compressive and tensile strength, modulus of elasticity and stress-strain response of constituent materials at elevated temperatures.

The strength of concrete at elevated temperatures depends primarily on the type and amount of aggregate and the level of stress. Greater proportions of aggregate result in smaller strength loss at high temperature and the presence of applied load also tends to decrease the strength loss. Strength loss occurs at higher temperatures for concrete with carbonate or lightweight aggregates. (Luke, 2003).An effective method for improving the strength and toughness of concrete mixture is adding fiber into it. (S. Ehsan, Peyman, & M. Reza, 2019)

#### *2.6.1.1.Compressive strength of concrete at an elevated temperature*

It is one of primary interest in fire resistance design. Compressive strength of concrete at ambient temperature depends upon water- cement ratio, aggregate- paste, interface transition zone, curing conditions, aggregated type and size admixture types and types of stress. At

high temperature, compressive strength is highly influenced by room temperature strength, rate of heating and binders in batch mix.

It is known that the compressive strength of concrete will reduced after it is heated. The addition of fibers found to improve the tensile strength and fracture toughness of fire concrete at elevated temperature. However, percent of adding fiber have impact on the strength of the concrete. (Alwyn, D.Jasper, Selva, Anand, & Prince, 2018)

It is investigated that the compressive strength of concrete will increase with the addition of fibers to concrete mix, however further addition of fiber will indicate a gradual decrease in strength aspects this is due to the reduction of workability. (Muhammed & Bekir, 2018)

#### *2.6.1.2.Tensile strength of concrete*

Concrete is weak in tension and tensile strength is only 10% of its compressive strength. Cracking in concrete is generally due to tensile stresses and the structural damage of the member in tension is often generated by progression in micro cracking. Under fire condition tensile strength pf concrete can be even more crucial in cases where fire induced spalling occurs in a concrete structural member. Tensile strength of concrete depends on almost same factors as compressive strength of concrete.

#### *2.6.1.3.Flexural strength*

Glass fiber have an effect on increase in the flexural strength of concrete. These fibers resist the propagation of cracks and tend to reduce the sudden failure of structure of concrete and so they lead to an increase in the load capacity of concrete. (Muhammed & Bekir, 2018)

#### *2.6.1.4.Modulus of elasticity of concrete*

Modulus of elasticity of fire-affected concrete found to decrease with increase in temperature. However, Concrete mixed with glass fiber has higher modulus of elasticity than the concrete without fiber in all heated conditions. It is concluded that addition of fiber enhanced the modulus of elasticity of specimens exposed to elevated temperature, since these fibers have high melting point. (Alwyn, D.Jasper, Selva, Anand, & Prince, 2018)

## **CHAPTER 3-MATERIALS AND METHODS**

### **3.1.General**

A concrete grade of C25/30 is used in this research, since it is commonly used in most construction in our country. The performance of concrete at any temperature depends on the properties of the cement, the aggregates, and the bond between them. The type of aggregates used, mix design, moisture condition and age are factors that govern the behavior of concrete under extreme exposure of fire.

Good materials should be selected in order to have a better strength, which withstand fire and high temperature. In order to decrease the spreading of fire throughout the structures it is advisable to use concrete materials that can extinguish fire and will not spread it through the building in addition to that some fibers can be used in order to strengthen the concrete mix.

Physical tests of material, compressive strength, split tensile test and flexural tests for concrete were carried out in this research. In addition, furnace time vs temperature curve plotted and then compared with ISO standard time vs. temperature curve. The color change, weight loss, occurring of spalling and cracks on concrete after exposed to fire under different magnitude of temperature for different durations was also investigated.

### **3.2.Materials**

#### **3.2.1. Coarse Aggregate**

The type of aggregate has impact on fire resistance of concrete. Most of the time aggregates used in concrete are carbonate: includes limestone and dolomite, siliceous: consisting of silica, granite as well as sand stone and lightweight: aggregates includes shale, slate and clay.

Carbonate containing aggregates, basalts, can withstand fire up to 660<sup>0</sup>C (Ian, Stephen, Jose, Richard, & Asif, 2007) so for this research carbonate containing aggregate with 20mm is used. It can transmit heat at slower rate than normal weight concrete with same thickness and therefore basalts is selected.

#### **3.2.2. Fine Aggregate**

Fine aggregate generally consists of natural sand or crushed stone with most particles passing through 4.75mm sieve. River sand with fineness modulus of 2.93, a specific gravity of 2.47 and water absorption of 2.3% is used as a fine aggregate in this study.

### 3.2.3. Cement

Cement is a binding material, which manufactured through a closely controlled chemical combination of calcium, silicon, aluminum, iron and other ingredients. It holds fine aggregate, coarse aggregate or other ingredients together in a hardened mass. The properties of concrete depends on the quantities and qualities of its ingredients.

For this study Dangote Ordinary Portland cement chosen because OPC is rapid hardening Portland cement, sulphate resisting Portland cement and a low heat cement.

Even if these good materials are selected for the resisting of fire in concrete during the exposure of fire, the paste will start to crack while the aggregates expands which leads concrete losing its strength and stiffness. So in order to minimize the loss of concrete strength and stiffness it is advisable to strengthen the concrete by adding glass fibers to it.

### 3.2.4. Glass fiber

Glass fiber is a material made from extremely fine fibers of glass. Its bulk strength and weight properties are also very favorable when compared to metals, and it can be easily formed using molding processes. They possess high strength-to-weight ratios; have low thermal properties, which it can protect up to 315<sup>0</sup>C temperature. It is the cheapest fiber and most available in Ethiopia.

Table 3.1-Properties of glass fibers (ACICommitte544, 2002)

Property	A-Glass	E-Glass	Cem-FIL AR-Glass	NEG AR-Glass
Specific gravity	2.46	2.54	2.70	2.74
Tensile strength, ksi	450	500	360	355
Modulus of elasticity, ksi	9400	10,400	11,600	11,400
Strain at break, percent	4.7	4.8	3.6	2.5

Based on (ACICommitte544, 2002) the properties of glass fiber is observed as shown in Table 3.1. , as it is shown, the E-glass fiber has better tensile strength than the other glass fiber types. So this E-glass fiber is selected to be used for this research since it is expected to increase the tensile strength of the concrete.

Table 3.2-Compositions of glass fibers (Frederick & T.W., 2001)

Fiber	Ref	SO <sub>2</sub>	B <sub>2</sub> O <sub>3</sub>	AL <sub>2</sub> O <sub>3</sub>	CAO	MgO	ZaO	Na <sub>2</sub> O	K <sub>2</sub> O	Fe <sub>2</sub> O <sub>3</sub>	F <sub>2</sub>
<b>General-purpose fibers</b>											
Boron-containing E-glass	1.2	52 -56	4-6	12-15	21-23	0.4-4	-	0.2-0.5	Trace	0.2-0.4	0.2-0.7
Boron-free E-glass	7.0	59.0	-	12.1	22.6	3.4	-	1.5		0.2	
<b>Special-purpose fibers</b>											
E-glass	1.2	58.2	-	11.6	21.7	2	2.9	2.5	0.2	0.1	Trace
D-glass	1.2	74.5	22	0.3	0.5	-	-	-	<1.3	-	-
S,R,and Te-glass	1.2	60-65.5	-	23- 25	0-9	6-11	-	-	-	0-0.1	-
Silica/quartz	1.2	100	-	-	-	-	-	-	-	-	-

According to (Frederick & T.W., 2001) E-glass fiber has a composition as shown in table 3.1. It is possible to use E-glass fiber in mixing with concrete since these chemical compositions has no impact on any of the ingredients of concrete mix.

Out of different types of glass fibers, the E-glass fiber found to be the best glass fiber type that can resist fire. So for this study chopped E-glass fiber with a length of 6cm and 14µm diameter is used.



Figure 3.1. Glass Fiber

### 3.3.Methodology

#### 3.3.1. Studying physical properties of materials

The physical properties of the materials used for the test were determined prior to mix design. Based on ACI requirement the following investigations obtained and the range of these physical properties compared according to Table 3.2.

Table 3.3-Ranges in physical properties for normal weight aggregates used in concrete (ACICommitte, E-701)

Property	Typical ranges
Fineness modulus of fine aggregate	2.0 to 3.3
Nominal maximum size of coarse aggregate	9.5 to 37.5mm
Water Absorption	0.5 to 4%
Bulk specific gravity (relative density)	2.3 to 2.9
Dry-rodded bulk density of coarse aggregate	1280 to 1920 Kg/m <sup>3</sup>
Surface moisture content C.A	0-2%
Surface moisture content F.A	0-10%

### 3.3.1.1. Silt content

This test is for fine aggregate, first take graduated cylinder with a capacity of greater than 100ml then pour 30ml of sand to cylinder and fill approximately  $\frac{3}{4}$  of the cylinder with water. Then shake the cylinder vigorously for about a minute and leave the cylinder for about 24hr to allow the silt to settle on the layer of the sand. Finally measure the amount of fines forming a separate layer in the top of the washed sand. If more than 3mm of silt skin formed, then the sand is too dirty to form strong concrete, so if it is possible change the sand or if not possible wash the sand in order to remove the dust particles.

In this research, first, the silt content of unwashed fine aggregate was conduct and it is found to have 10.5% of silt content so that the sand is washed. After washing it, the silt content is checked and it has passed the requirement, which is below 6% of silt content.



Figure 3.2. Measuring silt content of sand

### 3.3.1.2. Sieve analysis for fine and coarse aggregate

This test method covers the determination of particle size distribution of fine and coarse aggregates by sieving. The main objective of this test is to know the grade and fines modulus of aggregates.

The first procedure is taking 32 Kg of sample of coarse aggregates and for fine aggregate 2Kg then select a representative sample by quartering the total sample. From the quartered sample, take 8 Kg for coarse aggregate and 500g for fine aggregate. After weighting the empty sieves and recording the data, place quartered sample on top sieve then after, shake the sample for about 8-10 minutes in a sieve shaker. Finally weigh each sieve together with the aggregate retained on and calculate the weight retained on each sieve. Based on ACI Committee E-701 sieve size standard, results of both aggregates compared.





Figure 3.3. Measuring sieve analysis for CA and FA

### 3.3.1.3. Fineness modulus for fine aggregates

Fineness Modulus is used in determining the degree of uniformity of the aggregate gradation. It is an empirical number relating to the fineness of the aggregate. If the higher value of FM, the aggregate is coarser, if the low value of FM, the aggregate is finer. It is calculated as follows:-

$$\text{Fineness Modulus, } FM = \frac{\text{Total of Cumulative Percentage of retained}(\%)}{100}$$

### 3.3.1.4. Moisture content for fine aggregate and coarse aggregate

There are two types of moisture content in aggregates; these are absorbed moisture and surface moisture. Surface moisture is which clings to the surface of the particle whereas absorbed moisture is that which is taken in by the voids in aggregate particles and may not be apparent on the surface. The moisture content for aggregates is needed to be determined in order to control the net water content of a concrete mix and to make adjustments in batch weight of the materials.

The procedure for moisture content is, first weigh a sample of 500g for fine aggregate and 2Kg of coarse aggregate then insert this sample in oven for about 24hrs with a temperature of 100<sup>0</sup>c. After 24hrs remove the samples from oven and leave it for about an hour in order to cool it. Finally weigh the aggregates then calculate the moisture content of aggregates.



Figure 3.4. Measuring moisture content for both FA and CA

### 3.3.1.5. Unit weight for fine aggregate and coarse aggregate

This test method covers the determination of bulk density or unit weight of both coarse and fine aggregates in a compacted or loose condition. Unit weight is the traditional terminology used to describe the property determined by this test method, which is weight per unit volume.

The procedure is, first take a mold, which has a weight of 5.4 Kg and a volume of 9litter. For weight of mold loosely insert aggregate inside mold and measure the weight of mold with aggregate. For mold with aggregate fully compacted, insert the aggregates in the mold

in three layers for each layers compact the aggregate 25 times. Finally weigh the compacted aggregate with mold then calculate loose unit weight and compacted unit weight.



Figure 3.5. Measuring dry unit weight for both FA and CA

### 3.3.1.6. Specific gravity and Water Absorption of coarse aggregate

Specific gravity of aggregate is a characteristic of the material that needs to be determined. It is use in making calculation related to mix design. Specific gravity of most normal weight aggregates will range from 2.3-2.9.

The procedure for measuring of specific gravity and water absorption of coarse aggregate is at first, take about 10Kg of coarse aggregate and in order to remove the dust soak it in a water at room temperature for a period of 24hr. Then remove the sample from the water and roll in a towel. Then take only 4Kg of sample and weigh the sample in the saturated-surface-

dry condition then immediately place the saturated-surface-dry sample in the sample container and determine its weight in water at room temperature. Then after that insert the sample in oven for about 24hr at a temperature of 100<sup>0</sup>C. Finally after 24hrs remove it from oven and after it gets cool measure the aggregate after that calculate the specific gravity, bulk specific gravity, apparent specific gravity and water absorption.



Figure 3.6. Measuring specific gravity for CA

The procedure for measuring of specific gravity and water absorption of fine aggregate is, take at first about 1000g of fine aggregate from the sample by use of a sample splitter or by quartering. In order to remove the dust soak it in a water at room temperature for a period of 24hr. Then remove the sample from the water and then remove it from the water then spread the sample on a flat surface exposed to a gently moving current of warm air, and stir frequently to secure uniform drying. Continue this operation until the test sample approaches a free-flowing condition. Then place a portion of the partially dried fine aggregate loosely into the mold, held firmly on a smooth non-absorbent surface with the large diameter down,

lightly tamp the surface 25 times with the tamper, and lift the mold vertically. If surface moisture is still present, the fine aggregate will retain the molded shape. Continue drying with constant stirring and test at frequent intervals until the tamped fine aggregate slumps slightly up on removal of the mold. This indicates that it has reached a surface-dry condition. Then introduce in to the pycnometer 500g of fine aggregate sample prepared and fill with water to approximately 90% of the capacity. Roll, invert and agitate the pycnometer to eliminate all air bubbles. Then determine the total weight of the pycnometer, sample and water and record. Then remove the fine aggregate from pycnometer, dry it oven for about 24hr at 100°C temperature. Then after 24hr remove it from oven then when it cools, weigh the fine aggregate.



Figure 3.7. Measuring specific gravity for FA

### **3.3.2. Mix Design**

Mix design is used to have economical mix proportions for the available concrete materials that complies with the contract specification in all aspects.

Mix design based on (ACICommittee 211.1-91, 2002) for C25/30 grade of concrete with Ordinary Portland Cement (OPC) of 42.5 grades from Dangote cement factory, fine aggregate with fineness modulus 2.925 and coarse aggregate has 37.5mm maximum size of aggregate and 25 mm of nominal maximum size of aggregate is stated as follows:-

#### *3.3.2.1. Selecting of slump*

Slump test is the simplest test for workability and is most widely used in construction sites as well as in laboratories. In slump test, the distance that a cone full of concrete slumps down is measured when the cone is lifted from around the concrete. Slump can vary from nil on dry mixes to complete collapse on very wet ones.

In this research since the mix is mass concrete, a max of 75mm slump and minimum of 25mm slump is chosen from (ACICommittee 211.1-91, 2002) table A1.5.3.1.

#### *3.3.2.2. Selecting nominal maximum size of aggregate*

According to (ACICommittee, E-701) maximum size is defined as the smallest sieve opening through which the entire amount of aggregate is required to pass, whereas nominal maximum aggregate size is defined as the smallest sieve opening through which the entire amount of aggregate is permitted to pass. In this research, the coarse aggregate has 37.5mm maximum size of aggregate and 25 mm of nominal maximum size of aggregate. For the design of mix, the nominal maximum size of aggregate is used.

#### *3.3.2.3. Estimation of mixing water and air content*

By selecting the concrete to be air-entrained concrete and having a maximum size of aggregate 25 from (ACICommittee 211.1-91, 2002) Table A1.5.3.3, the amount of water added is found to be 175Kg/m<sup>3</sup>.

#### *3.3.2.4. Water to cement ratio*

Water to cement ratio is defined as the ratio of weight of water to the weight of cement this ratio is used in mix design to control the concrete strength. Most of concrete specification requires that mixing water shall be potable, which is clean and free from impurities harmful

to concrete. Strength of concrete depends on water/cement ratio, to obtain higher strength of concrete, the water/ cement ratio should be low.

In this study, it is expected to get C25/30 means the cube compressive strength should be 30mpa so for the cylinder it will be -  $F_{ck}=f_{cu}*0.8 \rightarrow F_{ck}=30*0.8=24$  So for compressive strength of 24Mpa from (ACICommitte211.1-91, 2002) table A1.5.3.4. The w/c ratio by interpolating it is found to be 0.54.

### 3.3.2.5. Computing cement content

The cement content can be found based on the recommended water to cement ratio and the water content. Therefore, for water amount of  $175 \text{Kg/m}^3$  with 0.54 water to cement ratio the products will give the cement content that is -

$$\text{Cement content} = 0.54 * 175 \text{Kg/m}^3 = 324.1 \text{Kg/m}^3$$

### 3.3.2.6. Estimation of coarse aggregate

In this study, finest modulus of coarse aggregate is 3 and nominal maximum aggregate size of 25mm, so from (ACICommitte211.1-91, 2002) table A1.5.3.6 by observing F.M and maximum aggregate size the dry mass of coarse aggregate required for cubic meter of concrete is equals to be 0.66.

Multiplying this value by dry-rodded unit mass of the aggregate  $1677.8 \text{ Kg}$  will give us estimated coarse aggregate value that is  $0.66 * 1677.8 \text{ Kg/m}^3 = 1107.3 \text{Kg/m}^3$

### 3.3.2.7. Estimate of fine aggregate

From (ACICommitte211.1-91, 2002) table A1.5.3.7.1 first estimate of mass of fresh concrete is found to be 2290 because of maximum size of aggregate is 25mm and it is air-entrained concrete.

Table 3.4. Mix Proportion

Water	$175 \text{ Kg/m}^3$
Cement	$324.074 \text{Kg/m}^3$
C.A	$1107.33 \text{ Kg/m}^3$
Total	$1606.407 \text{ Kg/m}^3$

$$F.A=2290-1606.407407= 683.5925\text{Kg/m}^3$$

### 3.3.2.8. Adjustment for moisture, to find water to be added

Moisture content for coarse aggregate is found to be 1.56% and for fine aggregate 1.67%.

#### 1. Adjusted coarse aggregate

$$C.A=1107.3 + 1107.3 * 1.56\% \rightarrow C.A=1124.7 \text{ Kg/m}^3$$

#### 2. Adjusted Fine aggregate

$$F.A=324.1 + 324.1 * 1.67\% \rightarrow F.A=695.1 \text{ Kg/m}^3$$

Absorption of water for coarse aggregate is 2.19% and for fine aggregate, it is 2.33%

#### 3. Water to be added will be

$$\text{For C.A}=1.56\% - 2.19\% = -0.631 \text{ and For F.A}=1.67\% - 2.33\% = -0.655$$

Then finally

$$\text{Water to be added} = 175 - (-0.631 * 1124.7) - (-0.655 * 324.1) = 186.66 \text{ Kg/m}^3$$

Table. 3.5. Final Mix Proportion

Finally	Water Added	186.7Kg/m <sup>3</sup>
	Cement	324.1 Kg/m <sup>3</sup>
	F.A	695.1 Kg/m <sup>3</sup>
	C.A	1124.7Kg/m <sup>3</sup>
	Total	2330.5Kg/m <sup>3</sup>

### 3.3.2.9. Mix proportion by weight for casting cubes

For compressive strength test cubes to be casted has a dimension of with 150mm x 150 mm x 150mm. The mix proportion for 3 cubes per mix with 0.5 wastage is stated as follows. The mix proportion has made with two trials and then the 2<sup>nd</sup> trial is taken as final mix proportion for cubes.

1<sup>st</sup> trial mix of concrete

Table. 3.6. First trial of Mix Proportion for cubes

Volume of Batch for 1pc	0.003375 m <sup>3</sup>
Volume of Batch for 3pc+0.5 wastage	0.0118125 m <sup>3</sup>
Water	2.204Kg
Cement	3.828 Kg
Fine Aggregate	8.210 Kg
Coarse Aggregate	13.285 Kg
Total	27.528Kg

2<sup>nd</sup> trial mix of concrete

Table. 3.7. Second trial of Mix Proportion for cubes

Volume of Batch for 1pc	0.003375 m <sup>3</sup>
Volume of Batch for 3pc+0.5 wastage	0.0118125 m <sup>3</sup>
Water	2.2 Kg
Cement	3.8 Kg
Fine Aggregate	8.5 Kg
Coarse Aggregate	13.5 Kg
Total	28 Kg

This implies the sum of all concrete ingredients for mixing of 3 cubes with a wastage of 0.5 is a total of 28Kg.

Because of the adjustment made on the mix the final mix design will be for all tests

Table. 3.8. Mix Proportion for all test after adjustment

Final Mix Design	Water Added	186.7Kg/m <sup>3</sup>
	Cement	324.1Kg/m <sup>3</sup>
	F.A	719. 6 Kg/m <sup>3</sup>
	C.A	1142.8 Kg/m <sup>3</sup>
	Total	2373.2 Kg/m <sup>3</sup>

3.3.2.10. Mix Proportion by weight for casting of cylinder

For split tensile test in this research a small size of cylinder used in which the mold is a PVC with 100mm diameter and 200mm length. This kind of cylinder is used due to the condition of the furnace carrying capacity is less compared to the number of the cylinder to be casted. Moreover, the amount of the mix ingredients for plenty of cylinders will be uneconomical for larger cylinder size. So a cylinder size with 100mm x 200mm, that is one of the standard for cylinder, is used for split tensile test.

Mixing the concrete there will be a waste due to casting since it is very small in size and it needs special care due to cast, so here it is used 1 and ½ of waste for 3 batch of mix. Moreover, to consume energy and time the mix is taken six similar properties with a wastage of three.

Table. 3.9. Mix Proportion for cylinders

Volume of Batch for 1pc	1.57*10 <sup>-0.3</sup> m <sup>3</sup>
Volume of Batch for 6pc+3wastage	0.0145 m <sup>3</sup>
Water	2.8 Kg
Cement	4.7 Kg
Fine Aggregate	10.8 Kg
Coarse Aggregate	16.5 Kg
Total	34.8 Kg

This implies the sum of all concrete ingredients for mixing of 6 cubes with a wastage of 3 is a total of 34.8 Kg.

3.3.2.11. Trial batch by weight for casting of Beam

For beams with 200mm x 200mm x 600mm, the mix proportion for 1 beam with 2 cubes and 1.5 wastage per mix is stated as follows

Table. 3.10. Mix Proportion for beams

Volume of Batch for 1pc	0.024 m <sup>3</sup>
Volume of Batch for 1pc+2cubes+1.5wastage	0.0358 m <sup>3</sup>
Water	6.7 Kg
Cement	11.6 Kg
Fine Aggregate	25.7 Kg
Coarse Aggregate	41 Kg
Total	85 Kg

This implies the sum of all concrete ingredients for mixing of 1 beam with 2 cubes and a wastage of 1.5 is 85Kg.

**3.3.3. Fiber Content**

In this study, the fiber content is used with respect to the weight of sum of each ingredient of concrete like water, cement, coarse aggregate and fine aggregate.

Based on ASTM glass fiber can be range from 0.1% to 3% of volume fraction or by weight of concrete.

The first trial percentage of fiber is 0%, 0.25%, 0.5%, 0.75%, 1% and 1.25% by weight of total concrete mix.

### 3.3.3.1. Fiber content for compressive strength tests

Table. 3.11. First trial Fiber content for compressive test

Percentage of Glass Fiber	Weight of concrete(Kg)	Weight of fiber for each mix(gm)
0%	28	0
0.25%	28	70
0.50%	28	140
0.75%	28	210
1%	28	280
1.25%	28	350

There was two major problems on the first trial of selecting percentage of glass fiber.

The first one is during mixing the concrete, there was a problem of workability since the fiber fills all the void part and it makes the concrete very dry. So that during mixing there was poor workability and the slump almost for all percentage of fiber became zero.

The second problem was when the compressive strength tested after 7 days of curing, except the percentage of glass fiber of 0.25% by weight; the other percentage of glass fiber starting from 0.5% to 1.25% by weight has decreased the strength of the concrete when it is compared to the control. 0.25% of glass fiber increase some amount from the control, so it is decided to decrease the amount of fiber content in the mix so that the second trial is chosen to be below 0.50% but not reaching 0.50%.

Then second trial is taken as percentage of glass fiber 0%, 0.09%, 0.18%, 0.27% and 0.36 %by weight of concrete.

Table. 3.12. Second trial fiber content for compressive strength test

Percentage of Glass Fiber	Weight of concrete(Kg)	Weight of fiber for each mix(gm)
0%	28	0
0.09%	28	25.2
0.18%	28	50.4
0.27%	28	75.6
0.36%	28	100.8

The second trial shows good results on the compressive strength so in this study the percentage of glass fiber 0%, 0.09%, 0.18%, 0.27% and 0.36% by weight of concrete mix is used for compressive strength test.

### 3.3.3.2. Fiber content for split tensile strength test

For split tensile strength test, the percentage of glass fiber 0%, 0.09%, 0.18%, 0.27% and 0.36% by weight of concrete is used.

Table. 3.13. Fiber content for tensile strength test

Percentage of Glass Fiber	Weight of concrete(Kg)	Weight of fiber for each mix(gm)
0%	34.8	0
0.09%	34.8	31.32
0.18%	34.8	62.64
0.27%	34.8	93.96
0.36%	34.8	125.28

### 3.3.3.3.Fiber content for flexural strength test

For flexural strength test, the percentage of glass fiber 0%, 0.18% and 0.27% by weight of concrete is used.

Table. 3.14. Fiber content for flexural strength test

Percentage of Glass Fiber	Weight of concrete(Kg)	Weight of fiber for each mix(gm)
0%	85	0
0.18%	85	153
0.27%	85	230

## 3.4.Experimental Procedure

### 3.4.1. Slump Test

According to (Abebe, 2002) there are three kinds of slumps

1. True slump- it is where the concrete just subsides, keeping its shape approximately
2. Shear Slump- where the top half of the cone shears off and slips sideways down an inclined plane
3. Collapse Slump- Where concrete completely collapses

The first type is associated with workable mix while the other two are usually associated with harsh mixes that lacks cohesion.

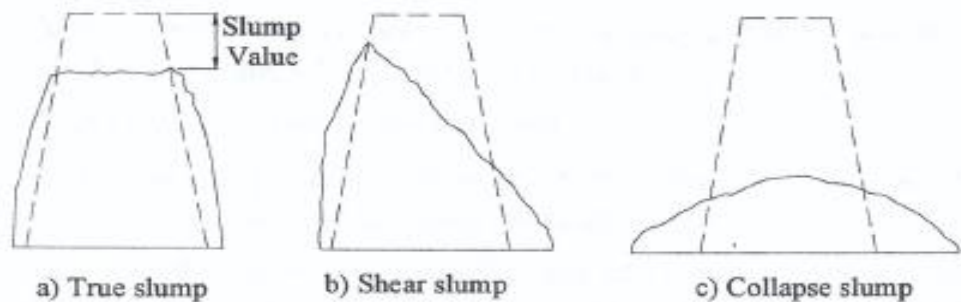


Figure 3.8. Types of slumps (Abebe, 2002)



Figure 3.9. Slump Test

### 3.4.2. Unit weight of fresh concrete

Knowing the unit weight of sample of concrete can help to figure the concrete is lightweight.

To compute unit weight of sample of concrete According to ASTM C138, one must get the weight of a full container of concrete, subtract the weight of the empty container and divide that by the volume of container.

Procedure for measuring of unit weight is first measure the empty container. Then place container on flat, level and solid surface. Then fill the container with 3 layers of concrete an equal volume and road each layer with 25 blows. Then measure full container with fresh concrete. After that using the following equation, the unit weight can be found.

$$\text{Unit Weight} = \frac{(\text{Mass of full container} - \text{mass of empty container})}{\text{Volume of container}}$$



Figure 3.10. Fresh concrete unit weight Test

### 3.4.3. Compressive Strength Test

Glass fiber is mixed with the concrete and casted after the slump test is measured. The mix is casted into 150mm height x 150mm width x 150mm length size cube mold. For this study, in addition to the trials for obtaining optimum glass fiber percentage a total of 129 cubes were casted for testing the compressive strength of concrete mixed with glass fiber and plain concrete after the exposure of fire.

To know the optimum percentage of glass fiber, in these study two trials were taken. The first trial is percentage of glass fiber 0%, 0.25%, 0.50%, 0.75%, 1% and 1.25% by weight of concrete. For each percentage of glass fiber, three specimens were taken for average purpose, which makes it total of 18 specimens for first trial.

Table. 3.15. Number of cubes for trial compressive strength test

Casting Day and Purpose of Cast	Trial Day			
	to know optimum of glass fiber			
Percentage of glass fiber	Magnitude of Temperature	Duration of fire(hr.)	Number of specimens	Remark
0%	Room Temp	No Fire	3	Trial
0.25%			3	Trial
0.50%			3	Trial
0.75%			3	Trial
1.00%			3	Trial
1.25%			3	Trial
Total Number of Cast for trial day			18	

After 7 days curing and testing the compressive strength of these cubes, except percentage of glass fiber 0.25% by weight of concrete, percentage of glass fiber starting from 0.5% to 1.25% by weight of concrete had decrease the strength of the concrete when it is compared to the plain concrete. 0.25% of glass fiber increase some amount from the control, so it is decided to decrease the amount of fiber content in the mix so the second trial is chosen to be below 0.50% but not reaching 0.50%.

Then for second trial, percentage of glass fiber 0%, 0.09%, 0.18%, 0.27% and 0.36% by weight of concrete is taken. For each percentage of glass fiber, three specimens are taken for average purpose that makes it 15 specimens in total. These 15 specimen are used for purpose of finding the optimum percentage of glass fiber and it also used as control specimen for comparing of concretes that are inserted in furnace with different magnitude of temperature for different durations.

Table. 3.16. Number of cubes which are not inserted in furnace

Casting Day and Purpose of Cast	Day 1			
	to know optimum of glass fiber			
Percentage of glass fiber	Magnitude of Temperature( <sup>0</sup> C)	Duration of fire(hr.)	Number of specimens	Remark
0%	Room Temp	No Fire	3	Control
0.09%			3	Control
0.18%			3	Control
0.27%			3	Control
0.36%			3	Control



Figure 3.11. Cubes for compressive strength test

After 28 days curing and testing the compressive strength of these cubes, percentage of glass fiber 0.36% by weight of concrete is illuminated because it decreased the compressive strength of concrete when compared to plain concrete. Therefore, for concrete to be exposed to fire the percentage of glass fiber is 0%, 0.09%, 0.18% and 0.27% by weight of concrete.

Concrete can withstand temperature of 100<sup>0</sup>C, however, when it is above this limit it will lose its strength and other properties will change. So in order to investigate the behavior of the concrete beyond this limit is selected for the first magnitude of temperature. In addition, as stated in previous works concrete will melt and lose its total strength after 600<sup>0</sup>C. Therefore, the lower and upper magnitude of temperature for this research is taken as 150<sup>0</sup>C to 600<sup>0</sup>C. Starting from 150<sup>0</sup>C with interval of 150<sup>0</sup>C, the following four-temperature magnitudes were taken. These are 150<sup>0</sup>C, 300<sup>0</sup>C, 450<sup>0</sup>C and 600<sup>0</sup>C.

According to previous works, the change of concrete properties can be observed after firing concrete for about 2 hours and above. So in order to investigate the properties change of concrete, firing durations are chosen to be 2 hr and 4 hr.

The cast made in a day is for a single temperature with one duration of firing hour. For one-day, 12 specimens are casted. For instance for temperature 150<sup>0</sup>C and firing duration of 2 hr. with percentage of glass fiber 0%, 0.09%, 0.18% and 0.27% by weight of concrete the specimen will be 12 in total, which take in account 3 specimen for each percentage of glass fiber. Likewise, this has done daily for every magnitude of temperature and duration of firing with these four different percentage of glass fiber addition.

Since the cast is made daily, there might be an error on measuring the ingredient so in order to get accurate comparison between the concrete exposed to fire and control one, out of every three specimen one specimen is not inserted in furnace. In addition to 15 controls that has casted on day 1 there would be 32 specimens that act as a control.

All 96 specimens are cured for 28 days, on the 28<sup>th</sup> day of curing from each percentage of glass fiber out of 3 specimen 2 will be inserted in furnace which makes it a total of 8 specimens inserted in furnace per day for compressive strength test. On the 29<sup>th</sup> day, the cubes tested. Table 3.16 explains the detail calculation: - According to this calculation, 96 specimens were casted for testing the compressive strength of concrete mixed with glass fiber and plain concrete after the exposure of fire.

Table. 3.17. Number of cubes for different magnitude of temperature and different durations.

Casting Day and Purpose of Cast	Day 2			
	For firing temperature 150°C and duration of fire 2hr.			
Percentage of glass fiber	Magnitude of Temperature(°C)	Duration of fire(hr.)	No. of specimen	Remark
0%	150°C	2hr.	3	only 2 inserted in furnace
0.09%			3	only 2 inserted in furnace
0.18%			3	only 2 inserted in furnace
0.27%			3	only 2 inserted in furnace
Total Number of Cast for Day 2			12	
Casting Day and Purpose of Cast	Day 3			
	For firing temperature 150°C and duration of fire 4hr.			
Percentage of glass fiber	Magnitude of Temperature(°C)	Duration of fire(hr.)	No. of specimen	Remark
0%	150°C	4hr.	3	only 2 inserted in furnace
0.09%			3	only 2 inserted in furnace
0.18%			3	only 2 inserted in furnace
0.27%			3	only 2 inserted in furnace
Total Number of Cast for Day 3			12	
Casting Day and Purpose of Cast	Day 4			
	For firing temperature 300°C and duration of fire 2hr.			
Percentage of glass fiber	Magnitude of Temperature(°C)	Duration of fire(hr.)	No. of specimen	Remark
0%	300°C	2hr	3	only 2 inserted in furnace
0.09%			3	only 2 inserted in furnace
0.18%			3	only 2 inserted in furnace
0.27%			3	only 2 inserted in furnace
Total Number of Cast for Day 4			12	
Casting Day and Purpose of Cast	Day 5			
	For firing temperature 300°C and duration of fire 4hr.			
Percentage of glass fiber	Magnitude of Temperature(°C)	Duration of fire(hr.)	No. of specimen	Remark
0%	300°C	4hr.	3	only 2 inserted in furnace
0.09%			3	only 2 inserted in furnace
0.18%			3	only 2 inserted in furnace
0.27%			3	only 2 inserted in furnace
Total Number of Cast for Day 5			12	
Casting Day and Purpose of Cast	Day 6			
	For firing temperature 450°C and duration of fire 2hr.			
Percentage of glass fiber	Magnitude of Temperature(°C)	Duration of fire(hr.)	No. of specimen	Remark

0%	450°C	2hr	3	only 2 inserted in furnace
0.09%			3	only 2 inserted in furnace
0.18%			3	only 2 inserted in furnace
0.27%			3	only 2 inserted in furnace
Total Number of Cast for Day 6			12	
Casting Day and Purpose of Cast	Day 7			
	For firing temperature 450°C and duration of fire 4hr.			
Percentage of glass fiber	Magnitude of Temperature(°C)	Duration of fire(hr.)	No. of specimen	Remark
0%	450°C	4hr	3	only 2 inserted in furnace
0.09%			3	only 2 inserted in furnace
0.18%			3	only 2 inserted in furnace
0.27%			3	only 2 inserted in furnace
Total Number of Cast for Day 7			12	
Casting Day and Purpose of Cast	Day 8			
	For firing temperature 600°C and duration of fire 2hr.			
Percentage of glass fiber	Magnitude of Temperature(°C)	Duration of fire(hr.)	No. of specimen	Remark
0%	600°C	2hr	3	only 2 inserted in furnace
0.09%			3	only 2 inserted in furnace
0.18%			3	only 2 inserted in furnace
0.27%			3	only 2 inserted in furnace
Total Number of Cast for Day 8			12	
Casting Day and Purpose of Cast	Day 9			
	For firing temperature 600°C and duration of fire 4hr.			
Percentage of glass fiber	Magnitude of Temperature(°C)	Duration of fire(hr.)	No. of specimen	Remark
0%	600°C	4hr	3	only 2 inserted in furnace
0.09%			3	only 2 inserted in furnace
0.18%			3	only 2 inserted in furnace
0.27%			3	only 2 inserted in furnace
Total Number of Cast for Day 9			12	



Figure 3.12. Casting of Cubes for compressive strength test

#### 3.4.4. Split Tensile Strength Test

Glass fiber is more important in increasing the tensile strength of concrete it is advisable to test the tensile strength of a concrete regarding to fire exposer. 100mm diameter X 200mm length cylinder is casted for split tensile test.

The size of this cylinder is decrease, due to material availability and the furnace size. In general, 63 number of specimen casted, out of this 15 were casted to know the optimum percentage of glass fiber and they all are not going to be inserted in furnace, so they will be as control. The rest 48 casted after the optimum is found and these were to check the performance of concrete with glass fiber under exposure of fire.

Table. 3.18. Number of cylinders for no fire and finding optimum percentage.

Casting Day and Purpose of Cast	Day 1			
	to know optimum of glass fiber			
Percentage of glass fiber	Magnitude of Temperature( <sup>0</sup> C)	Duration of fire(hr.)	No. of specimen	Remark
0%	Room Temp	No Fire	3	Control
0.09%			3	Control
0.18%			3	Control
0.27%			3	Control
0.36%			3	Control
Total Number of Cast for Day 1			15	

After 28 days of curing testing the split tensile strength of these cylinders, percentage of glass fiber 0.09% by weight of concrete is illuminated because it is possible to start from 0.18%. Therefore, for concrete to be exposed to fire the percentage of glass fiber is 0%, 0.18% 0.27% and 0.36% by weight of concrete.

The temperature of fire taken for split tensile is only 150<sup>0</sup>C and 600<sup>0</sup>C. This is because to know the effect of glass fiber on the lower and upper limit of the magnitude of temperature. However, the firing duration is taken for both 2hr and 4hr.

Table. 3.19. Number of cylinders for different firing temperature and firing hour.

Casting Day and Purpose of Cast	Day 2			
	For firing temperature 150 <sup>0</sup> C and duration of fire 2hr.			
Percentage of glass fiber	Magnitude of Temperature( <sup>0</sup> C)	Duration of fire(hr.)	No. of specimen	Remark
0%	150 <sup>0</sup> C	2hr	3	only 2 inserted in furnace
0.18%			3	only 2 inserted in furnace
0.27%			3	only 2 inserted in furnace
0.36%			3	only 2 inserted in furnace
Total Number of Cast for Day 2			12	
Casting Day and Purpose of Cast	Day 3			
	For firing temperature 150 <sup>0</sup> C and duration of fire 4hr.			
Percentage of glass fiber	Magnitude of Temperature( <sup>0</sup> C)	Duration of fire(hr.)	No. of specimen	Remark
0%	150 <sup>0</sup> C	4hr	3	only 2 inserted in furnace
0.18%			3	only 2 inserted in furnace
0.27%			3	only 2 inserted in furnace
0.36%			3	only 2 inserted in furnace
Total Number of Cast for Day 3			12	
Casting Day and Purpose of Cast	Day 4			
	For firing temperature 600 <sup>0</sup> C and duration of fire 2hr.			

Percentage of glass fiber	Magnitude of Temperature( <sup>0</sup> C)	Duration of fire(hr.)	No. of specimen	Remark
0%	600 <sup>0</sup> C	2hr	3	only 2 inserted in furnace
0.18%			3	only 2 inserted in furnace
0.27%			3	only 2 inserted in furnace
0.36%			3	only 2 inserted in furnace
Total Number of Cast for Day 4			12	
Casting Day and Purpose of Cast	Day 5			
	For firing temperature 600 <sup>0</sup> C and duration of fire 4hr.			
Percentage of glass fiber	Magnitude of Temperature( <sup>0</sup> C)	Duration of fire(hr.)	No. of specimen	Remark
0%	600 <sup>0</sup> C	4hr	3	only 2 inserted in furnace
0.18%			3	only 2 inserted in furnace
0.27%			3	only 2 inserted in furnace
0.36%			3	only 2 inserted in furnace
Total Number of Cast for Day 5			12	

Same as the cubes these cylinders casted daily, there might be an error on measuring the ingredient so in order to get accurate comparison between the control and the one exposed to fire, out of every three specimen one specimen is not inserted in furnace. In addition to 15 controls that has casted on day 1 there would be 16 specimens that will act as a control.

All 48 cylinders are cured for 28 days, on the 28<sup>th</sup> day of curing for each day casting from each percentage of glass fiber out of 3 specimen 2 will be inserted in furnace which makes it a total of 8 specimen to be inserted in furnace per day for tensile strength test. On the 29<sup>th</sup> day the cylinders tested.



Figure 3.13. Casting of cylinders for tensile strength test

### 3.4.5. Flexural Strength Test

#### 3.4.5.1. Manufacture of beams

For the flexural, test 6 beams casted with a size of 200mm depth X 200mm width X 600mm length. They have a compression reinforcement of 2 $\phi$ 8 and a tension reinforcement of 2 $\phi$ 10. The steel bars tied together with 8mm stirrups c/c 180mm along the beam. In all the beams, the clear concrete cover to the main flexural reinforcement is set to 25mm.



Figure 3.14. Form work and Bar for beams

#### 3.4.5.2. Testing of beams

The flexural test on concrete is conducted according to ASTM using point load test.

Here the beams are generally grouped as three different cases. The first case was two beams casted for control purpose, which means without glass fiber: second case two beams casted with the optimum percentage of glass fiber that has worked for split tensile test. Final case was two beams casted with the optimum percentage of glass fiber that has worked for compressive strength test. From each cases, one will be inserted in furnace but the other one remain for comparison purpose.

The firing temperature is taken only for maximum magnitude of temperature that is 600<sup>0</sup>c with firing duration of 4hr.

Table. 3.20 Number of beams casted

Percentage of glass fiber	Magnitude of Temperature( <sup>0</sup> C)	Duration of fire(hr.)	No. of specimen	Remark
0%	600 <sup>0</sup> c	4hr.	2	only 1 is inserted in furnace
0.18%			2	only 1 is inserted in furnace
0.27%			2	only 1 is inserted in furnace

There might be an error on measuring the ingredient so for accuracy purpose from each beam concrete mix 2 cubes are casted for measuring compressive strength. For each cubes one of the cube will inserted in furnace and the other will not. In general 12 cubes casted from the beam mixes. Therefore, from this cubes the compressive strength of this concrete mix can be found for beam.



Figure 3.15. Casting of beams for flexural strength test

### 3.5.Measuring of Temperature

Two kinds of instruments used for measuring temperature.

#### 3.5.1. Blast Furnace

Blast Furnace is an arrangement place to test specimen for fire. This place is well equipped with temperatures sensors to measure the controlled temperature and it has a system of controlled fuel flow of burning.

##### 3.5.1.1.Behavior of blast Furnace

The furnace that is used in this research is found in Addis Ababa Lideta Manufacturing College. Inside of the furnace dimension is 500mm width X 500mm height X 900mm length. It can heat to about 2500<sup>0</sup>C. It also has a timer that will tell when the adjusted temperature is reached.



Figure 3.16. Blast furnace

The behavior of the furnace, which used for this research, checked by adjusting the temperature level on 300<sup>0</sup>C, 600<sup>0</sup>C and 900<sup>0</sup>C before all the real samples inserted. During

this checking phase two main things observed on the behavior of furnace regarding to temperature and time.

The first thing observed is that the furnace will increase its temperature and will reach to the adjusted temperature gradually; in every step of increment of temperature it is easy to read the timer then finally the timer will tell at what time will the furnace will reach to that adjusted temperature. So using this the time vs temperature can be plotted.

The second thing that observed is this blast furnace will fluctuate when it is adjusted for higher temperature such as 900<sup>o</sup>c. This fluctuation of temperature will not tell us the exact behavior of concrete mixed with glass fiber exposed to fire. So in order to get some logical result in this study the maximum temperature is limited to be 600<sup>o</sup>c.

#### *3.5.1.2. Specimen inserted in Blast furnace*

Cubes for compressive strength test, cylinders for tensile strength test and beams for flexural strength test, all which are supposed to be inserted in furnace and be heated, are inserted in furnace on the 27<sup>th</sup> day of curing. Same as casting done day by day inserting of specimen also done using day by day.



Figure 3.17. Specimen in blast furnace

For instance, day 2 cubes and cylinders are casted for knowing the behavior of concrete on firing temperature of 150<sup>o</sup>C with duration of 2hr. So all specimens are inserted there and the furnace is adjusted for 150<sup>o</sup>C. Then gradually the furnace will increase its temperature and will reach to the temperature that is needed means 150<sup>o</sup>C. After it reached the required

temperature: the specimen leave there to be exposed to fire for duration of 2hr.. Finally, when it reaches, the furnace will be off. All the exposure of fire on concrete is done using this method one case per day.

During gradual increment of temperature to reach the adjusted temperature, the time vs temperature can be plotted by measuring the temperature with interval of 5<sup>0</sup>c while measuring the corresponding time.



Figure 3.18. Specimen after they are exposed to fire at desired temperature One of mechanism of testing specimens exposed to fire is by air cooling system and because of lack of measuring instrument in our country all specimens after exposed to fire they are left for 24 hour before they are tested. Then all tests are conducted accordingly.

### 3.5.2. Infrared thermometer

Infrared is a thermometer, which is used to measure temperature of burning fire and helps to keep the desired temperature of fire. It used to measure, without contact, surface temperature up to 1600°C.

This instrument used in order to check the furnace temperature while it was one and to check the surface temperature of specimens during and after exposure of fire.

This instrument is used for three different purposes

1. When the temperature of blast furnace is reached to adjusted temperature, during this time surface temperature of concrete is measured by opening the blast furnace for that moment.
2. At the end of firing concrete in furnace the surface temperature is measured
3. During strength testing of specimens the surface temperature is measured.



Figure 3.19. Infrared thermometer

## CHAPTER 4- EXPERIMENTAL TEST RESULTS AND DISCUSSIONS

### 4.1. Results on physical and chemical properties

#### 4.1.1. Silt content

Silt content of unwashed fine aggregate was conducted and it is found to have 10.5% of silt content so that the sand is washed. After washing it, the silt content is checked and it has passed the requirement that is below 6% of silt content.

Table. 4.1 Silt content result for both unwashed and washed sand

Sample	Average Silt Content
Unwashed	10.50%
Washed	4.18%

#### 4.1.2. Sieve analysis for fine and coarse aggregate

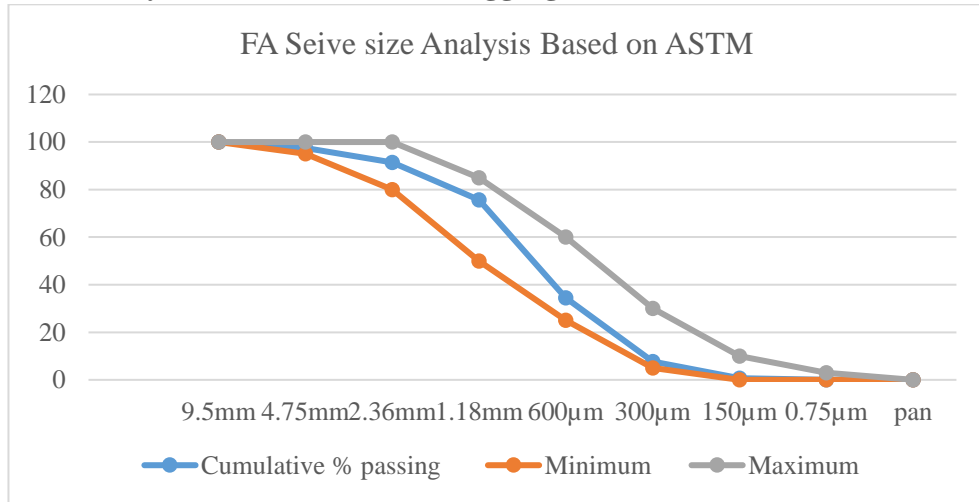


Figure 4.1. Sieve analysis result for fine aggregate

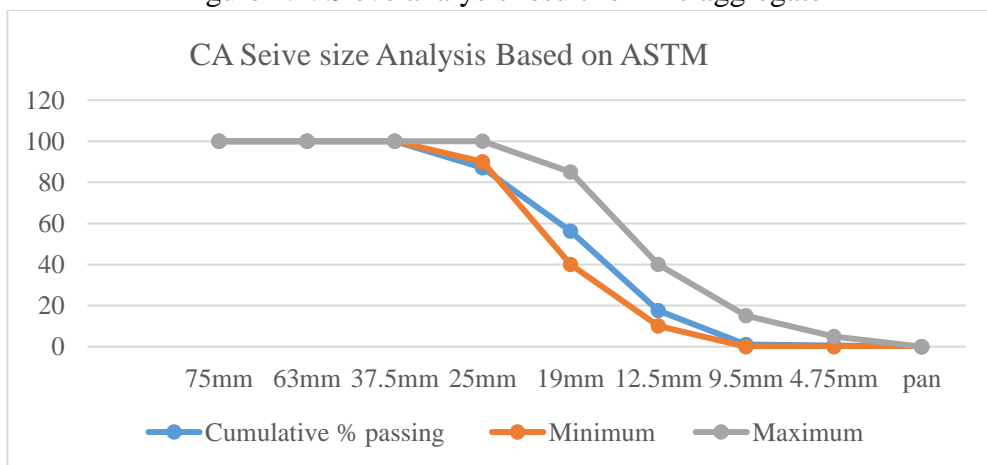


Figure 4.2. Sieve analysis result for Coarse aggregate

Sieve analysis for both fine aggregate and coarse aggregate has a good result in which they both are in the between the upper and lower limit, so that they pass this requirement.

#### **4.1.3. Fineness modulus for fine aggregates**

$$\text{Fineness Modulus, } FM = \frac{\text{Total of Cumulative Percentage of retained}(\%)}{100}$$

$$FM = \frac{292.54}{100}$$

$$FM = 2.925$$

The range for fineness modulus of fine aggregate is 2.0 to 3.3 since this sand is in the range it passes this property.

#### **4.1.4. Moisture content for fine aggregate and coarse aggregate**

Moisture content for fine aggregate is=1.67%

According to ACI the range for moisture content for fine aggregate is 0 – 10%, so the fine aggregate is safe regarding to its range

Moisture content for coarse aggregate is= 1.57%

According to ACI the range for moisture content for coarse aggregate is 0– 2%, so the coarse aggregate is safe regarding to its range

#### **4.1.5. Unit weight for coarse aggregate**

Unit weight for coarse aggregate is found to be 1677.8Kg/m<sup>3</sup>, which is in the range.

According to ACI the range for unit weight dry rodded is 1280 to 1920 Kg/m<sup>3</sup>

#### **4.1.6. Specific gravity and Water Absorption of coarse aggregate and fine aggregate**

Specific gravity for CA= 2.71% and Specific gravity for FA= 2.47%

For both FA and CA specific gravity is range between 2.3 to 2.9 according to (ACICommitte, E-701) so both pass according to this requirement.

Water Absorption for CA=2.198% and Water Absorption for FA=2.33%

According to (ACICommitte, E-701) for both fine aggregate and coarse aggregate the water absorption is range between 0.5 to 4%, so both pass according to this requirement.

## 4.2. Results on fresh concrete tests

### 4.2.1. Slump test

Table. 4.2. Slump test result

% glass fiber	Slump(mm)			Average slump	Percentage Drop%
0%	25	38	30	31	0
0.09%	25	27	25	25.666667	17.204301
0.18%	15	15	13	14.333333	53.763441
0.27%	0	5	5	3.333333	89.247312
0.36%	0	0	0	0	100

Table. 4.3. Slump requirement

Degree of workability	Slump	Compacting Factor
Very Low	0-25mm	0.78
Low	25-50mm	0.85
Medium	50-100mm	0.92
High	100-175mm	0.95
Very High	Collapsed	Not Applicable

According to the requirement, 0% and 0.09% has low degree of workability and the rest has very low degree of workability.

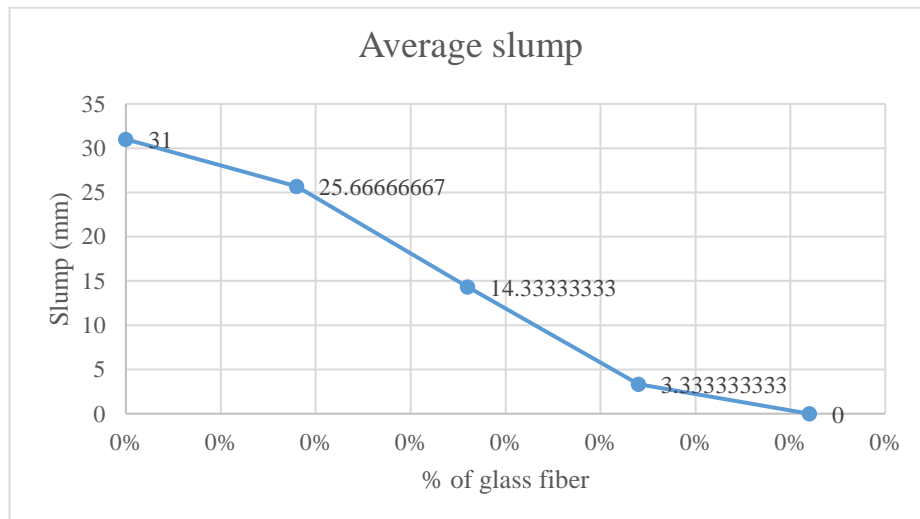


Figure 4.3 Average slump height vs percentage of glass fiber.

The experiment result shows that the slump of fiber reinforced concrete decrease while the percentage of glass fiber dosage rate increase.

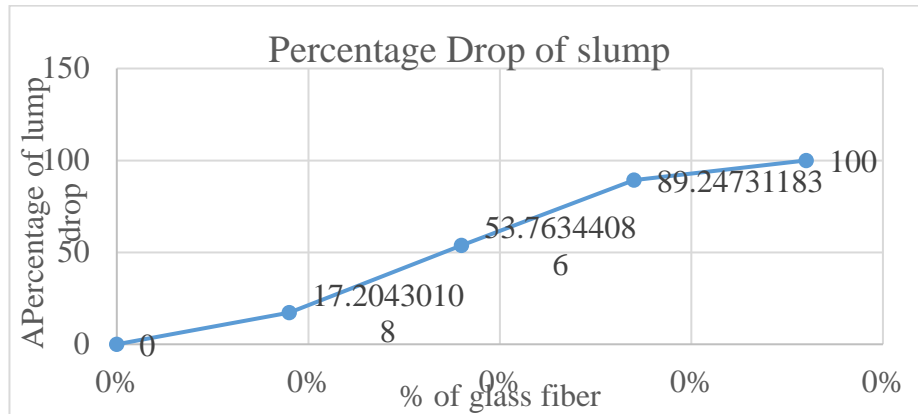


Figure 4.4. Percentage drop of slump vs percentage of glass fiber

#### 4.2.2. Unit Weight of Fresh concrete

The value of fresh concrete for each percentage fiber is as follows:

Table. 4.4. Unit weight of fresh concrete

% glass fiber	Mass of Empty container(Kg)	Volume of Container( $m^3$ )	Mass of full container(Kg)			Average mass of full container(Kg)	Unit Weight ( $Kg/m^3$ )
0%	5.4	0.009	27.5	27.5	27	27.333	2437.04
0.09%	5.4	0.009	27.5	27	27	27.167	2418.52
0.18%	5.4	0.009	27	27	26.5	26.833	2381.48
0.27%	5.4	0.009	26.5	26.5	26.5	26.500	2344.44
0.36%	5.4	0.009	26.5	26	26	26.167	2307.41

According to (ACICommitte211.1-91, 2002) Normal concrete unit weight is 2300 to 2500  $Kg/m^3$  this implies that all the mix that have been done are in the range.

#### 4.3. Compressive strength test results

##### 4.3.1. Compressive strength result of control specimens

For obtaining optimum percentage of glass fiber and for control purpose 15 cubes with percentage of glass fiber 0%, 0.09%, 0.18%, 0.27% and 0.36% by weight of concrete are tested after curing them for 28 days.

Table. 4.5. Average compressive strength for control cubes

Glass Fiber %	Average Compressive Strength (Mpa) of control cubes
0%	30.029
0.09%	33.896
0.18%	38.933
0.27%	34.237
0.36%	29.481

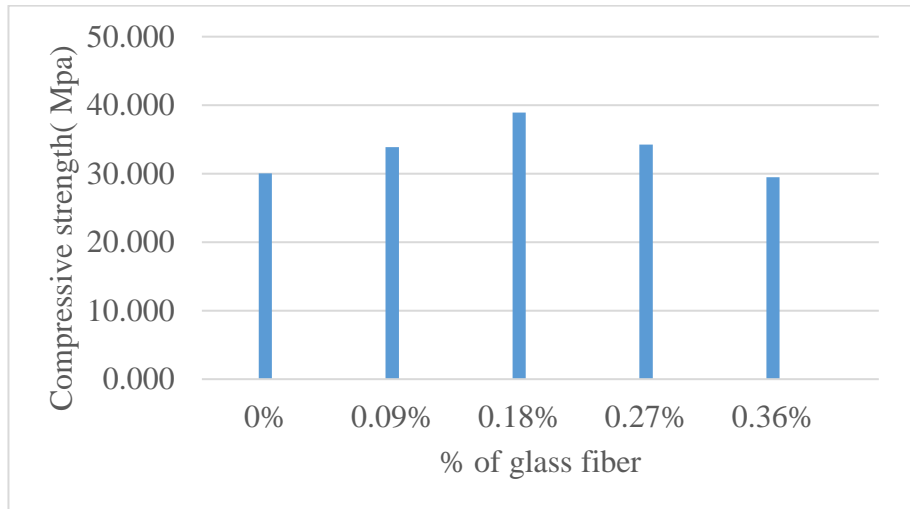


Figure 4.5. Comparison of compressive strength for each percentage of glass fiber addition

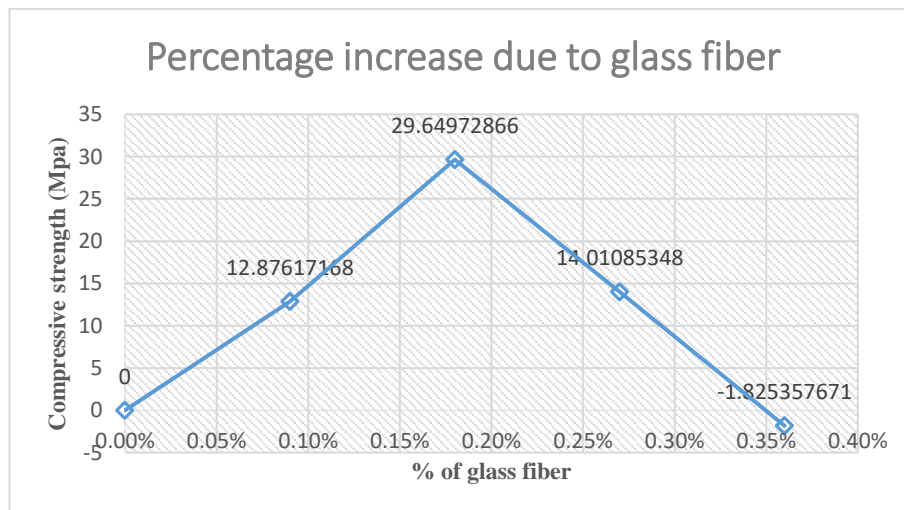


Figure 4.6. Percentage increase due to glass fiber for compressive strength test

It is observed that the compressive strength of GFRC has increased, for percentage of glass fiber 0.09% by 12.8%, for 0.18% by 29.7% and for 0.27% by 14.1% from plain concrete. This implies addition of glass fiber has increased the compressive strength of plain concrete until percentage of glass fiber 0.18% but after this point, the strength was decreasing.

The point where the strength starts to decrease is called optimum point. For this study in compressive strength test, the optimum percentage of glass fiber for concrete grade considered found to be 0.18%. Then after finding this optimum point, the last percentage of glass fiber is illuminated since it totally decreases the compressive strength.

### 4.3.2. Compressive strength result of specimens after exposed to fire

After illuminating the last percentage of glass fiber, the percentage of glass fiber 0%, 0.09%, 0.18% and 0.27% by weight of concrete was taken for the test of compressive strength test of concrete after exposed to fire. All specimen after they were exposed to fire, they cool down for 24 hours just simply using air-cooling system. Then the compressive strength test was conducted. Cubes both plain and GFRC that are not inserted in furnace is compared with cubes both plain and GFRC that are exposed to fire.

#### Case 1- Magnitude of temperature 150°C with fire duration of 2hr

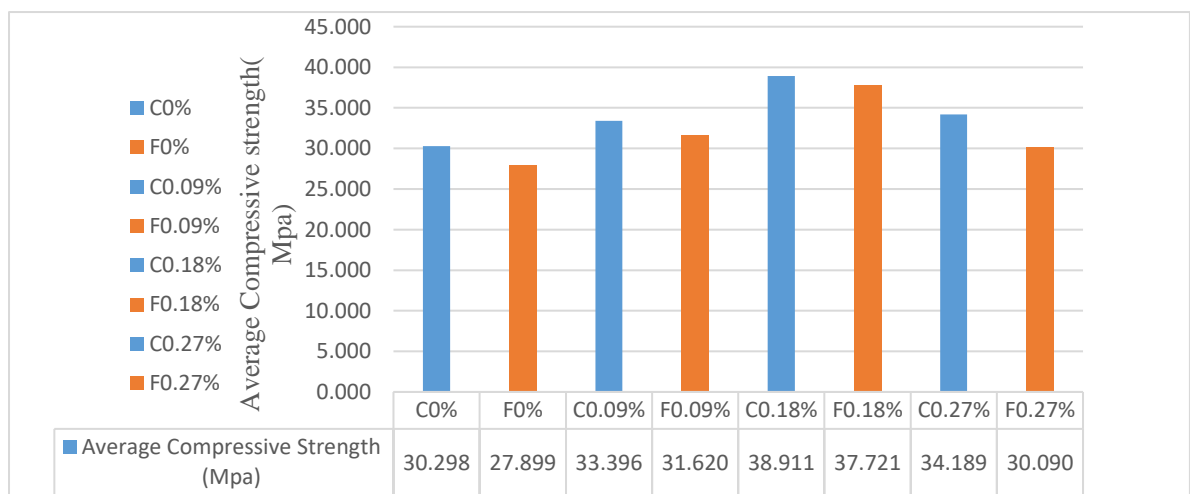


Figure 4.7. Comparison of compressive strength for temperature 150°C with fire duration of 2hr.

Table. 4.6. Results of compressive strength for temperature of 150°C with fire duration of 2hr.

Magnitude of temperature and fire duration	Fiber percentage	Loss of compressive strength (Mpa)		Loss of Compressive strength due to fire (%)	Compressive strength increment due to glass fiber (%)
		Before inserted to furnace	After exposed to fire		
150°C/2hr	0%	30.298	27.899	7.917%	0%
	0.09%	33.396	31.620	5.316%	13.337%
	0.18%	38.911	37.721	3.058%	35.206%
	0.27%	34.189	30.090	11.989%	7.854%

A plain concrete with 30.3 Mpa inserted in furnace, exposed to fire at a temperature of 150°C with fire duration of 2hr., then after it cool down for 24hours, the test was conducted. The compressive strength become 27.9 Mpa. This implies that the decreasing of strength from plain concrete is by 7.9%. Likewise, GFRC cubes with percentage of glass fiber 0.09%, 0.18% and 0.27% after exposed to fire under a temperature of 150°C with fire duration of

2hr., has shown a decrease of compressive strength from 33.4 to 31.6 Mpa, from 38.9 Mpa to 37.7 Mpa and from 34.7Mpa to 30.1Mpa respectively. Which means compressive strength for GFRC with percentage of glass fiber 0.09% and 0.18% has decreased by 5.3% and 3.1% respectively and for percentage of glass fiber 0.27% has decreased by 11.9% relative to the cubes that are not inserted to furnace. This implies that the loss of compressive strength due to fire exposure decreases as the percentage of glass fiber increases, however after the optimum point the loss will be higher than the plain concrete.

It is observed that after exposure of fire under a temperature of 150<sup>0</sup>C with firing duration 2hr, the compressive strength has increased for percentage of glass fiber 0.09% by 13.3%, for 0.18% by 35.2% and for 0.27% by 7.8% from plain concrete, which also exposed to same magnitude of fire. From control concretes, which all were not inserted in furnace, it is observed that the compressive strength has increased, for percentage of glass fiber 0.09% by 12.8%, for 0.18% by 29.7% and for 0.27% by 14.1% from plain concrete.

This result shows for concretes, which has been exposed to fire under a temperature of 150<sup>0</sup>C with firing duration 2hr, adding of glass fiber, has a greater impact on increasing the compressive strength relative to control concretes, which all are not inserted in furnace. However, for concretes exposed to fire when the percentage of glass fiber is beyond the optimum value there will be less increment of compressive strength when compared to the control concrete.

**Case 2- Magnitude of temperature of 150<sup>0</sup>C with fire duration of 4hr**

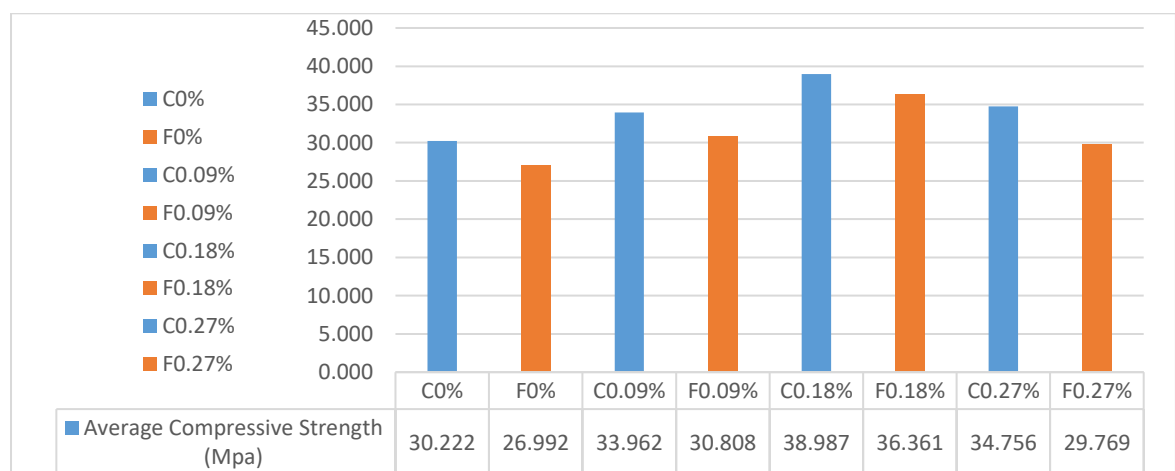


Figure 4.8. Comparison of compressive strength for temperature 150<sup>0</sup>C with fire duration of 4hr

Table. 4.7. Results of compressive strength for temperature of 150°C with fire duration of 4hr

Magnitude of temperature and fire duration	Fiber percentage	Loss of compressive strength (Mpa)		Loss of Compressive strength due to fire (%)	Compressive strength increment due to glass fiber (%)
		Before inserted to furnace	After exposed to fire		
150°C/4hr	0%	30.222	26.992	10.687%	0%
	0.09%	33.962	30.808	9.288%	14.135%
	0.18%	38.987	36.361	6.734%	34.709%
	0.27%	34.756	29.769	14.348%	10.286%

Like case 1 the loss of compressive strength due to fire exposure decreases as the percentage of glass fiber increases, however after the optimum point the loss will be higher than the plain concrete. Comparing the loss of compressive strength due to fire from case 1, this case has higher loss for each percentage of glass fiber; this is due to the increment of duration of fire exposure.

In case 2 adding of glass fiber, has a greater impact on increasing the compressive strength relative to control concretes, which all are not inserted in furnace. However, when comparing it to case 1, 0.09% and 0.27% has good increment on compressive strength but the optimum value slightly decreased the increment of compressive strength.

**Case 3- Magnitude of temperature of 300°C with fire duration of 2hr**

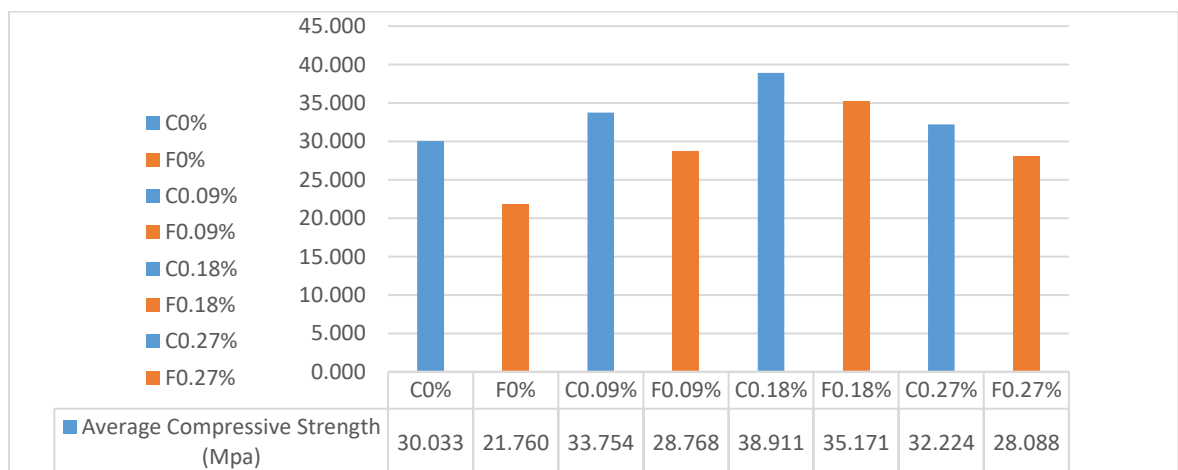


Figure 4.9. Comparison of compressive strength for temperature of 300°C with fire duration of 2hr

Table. 4.8. Results of compressive strength for temperature of 300<sup>0</sup>C with fire duration of 2hr

Magnitude of temperature and fire duration	Fiber percentage	Loss of compressive strength ( Mpa)		Loss of Compressive strength (%)	Compressive strength increment due to glass fiber (%)
		Before inserted to furnace	After exposed to fire		
300 <sup>0</sup> C/2hr	0%	30.033	21.760	27.547%	0%
	0.09%	33.754	28.768	14.771%	32.204%
	0.18%	38.911	35.171	9.612%	61.632%
	0.27%	32.224	28.088	12.837%	29.079%

The compressive strength loss due to fire exposure decreases as the percentage of glass fiber increases but for 0.27% it will increase. Comparing the loss of compressive strength due to fire from case 1 and case 2, this case has higher loss for each percentage of glass fiber this is due to increment of the magnitude of temperature. The new thing observed from previous cases is during 0.27% the loss is less than that of plain concrete, which is a good progress from the previous cases.

In case 3 adding of glass fiber, has a greater impact on increasing the compressive strength relative to control concretes, which all are not inserted in furnace. Moreover, when comparing it to case 1 and case 2, on all percentage of glass fiber it has a marvelous increment on compressive strength.

**Case 4- Magnitude of temperature of 300<sup>0</sup>C with fire duration of 4hr**

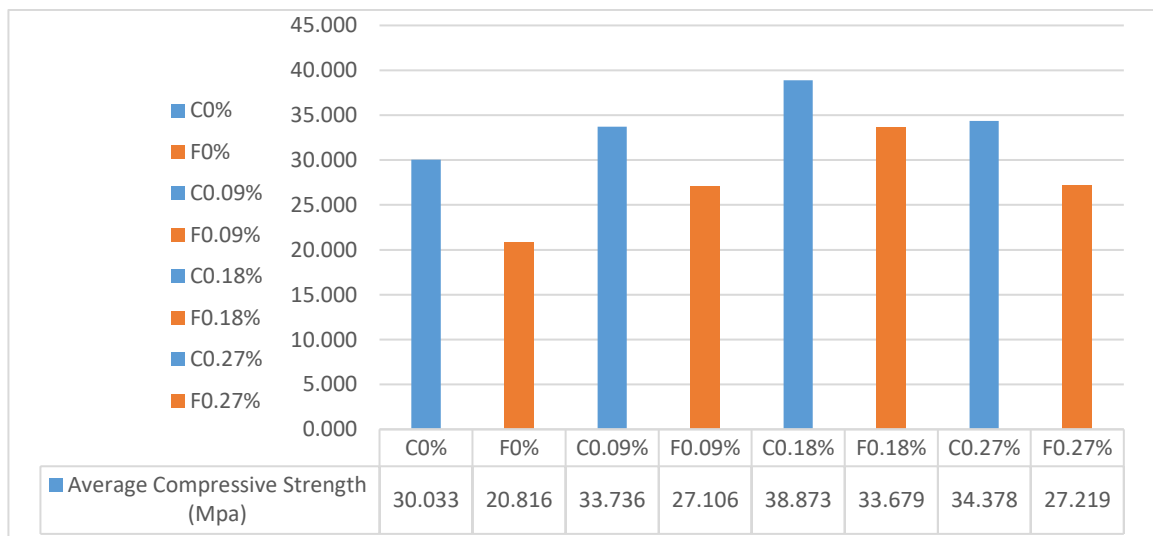


Figure 4.10. Comparison of compressive strength for temperature of 300<sup>0</sup>C with fire duration of 4hr

Table. 4.9. Results of compressive strength for temperature of 300<sup>0</sup>C with fire duration of 4hr

Magnitude of temperature and fire duration	Fiber percentage	Loss of compressive strength ( Mpa)		Loss of Compressive strength (%)	Compressive strength increment due to glass fiber (%)
		Before inserted to furnace	After exposed to fire		
300 <sup>0</sup> C/4hr	0%	30.033	20.816	30.692%	0%
	0.09%	33.736	27.106	19.653%	30.217%
	0.18%	38.873	33.679	13.362%	61.797%
	0.27%	34.378	27.219	20.824%	30.762%

The compressive strength loss due to fire exposure decreases as the percentage of glass fiber increases but for 0.27% it will increase. Comparing the loss of compressive strength due to fire from case 3, this case has higher loss for each percentage of glass fiber this is due to increment of the fire duration. In addition, like case 3, on 0.27% the loss is less than that of plain concrete, which is a good progress from the previous cases.

In case 4 adding of glass fiber, has a greater impact on increasing the compressive strength relative to control concretes, which all are not inserted in furnace. When comparing it to case3, 0.27% and the optimum value has good increment on compressive strength however, 0.09% slightly decreased the increment of compressive strength.

**Case 5- Magnitude of temperature of 450<sup>0</sup>C with fire duration of 2hr**

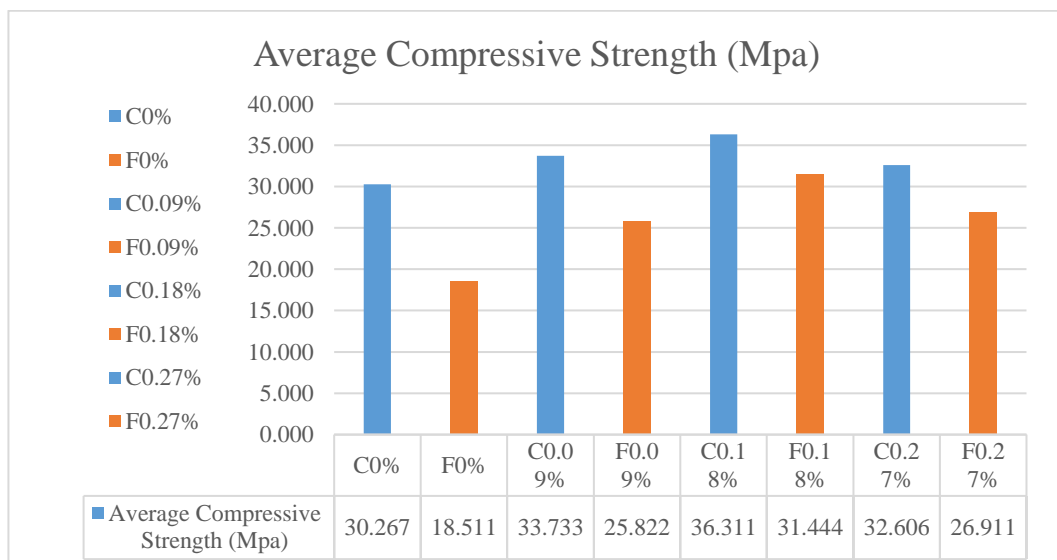


Figure 4.11. Comparison of compressive strength for temperature of 450<sup>0</sup>C with fire duration of 2hr

Table. 4.10. Results of compressive strength for temperature of 450°C with fire duration of 2hr

Magnitude of temperature and fire duration	Fiber percentage	Loss of compressive strength ( Mpa)		Loss of Compressive strength (%)	Compressive strength increment due to glass fiber (%)
		Before inserted to furnace	After exposed to fire		
450°C/2hr	0%	30.267	18.511	38.840%	0%
	0.09%	33.733	25.822	23.452%	39.496%
	0.18%	36.311	31.444	13.403%	69.868%
	0.27%	32.606	26.911	17.467%	45.378%

Here loss of compressive strength due to fire exposure decreases as the percentage of glass fiber increases. Comparing the loss of compressive strength due to fire from case 3 and case 4, this case has higher loss for each percentage of glass fiber this is due to increment of the magnitude of temperature. Here during 0.27% the loss is much lesser than that of plain concrete, which is a good progress from the previous cases.

In case 5 adding of glass fiber, has a greater impact on increasing the compressive strength relative to control concretes, which all are not inserted in furnace. In addition, when comparing it to pervious cases, on all percentage of glass fiber it has a marvelous increment on compressive strength.

**Case 6- Magnitude of temperature of 450°C with fire duration of 4hr**

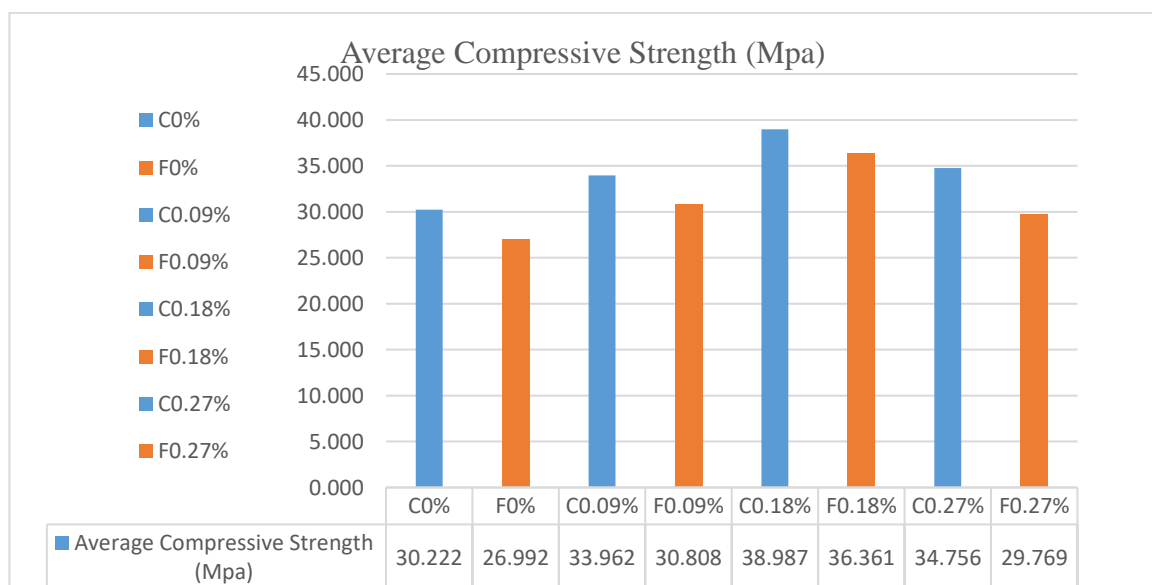


Figure 4.12. Comparison of compressive strength for temperature of 450°C with fire duration of 4hr

Table. 4.11. Results of compressive strength for temperature of 450<sup>0</sup>C with fire duration of 4hr

Magnitude of temperature and fire duration	Fiber percentage	Loss of compressive strength ( Mpa)		Loss of Compressive strength (%)	Compressive strength increment due to glass fiber (%)
		Before inserted to furnace	After exposed to fire		
450 <sup>0</sup> C/4hr	0%	30.00	17.778	40.741%	0%
	0.09%	33.333	24.822	25.533%	39.625%
	0.18%	36.222	29.400	18.834%	65.375%
	0.27%	32.104	25.778	19.706%	45%

The compressive strength loss due to fire exposure decreases as the percentage of glass fiber increases but for 0.27% it will increase from 0.18%. Comparing the loss of compressive strength due to fire from case 5, this case has higher loss for each percentage of glass fiber this is due to increment of the fire duration. In addition, like case 5, on 0.27% the loss is less than that of plain concrete, which is a good progress from the previous cases.

In case 6 adding of glass fiber, has a greater impact on increasing the compressive strength relative to control concretes, which all are not inserted in furnace. When comparing it to case5, 0.09% has good increment on compressive strength however, 0.18% and 0.27% slightly decreased the increment of compressive strength from the plain concrete.

**Case 7- Magnitude of temperature of 600<sup>0</sup>C with fire duration of 2hr**

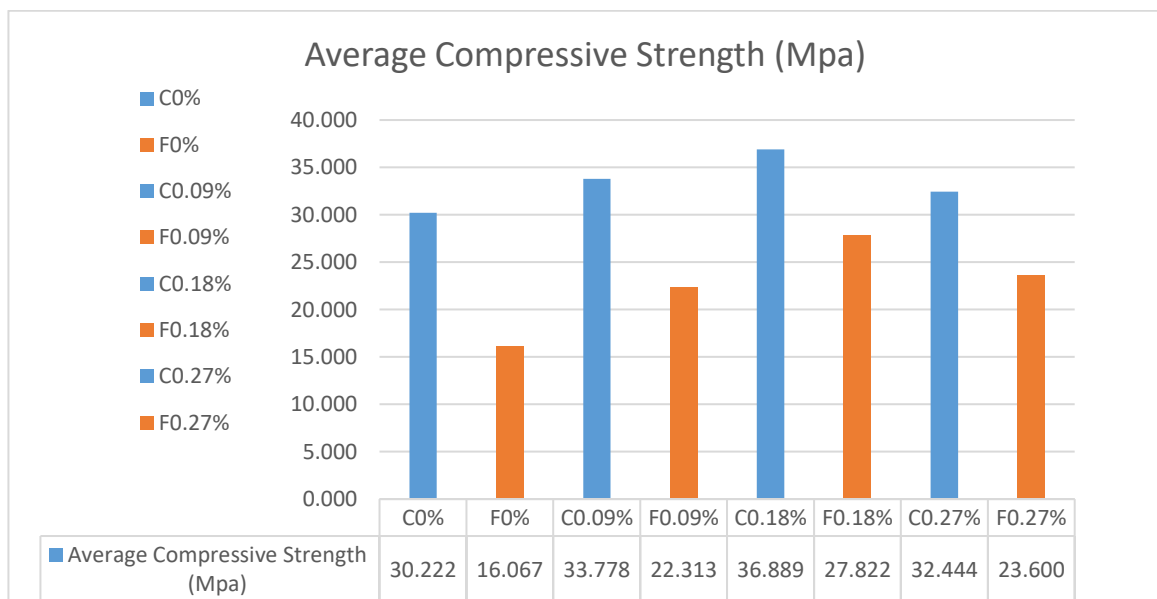


Figure 4.13. Comparison of compressive strength for temperature of 600<sup>0</sup>C with fire duration of 2hr

Table. 4.12. Results of compressive strength for temperature of 600°C with fire duration of 2hr

Magnitude of temperature and fire duration	Fiber percentage	Loss of compressive strength ( Mpa)		Loss of Compressive strength (%)	Compressive strength increment due to glass fiber (%)
		Before inserted to furnace	After exposed to fire		
600°C/2hr	0%	30.222	16.067	46.838%	0%
	0.09%	33.778	22.313	33.942%	38.877%
	0.18%	36.889	27.822	24.578%	73.167%
	0.27%	32.444	23.600	27.260%	46.888%

Here loss of compressive strength due to fire exposure decreases as the percentage of glass fiber increases. Comparing the loss of compressive strength due to fire from all previous cases, this case has higher loss for each percentage of glass fiber this is due to increment of the magnitude of temperature. Here during 0.27% the loss is much lesser than that of plain concrete, which is a good progress from the previous cases.

In case 7 adding of glass fiber, has a greater impact on increasing the compressive strength relative to control concretes, which all are not inserted in furnace. When comparing it to pervious cases, on all percentage of glass fiber it has a marvelous increment on compressive strength.

**Case 8- Magnitude of temperature of 600°C with fire duration of 4hr**

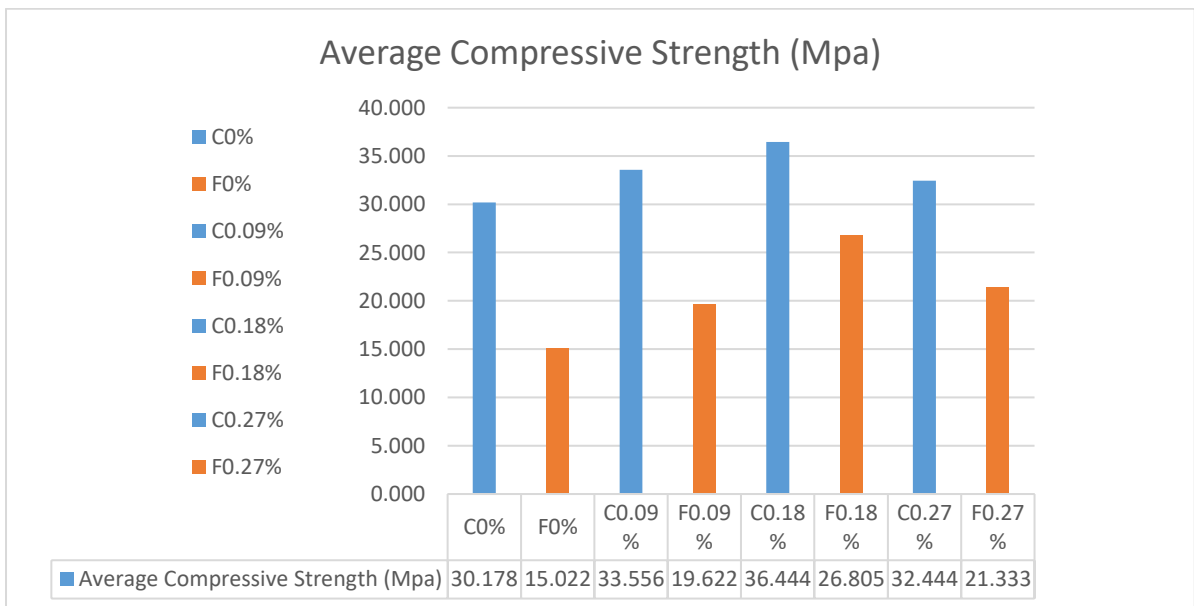


Figure 4.14. Comparison of compressive strength for temperature of 600°C with fire duration of 4hr

Table. 4.13. Results of compressive strength for temperature of 600<sup>0</sup>C with fire duration of 4hr

Magnitude of temperature and fire duration	Fiber percentage	Loss of compressive strength ( Mpa)		Loss of Compressive strength (%)	Compressive strength increment due to glass fiber (%)
		Before inserted to furnace	After exposed to fire		
600 <sup>0</sup> C/4hr	0%	30.178	15.022	50.221%	0%
	0.09%	33.556	19.622	41.523%	30.621%
	0.18%	36.444	26.805	26.449%	78.437%
	0.27%	32.444	21.333	34.247%	42.011%

Comparing the loss of compressive strength due to fire from all cases, higher loss of compressive strength is observed in this case. Almost 50% of the compressive strength has been loss due exposure of fire under temperature of 600<sup>0</sup>C with fire duration of 4hr on plain concrete. However, for GFRC the loss of compressive strength somehow decreased relative to the plain concrete, especially for percentage of glass fiber 0.18%, the loss is by 26.4%, that is almost half of the loss of compressive strength on plain concrete.

In case 8 adding of glass fiber, has a greater impact on increasing the compressive strength relative to control concretes, which all are not inserted in furnace. When comparing it to case7, 0.18% has good increment on compressive strength however, 0.09% and 0.27% slightly decreased the increment of compressive strength from the plain concrete.

#### 4.3.3. General comparison of compressive strength between plain and GFRC

For all cases, it is observed that when magnitude of temperature increased there was a major loss of compressive strength on control as well as GFRC cubes. However, GFRC cubes has a good performance on resisting fire exposure especially the optimum value 0.18% has shown a good result.

Although there is a loss of compressive strength on concrete due to fire as magnitude of temperature increases, E-glass fiber can decreases the major loss of compressive strength. Especially for higher magnitude of temperature, this E-glass fiber has shown a marvelous result on increasing of compressive strength from plain concrete.

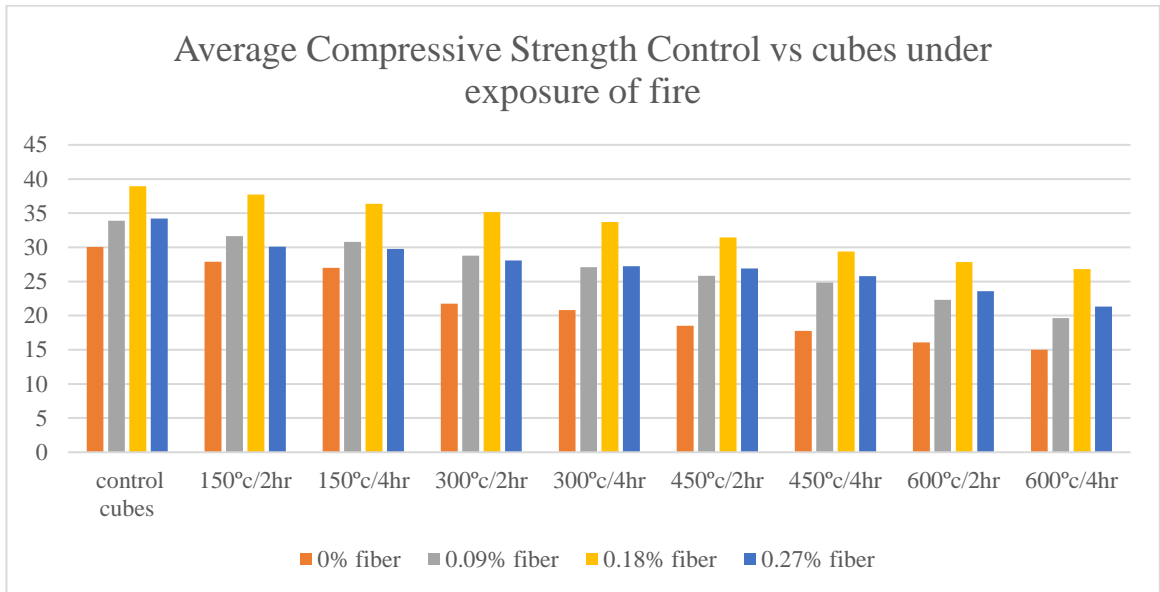


Figure 4.15. Comparison of compressive strength for all cases

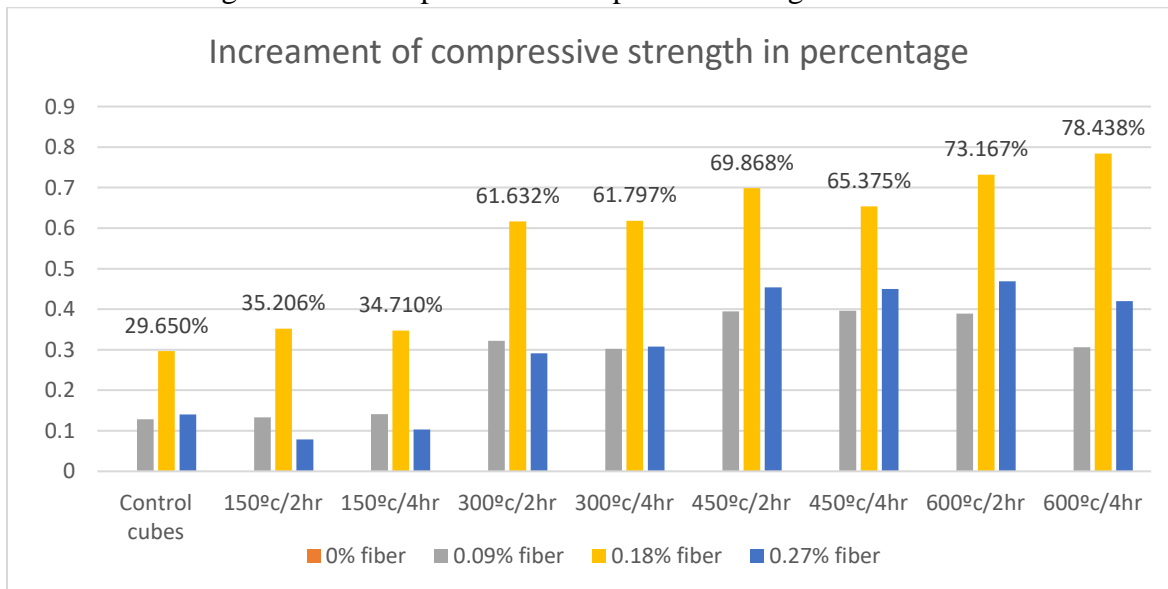


Figure 4.16. Percentage increase of compressive strength due to addition of glass fiber

Despite the decreasing of compressive strength from the other two percentage of glass fiber, percentage of glass fiber 0.27% by weight has shown a good result during the magnitude of temperature increased. As it can be seen on lower magnitude of temperature, this percentage of glass fiber has negative impact on increasing compressive strength relative to plain concrete. However, for higher magnitude of temperature it has shown a good result in increasing the compressive strength from the plain concrete. This implies that adding more fiber in concrete can withstand fire exposure especially in higher level of temperature.

#### 4.4. Tensile strength test

##### 4.4.1. Tensile strength result of control specimens

For obtaining optimum percentage of glass fiber and for control purpose 15 cylinders with percentage of glass fiber 0%, 0.09%, 0.18%, 0.27% and 0.36% by weight of concrete were tested after curing them for 28 days.

Table. 4.14. Average tensile strength for control cylinders

Glass Fiber %	Average Tensile Strength (Mpa) of Cylinders
0%	2.939
0.09%	3.382
0.18%	3.625
0.27%	3.865
0.36%	3.291

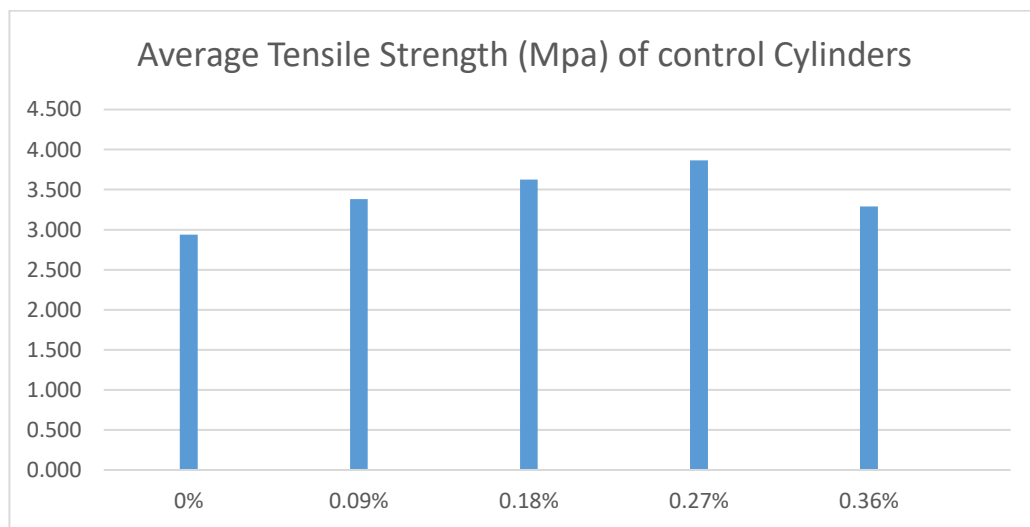


Figure 4.17. Comparison of tensile strength for each percentage of glass fiber addition. It is observed that the tensile strength has increased, for percentage of glass fiber 0.09% by 15.1%, for 0.18% by 23.3%, for 0.27% by 31.5% and for 0.36% by 11.9% from plain concrete. This implies addition of glass fiber has increased the tensile strength of plain concrete until percentage of glass fiber 0.27% but after this point, there was a decreasing of strength.

The point where the strength starts to decrease is called optimum point. For this study in tensile strength test, the optimum percentage of glass fiber for concrete grade considered found to be 0.27%.

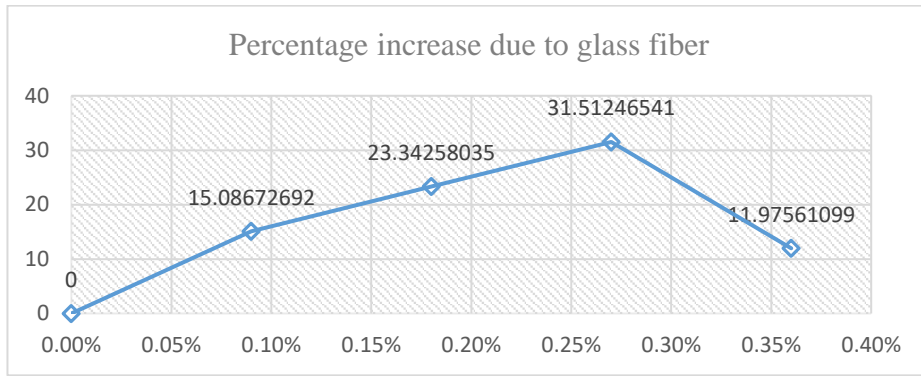


Figure 4.18. Percentage increase due to glass fiber for tensile strength test  
 For compressive strength test, the optimum that is 0.18% has increase the strength at about 29.9% but here the optimum which is 0.27% has increase the tensile strength with 31.5%. Here unlike compressive strength result the optimum has changed for tensile strength. In addition adding of glass fiber has a greater impact on tensile strength than compressive strength.

#### 4.4.2. Tensile strength result of specimens after exposed to fire

After illuminating the first glass fiber percentage, percentage of glass fiber 0%, 0.18%, 0.27% and 0.36% is taken for the test of tensile strength of concrete after exposed to fire. All specimen after they were exposed to fire, they cool down for 24 hours just simply using air-cooling system. Then the tensile strength test was conducted. Cylinders both plain and GFRC that are not inserted in furnace is compared with cylinders both plain and GFRC that are exposed to fire.

##### Case 1- Magnitude of temperature of 150°C with fire duration of 2hr

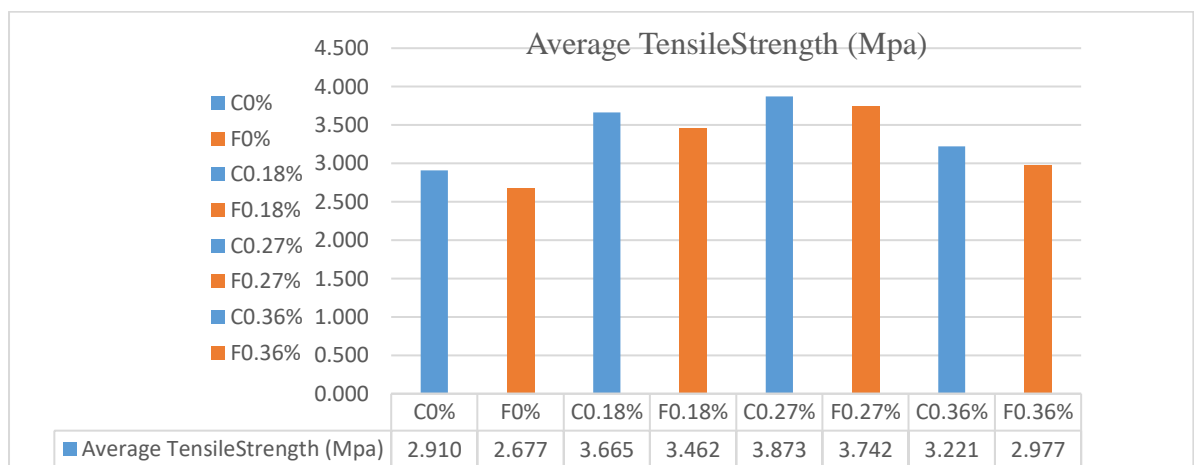


Figure 4.19. Comparison of tensile strength for temperature of 150°C with fire duration of 2hr

Table. 4.15. Results of tensile strength for temperature of 150<sup>0</sup>C with fire duration of 2hr

Magnitude of temperature and fire duration	Fiber percentage	Loss of tensile strength ( Mpa)		Loss of tensile strength (%)	Tensile strength increment due to glass fiber (%)
		Before inserted to furnace	After exposed to fire		
150 <sup>0</sup> C/2hr	0%	2.910	2.677	8.017%	0%
	0.18%	3.665	3.462	5.539%	29.348%
	0.27%	3.873	3.742	3.381%	39.811%
	0.36%	3.221	2.977	7.596%	11.204%

A plain concrete with 2.9Mpa inserted in furnace, exposed to fire at a temperature of 150<sup>0</sup>C with fire duration of 2hr., after cooling it for 24 hour, and test it. The tensile strength become 2.7 Mpa. This implies that the decreasing of strength from plain concrete is by 8%. Likewise, GFRC cylinders with percentage of glass fiber 0.18%, 0.27% and 0.36% after exposed to fire under a temperature of 150<sup>0</sup>C with fire duration of 2hr., has shown a decrease of tensile strength from 3.6 to 3.4 Mpa, from 3.8 Mpa to 3.7 Mpa and from 3.2 Mpa to 2.9 Mpa respectively. Which means tensile strength for GFRC with percentage of glass fiber 0.18% and 0.27% has decreased by 5.5% and 3.3% respectively and for percentage of glass fiber 0.36% has decreased by 7.6% relative to the cylinders that are not inserted to furnace. This implies that the loss of tensile strength due to fire exposure decreases as the percentage of glass fiber increases.

It is observed that after exposure of fire under a temperature of 150<sup>0</sup>C with fire duration of 2hr, the tensile strength has increased for percentage of glass fiber 0.18% by 29.3%, for 0.27% by 39.8% and for 0.36% by 11.2% from plain concrete, which also exposed to same magnitude of fire. From control concretes, which all were not inserted in furnace, it is observed that the tensile strength has increased, for percentage of glass fiber for 0.18% by 23.3%, for 0.27% by 31.5% and for 0.36% by 11.9% from plain concrete.

This result shows for concretes, which has been exposed to fire under a temperature of 150<sup>0</sup>C with fire duration of 2hr, adding of glass fiber, has a greater impact on increasing the tensile strength relative to control concretes, which all are not inserted in furnace. However, for concretes exposed to fire when the percentage of glass fiber is beyond the optimum value there will be less increment of tensile strength when compared to the control concrete.

**Case 2- Magnitude of temperature of 150<sup>0</sup>C with fire duration of 4hr**

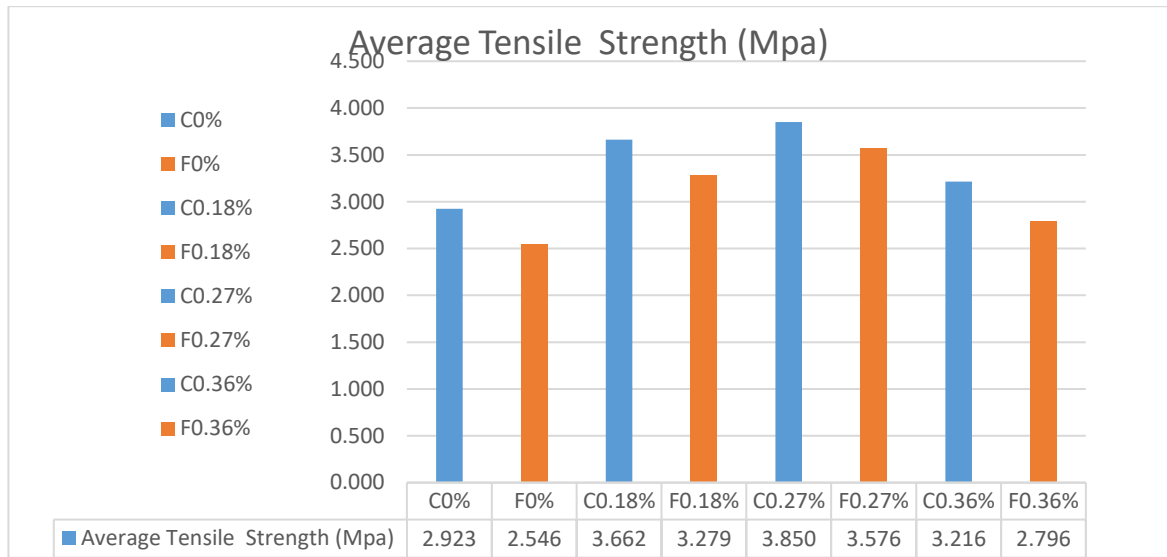


Figure 4.20. Comparison of tensile strength for temperature of 150<sup>0</sup>C with fire duration of 4hr

Table. 4.16. Results of tensile strength for temperature of 150<sup>0</sup>C with fire duration of 4hr

Magnitude of temperature and fire duration	Fiber percentage	Loss of tensile strength ( Mpa)		Loss of tensile strength (%)	Tensile strength increment due to glass fiber (%)
		Before inserted to furnace	After exposed to fire		
150 <sup>0</sup> C/4hr	0%	2.923	2.546	12.874%	0%
	0.18%	3.662	3.279	10.464%	28.755%
	0.27%	3.850	3.576	7.101%	40.446%
	0.36%	3.216	2.796	13.048%	9.804%

Like case 1 the loss of tensile strength due to fire exposure decreases as the percentage of glass fiber increases, however, after the optimum point the loss will be higher than the plain concrete. Comparing the loss of tensile strength due to fire from case 1, this case has higher loss for each percentage of glass fiber; this is due to the increment of duration of fire.

In case 2 adding of glass fiber, has a greater impact on increasing the tensile strength relative to control concretes, which all are not inserted in furnace. However, when comparing it to case 1, all percentage of glass fiber has shown a good result in increasing the tensile strength from the plain concrete. Especially the optimum values has shown a greater increment.

**Case 3- Magnitude of temperature of 600<sup>0</sup>C with fire duration of 2hr**

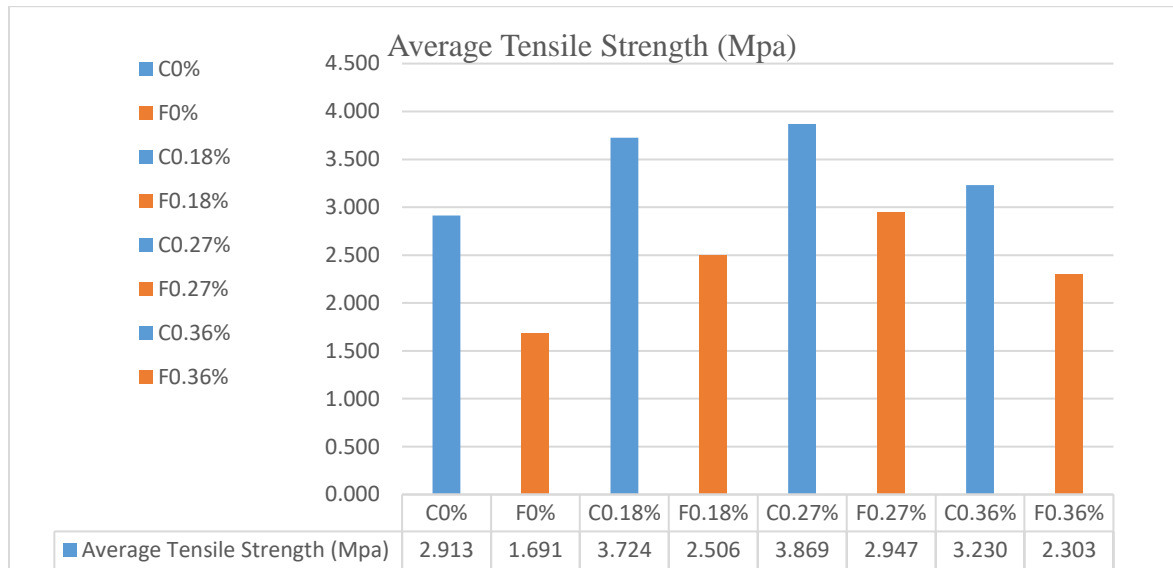


Figure 4.21. Comparison of tensile strength for temperature of 600<sup>0</sup>C with fire duration of 2hr

Table. 4.17. Results of tensile strength for temperature of 600<sup>0</sup>C with fire duration of 2hr

Magnitude of temperature and fire duration	Fiber percentage	Loss of tensile strength ( Mpa)		Loss of tensile strength (%)	Tensile strength increment due to glass fiber (%)
		Before inserted to furnace	After exposed to fire		
600 <sup>0</sup> C/2hr	0%	2.913	1.691	41.953%	0%
	0.18%	3.724	2.506	32.702%	48.206%
	0.27%	3.869	2.947	23.828%	74.298%
	0.36%	3.230	2.303	28.723%	36.162%

Here loss of tensile strength due to fire exposure decreases as the percentage of glass fiber increases. Comparing the loss of tensile strength due to fire from all previous cases, this case has higher loss for each percentage of glass fiber this is due to increment of the magnitude of temperature. Here during 0.36% the loss is much lesser than that of plain concrete, which is a good progress from the previous cases.

In case 3 adding of glass fiber, has a greater impact on increasing the tensile strength relative to control concretes, which all are not inserted in furnace. However, when comparing it to pervious cases, on all percentage of glass fiber it has a marvelous increment on tensile strength.

**Case 4- Magnitude of temperature of 600<sup>0</sup>C with fire duration of 4hr**

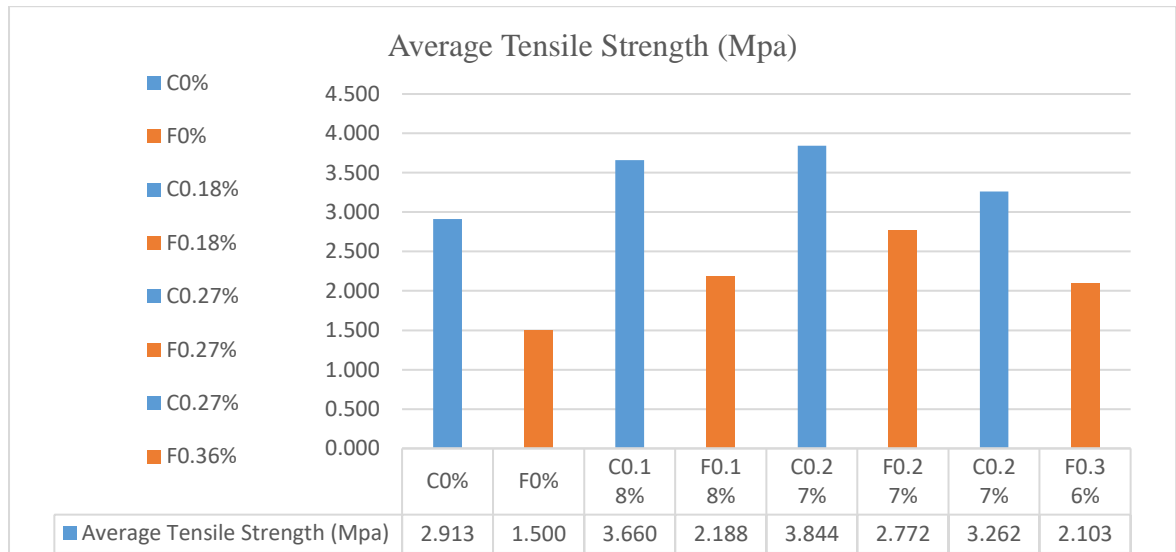


Figure 4.22. Comparison of tensile strength for temperature of 600<sup>0</sup>C with fire duration of 4hr

Table. 4.18. Results of tensile strength for temperature of 600<sup>0</sup>C with fire duration of 4hr

Magnitude of temperature and fire duration	Fiber percentage	Loss of tensile strength ( Mpa)		Loss of tensile strength (%)	Tensile strength increment due to glass fiber (%)
		Before inserted to furnace	After exposed to fire		
600 <sup>0</sup> C/4hr	0%	2.913	1.50	48.512%	0%
	0.18%	3.660	2.188	40.231%	45.855%
	0.27%	3.844	2.772	27.886%	84.825%
	0.36%	3.262	2.103	35.531%	40.204%

Comparing the loss of tensile strength due to fire from all cases, higher loss of compressive strength is observed in this case. Almost 48% of the tensile strength has been loss due exposure of fire under temperature of 600<sup>0</sup>C with fire duration of 4hr on plain concrete. However, for GFRC the loss of tensile strength somehow decreased relative to the plain concrete, especially for percentage of glass fiber 0.27%, the loss is by 27.8%, that is above half of the plain concrete loss of tensile strength.

In case 4 adding of glass fiber, has a greater impact on increasing the tensile strength relative to control concretes, which all are not inserted in furnace. When comparing it to case3, all percentage of glass fiber has good increment on tensile strength from the plain concrete.

#### 4.4.3. General comparison of tensile strength between plain and GFRC

For all cases, it is observed that when magnitude of temperature increased there was a major loss of tensile strength on control as well as GFRC cubes. However, GFRC cylinders has a good performance on resisting fire exposure especially the optimum value 0.27% has shown a good result.

Although there is a loss of tensile strength on concrete due to fire as magnitude of temperature increases, E-glass fiber can decrease the major loss of tensile strength. Especially for higher magnitude of temperature, this E-glass fiber has shown a marvelous result on increasing of tensile strength from plain concrete.

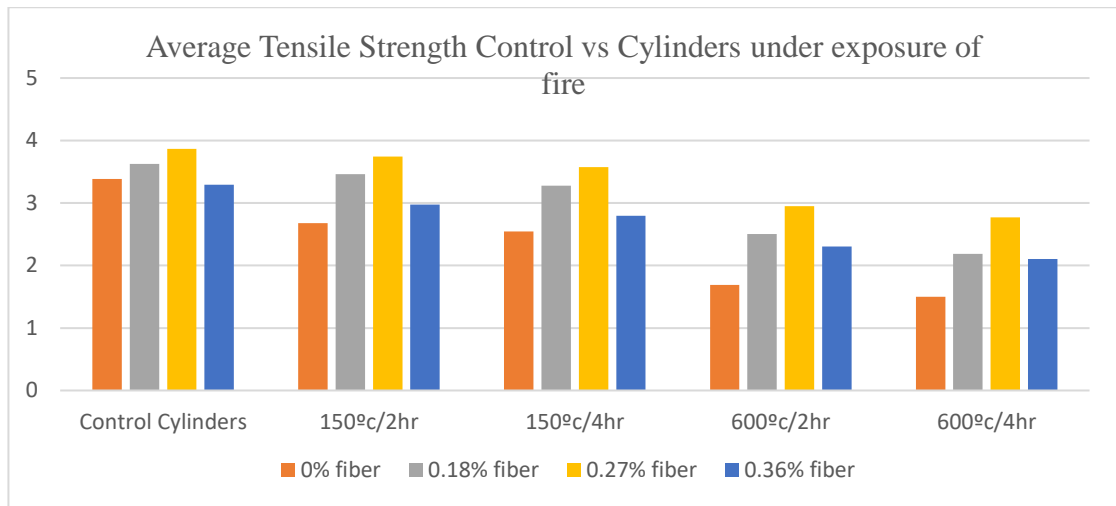


Figure 4.23. Comparison of tensile strength for all cases

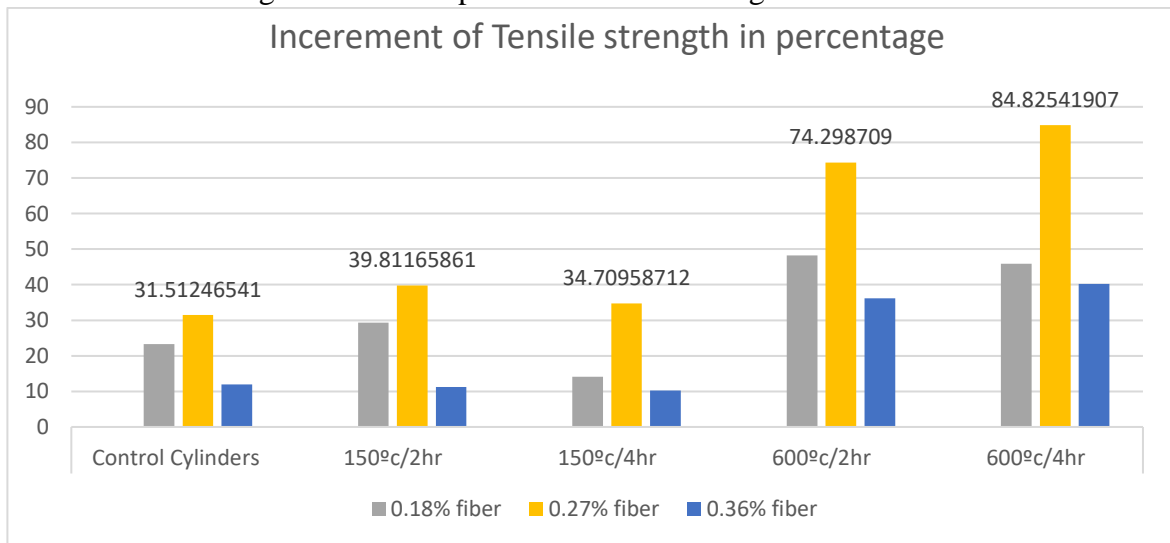


Figure 4.24. Percentage increase of tensile strength due to addition of glass fiber

#### 4.5. Flexural Strength for beams

##### 4.5.1. Flexural Failure Loads

Six beams were casted and tested for flexure. This has been done to check the performance of concrete mixed with two different percentage of glass fiber addition, fire exposure under the maximum magnitude of temperature with the maximum duration of fire. So out of six beams three were inserted in furnace with a temperature of 600<sup>0</sup>C and duration of 4hr. After they all inserted and exposed to fire, cooling phase takes place for 24-hour then they were tested for flexural strength using one-point load.

Table. 4.19. Failure Loads for all beams

Glass Fiber Percentage	Failure Load(KN)	
	Control beams	Beams exposed to fire
0%	131.5	88.28
0.18%	189.6	103.95
0.27%	191.02	124.02

It is observed that failure load for flexure is higher when the percentage of glass fiber addition is 0.27%. The failure load for beams that are not exposed to fire increased by 44% and 45.3% for percentage of glass fiber 0.18% and 0.27% by respectively from plain beams.

For beams exposed to fire under temperature of 600<sup>0</sup>C and 4hr duration of fire, the failure load increased by 17.750% and 40.485% for percentage of glass fiber 0.18% and 0.27% by weight respectively from plain beams. This implies that the addition of glass fiber can withstand the fire exposure.

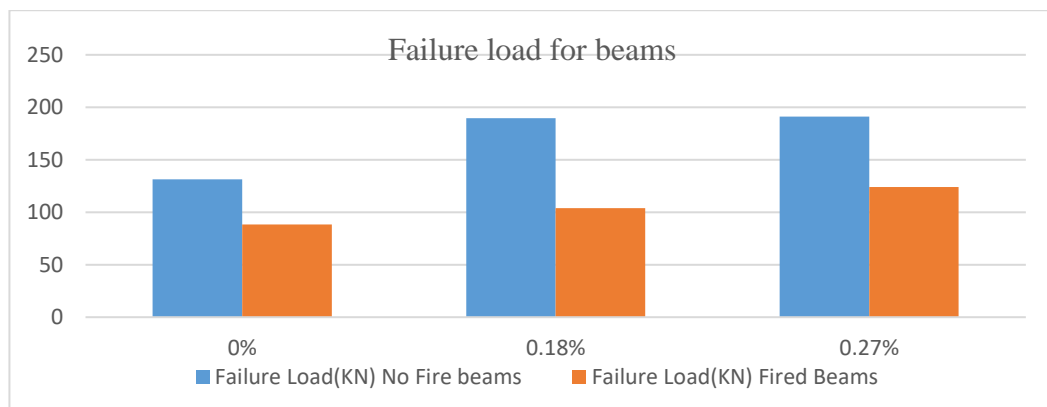


Figure 4.25. Failure load comparison for both fired and no fire beams

#### 4.5.2. Load Vs Deflection curve

After finding the failure load and deformation of plain and GFRC beams, load vs deformation curve is plotted for all beams. Then finally, it is compared according to beams exposed to fire and beams not exposed to fire. Almost all GFRC beams behave a ductile manner of failure and give large deflection before the final failure.

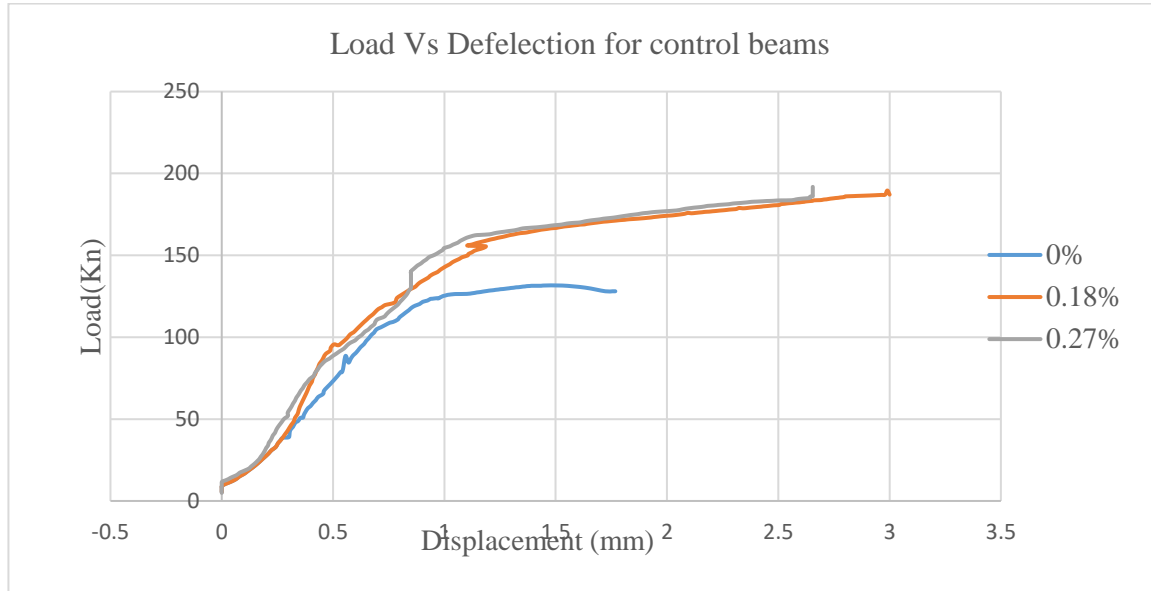


Figure 4.26. Load Vs Deflection curve for beams not exposed to fire

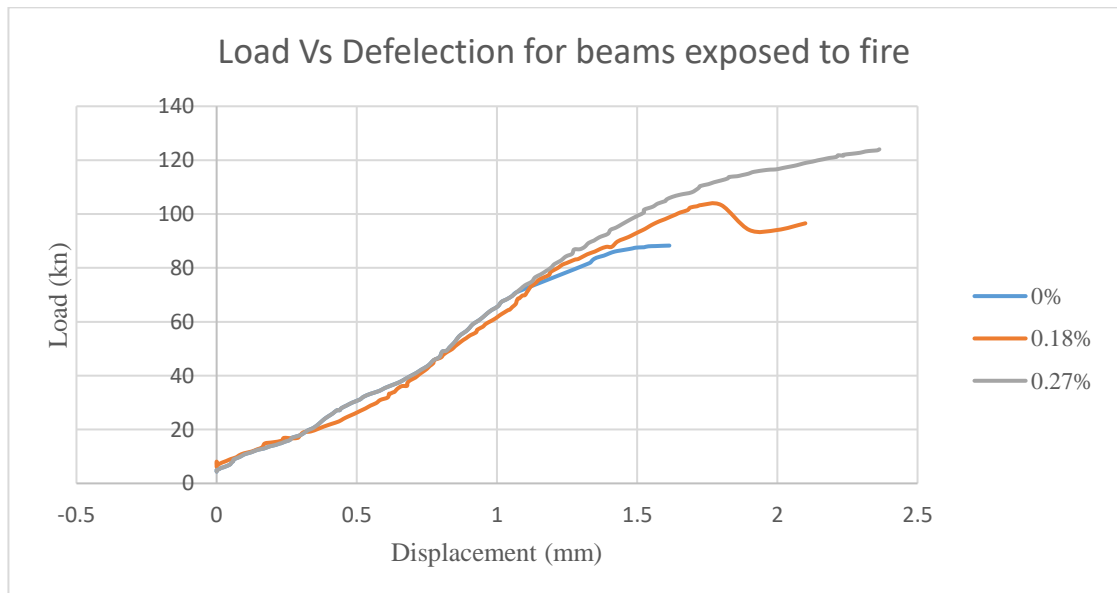


Figure 4.27. Load Vs Deflection curve for beams after exposed to fire  
Beams that are GFRC has shown good performance during this case. Adding of glass fiber in concrete mix makes beams to deform less with higher load. Although all RC beams has

shown a ductile behavior, more ductile is observed on GFRC beams. Especially when the amount of adding glass fiber is increased the load vs deflection curve shows more ductile.

GRFC beams has shown ductile failure than the plain beams, after exposing to fire. Here two benefits are observed the first one is adding of glass fiber in concert mix can make the concrete more ductile and the second one addition of glass fiber has a great impact in resisting fire.

#### 4.6. Time-Temperature curve

##### 4.6.1. Furnace time vs temperature curve

There were four different, magnitude of temperatures adjusted in the furnace for this study 150<sup>0</sup>C, 300<sup>0</sup>C, 450<sup>0</sup>C and 600<sup>0</sup>C. After adjusting the temperature for each of them, the time is recorded manually. It is observed that when the furnace is adjusted for smaller magnitude of temperature it will reach to adjusted temperature within a few minutes. However, when it is adjusted for higher magnitude of temperatures, there will be fluctuation of results since the furnace maintain its temperature: the temperature will once get higher then after some minutes later, it will fall down until it reaches the desired temperature.

Depending on the test made for samples, all samples are inserted in furnace with a magnitude temperature of 150<sup>0</sup>C, 300<sup>0</sup>C, 450<sup>0</sup>C and 600<sup>0</sup>C then it is adjusted to reach these limit. Then the time in every 5<sup>0</sup>C was recorded. The time where the furnace reach to the desired temperature is 13min, 32min, 186min and 234min for temperature of 150<sup>0</sup>C, 300<sup>0</sup>C, 450<sup>0</sup>C and 600<sup>0</sup>C respectively.

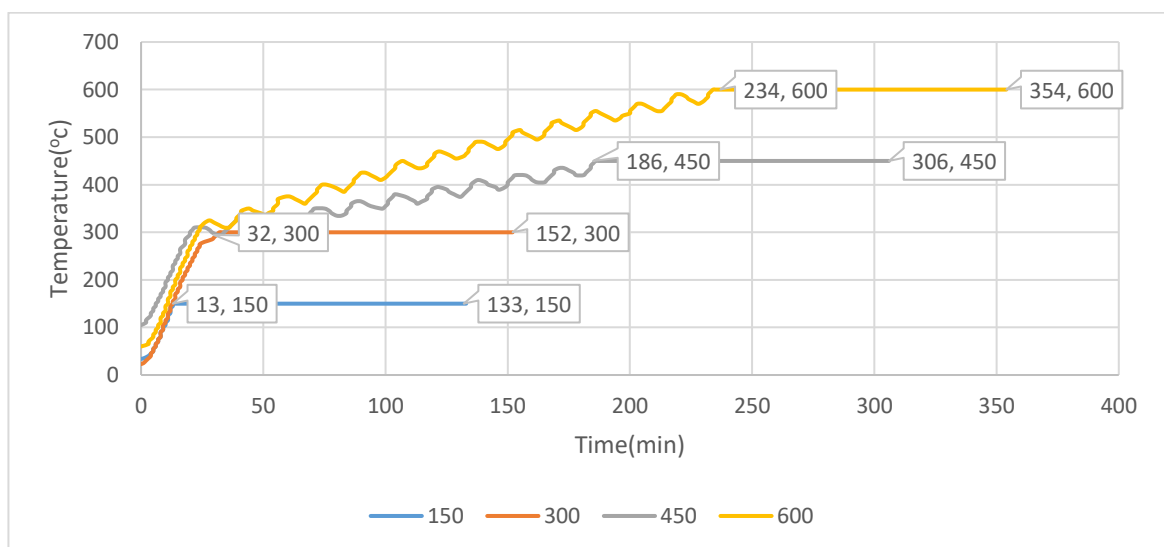


Figure 4.28. Time Vs Temperature curve of different temperature levels

#### 4.6.2. Comparison of furnace time vs temperature curve with ISO standard curve

When the furnace time vs temperature curve that is used for this research is observed, it is found that it has somehow similarity with the standard ISO time- temperature curve.

According to (Eurocode1991-1-2, 2002) standard ISO temperature-time curve can be plotted using this formula:

$$\theta_g = \theta_0 + 345 \log(8t + 1)$$

Where

$\theta_g$  is the gas temperature in the fire compartment ( $^{\circ}\text{C}$ )

T is the time (min)

$\theta_0$  is initial temperature in the fire compartment( $^{\circ}\text{C}$ )

The ISO curve in this study is plotted using the time, which is record during this research and inserted to the equation, then it is found to have a curve as it looks like in figure 4.29. Then the recorded time vs temperature also plotted and comparison between those two curves is done in every magnitude of temperature.

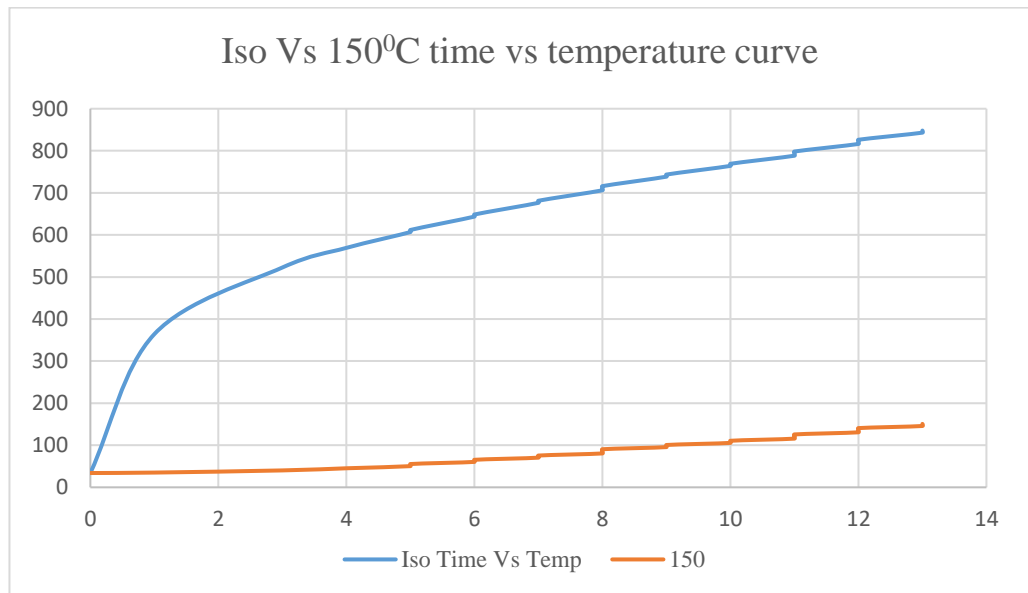


Figure 4.29. ISO Standard curve vs. recorded time-temperature curve for temperature 150 $^{\circ}\text{C}$

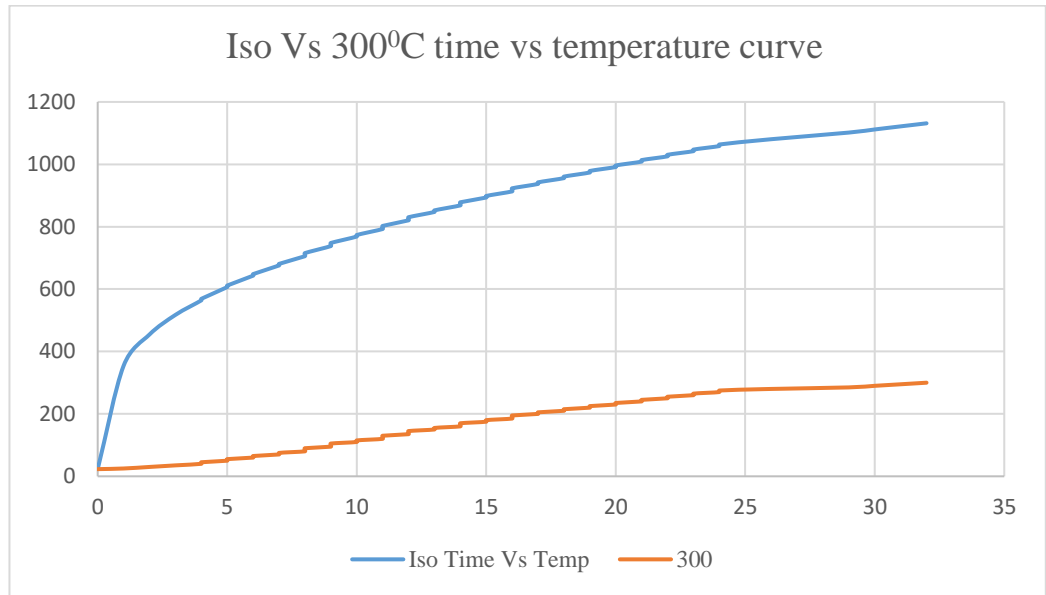


Figure 4.30. ISO Standard curve vs. recorded time-temperature curve for temperature 300°C

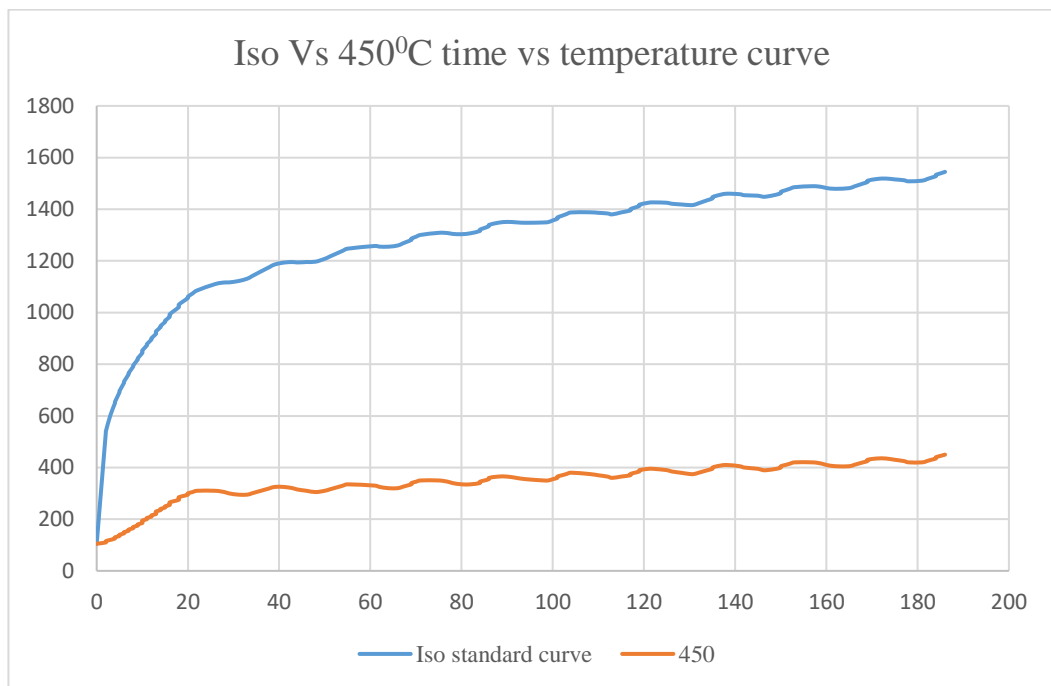


Figure 4.31. ISO Standard curve vs. recorded time-temperature curve for temperature 450°C

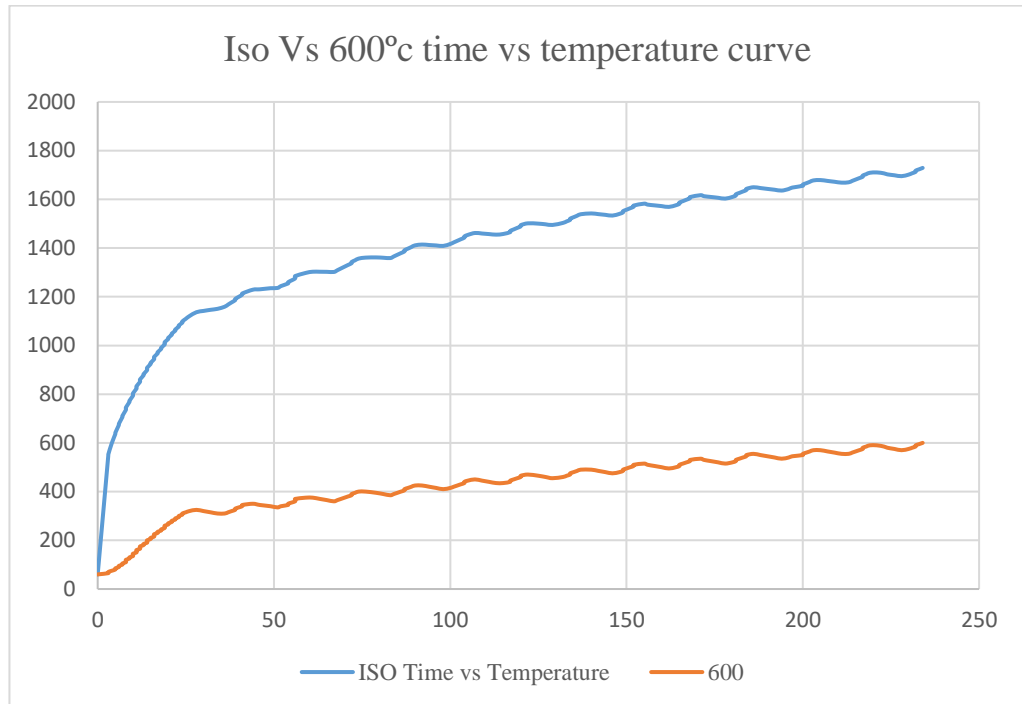


Figure 4.32. ISO Standard curve vs. the recorded time-temperature curve for temperature 600°C

It is observed that even if the flow of temperature is similar there is visible difference between those two curves. However, when the temperature of the furnace rise from lower temperature to higher the similarity of these two curves will be more visible.

In addition when checking the equation of ISO standard curve for this furnace, it is found that there will be a change for the equation in order to get a curve similar to ISO curve.

This was the equation for ISO curve:-  $\theta_g = \theta_0 + 345 \log(8t + 1)$

However, for this specific furnace the modified equation, which works for all four different magnitude of temperature, is found to be

$$\theta_g = \theta_0 + 3 \log(0.069t + 1)$$

Where

$\theta_g$  is the gas temperature in the fire compartment (°C)

T is the time (min)

$\theta_0$  is initial temperature in the fire compartment(°C)

#### 4.7. Checking physical properties of concrete

Concrete both plain and GFRC that has been exposed to fire has checked physically and compared with concrete that are not exposed. Weight loss, occurring of spalling and cracks and finally color change due to different magnitude of temperature change is checked.

##### 4.7.1. Weight of specimen

Weight of specimens is taken before exposed to fire and then specimens which has been exposed to fire measured after they cool for 24hr then comparison made.

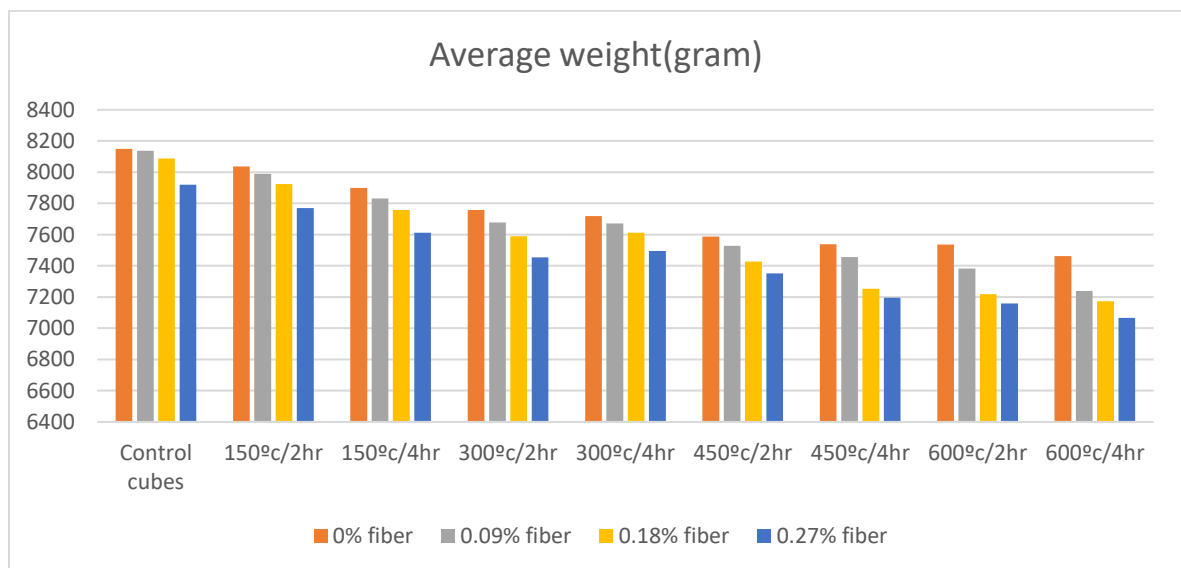


Figure 4.33. Comparison of weight loss during different magnitude of temperature

The weight of specimen decreases as the amount of fiber is increased. This is because while adding of glass fiber there is waste on the other ingredient, so the concrete become lighter than the plain one. This implies that addition of glass fiber in concrete will make the concrete lighter than it used to be.

In addition, when the magnitude of temperature and duration of fire increases, the weight loss also increases. This is due to water evaporate from concrete while it was exposed to fire, this evaporation was very noticeable it was even seen by bare eyes during the exposure. Then the evaporation of water makes the concrete lighter than it used to be. Concrete after exposed to fire it has a disturbing noise, this occur because of the loss of more water from the concrete, which was caused by the evaporation.

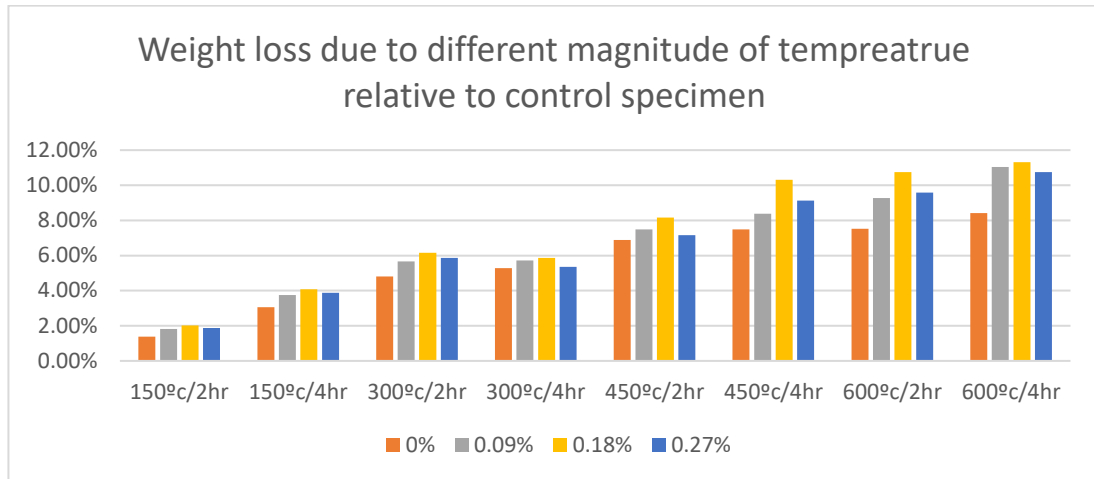


Figure 4.34. Loss of weight due to different magnitude of temperature relative to control specimen

#### 4.7.2. Spalling and Cracks

Visual checking was done for both occurring of spalling and cracks during fire exposure of different specimens. Spalling on this study has been observed during temperature level reaches 300°C. Spalling occurred at this magnitude of temperature is lesser and but it was visible. However, spalling during 450 °C and 600°C explosive spalling occurs, especially when the temperature is at 600°C the spalling was very high and easily visible.

Even though spalling is higher when the temperature is rise, adding of glass fiber in concrete has a greater impact on resisting occurring of explosive spalling during high magnitude of temperature. Comparing the spalling of conventional concrete with concrete that has glass fiber, the spalling occurrence somehow minimized, this is because of the behavior of glass fiber when they get heated they melted and fill the gap that has been occurred during higher temperature.



Figure 4.35. Spalling at temperature level of 300°C



Figure 4.36. Explosive Spalling at temperature level of 600°C

Parallel to spalling cracks also has been detected during concretes exposed to fire in different magnitude of temperature. For crack checking, beams, which were used for flexural test, were observed. For both beams inserted in furnace and as well as remain outside, crack width for plain concrete beams is higher than that of beams with GFRC. This implies that inserting of glass fiber in concrete mix can fill the concrete crack, which occurs during flexural test as well as which do occurs during fire exposure at maximum magnitude of temperature with maximum duration of fire.



Figure 4.37. Crack of RC beam without glass fiber



Figure 4.38. Crack of RC concrete with glass fiber

### 4.7.3. Color change

Adding of glass fiber in concrete eventually changes the color of concrete. The concrete color will be more whitish than it used to be.

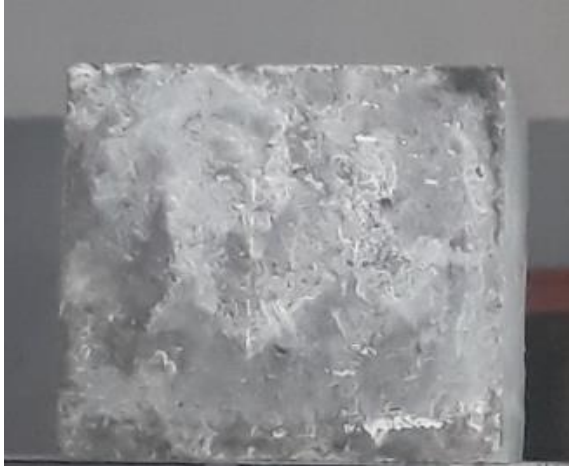


Figure 4.39. Color of plain concrete



Figure 4.40. Color of glass fiber concrete

When both plain concrete and GFRC inserted in furnace there is more less color change between them however, during magnitude of temperature increases from 150<sup>0</sup>C to 600<sup>0</sup>C there is a change in color. Since the change of color between plain concrete and GFRC is more likely similar, investigation on change of color in general based on the magnitude of temperature and duration of fire has made.

Adding of glass fiber has a color effect on concrete, which is not inserted in furnace however; when it is inserted in furnace, the change of color is not significant as the plain concrete. Here, duration of fire has impact on color change, when the duration of fire increases, the color change will be darker. It shows darker color on 4hr of fire duration of than 2hr.

For every magnitude of temperature, the color change is observed. For magnitude of temperature 150<sup>0</sup>C, the water is removed from heated concrete, so simply gray color observed during this process. As the temperature increases to 300<sup>0</sup>C cement paste will decompose, it becomes  $\text{Ca(OH)}_2 \rightarrow \text{CaO} + \text{H}_2\text{O}$ , so this CaO created in this reaction will make the concrete color to be darker color. Then when the temperature is reached around 450<sup>0</sup>C there is occurrence of hydrate decomposition and iron oxidation. The iron component in aggregates will make the color of the concrete to be pink. Then finally, when its reach to 600<sup>0</sup>C the water will totally remove from concrete and the cement and aggregate will burn highly on which the color will change to whitish.

- Light Gray color is observed at 150°C and 2hr



Figure 4.41. Color of specimen under 150 °C and 2hr

- Gray color is observed at 150°C and 4hr



Figure 4.42. Color of specimen under 150 °C and 4hr

- Dark Gray color is observed at 300°C and 2hr



Figure 4.43. Color of specimen under 300 °C and 2hr

- Darker Gray color is observed at 300°C and 4hr



Figure 4.44. Color of specimen under 300 °C and 4hr

- Light pink color is observed at 450°C and 2hr



Figure 4.45. Color of specimen under 450°C and 2hr

- Pinkish color is observed at 450°C and 2hr



Figure 4.46. Color of specimen under 450°C and 4hr

- Whitish color is observed during 600°C and 2hr



Figure 4.47. Color of specimen under 600°C and 2hr

- More whitish color is observed during 600°C and 4hr



Figure 4.48. Color of specimen under 600°C and 4hr

## CHAPTER 5- SUMMARY, CONCLUSION AND RECOMMENDATIONS

### 5.1. Summary

An experimental investigation was carryout under exposure of fire on plain concrete (0%) and GFRC at 28 days with a percentage of glass fiber 0.09%, 0.18%, 0.27% and 0.36% by weight of concrete for the compressive strength test. Moreover, percentage of glass fiber 0%, 0.09%, 0.18%, 0.27% and 0.36% by weight for split tensile strength test and as well 6 beams with percentage of glass fiber 0%, 0.18% and 0.27% by weight for flexural test.

Concrete loses both its compressive and tensile strength after exposure to fire. However, adding glass fiber has shown a marvelous increment in strength on concrete that exposed to fire. For all cases as the temperature magnitude increases, compressive strength as well as tensile strength decreases on both plain concrete and GFRC. However, GFRC has good performance on resisting fire exposure, especially on the optimum values.

When the concrete is exposed to fire, the cement paste will shrink due to dehydration and the aggregate will expand due to the high rise of temperature, this leads to cracking, and spalling, which finally lead strength lose on concrete. However, glass fibers has the tendency to fill the crack which occur during this high-rise temperature, so then the reduction of strength due fire is minimized and due to the good tensile property of glass fiber, it makes the beam to fail more ductile than it used to be.

### 5.2. Conclusions

- Concrete workability decreases as the percentage of glass fiber in concrete mix increased that is because the void is filled with glass fibers, making the mix drier than it was.
- The optimum percentage of glass fiber for concrete grade considered in this study found to be 0.18% for the compressive strength test and 0.27% for tensile strength test.
- For flexural strength, the failure load for flexure is observed to be higher when the percentage of glass fiber is 0.27%.
- Therefore, for compressive members 0.18% addition of glass fiber can be used and for flexural members 0.27% of addition of glass fiber can be used.
- There is a loss of concrete strength due to fire as the temperature magnitude increases; E-glass fiber decreases the loss of strength. It has shown a marvelous

result, especially for a higher temperature, in increasing of the strength from plain concrete.

- Glass fiber addition has a significant effect on load vs deformation, making both plain and GFRC beams failures more ductile than they used to be.
- For the furnace Time vs Temperature, the duration of the furnace hitting the target temperature is 13min, 32min, 186min, and 234min respectively, for temperature 150<sup>0</sup>C, 300<sup>0</sup>C, 450<sup>0</sup>C and 600<sup>0</sup>C.
- Furnace Time vs Temperature used for this study has ISO standard curve similarities. However, somehow the equation of this ISO standard curve changed to meet the curve for this particular furnace.
- The specimen weight decreases as the fiber quantity increases. This implies that the glass fiber applied to concrete would make the concrete lighter than it used to be. Additionally, as temperature and duration of fire increase, weight loss also increases.
- Adding glass fiber has a color effect on concrete that is not inserted in the furnace. However, the change in color between GFRC and plain concrete is not differentiable for concrete exposed to fire. After 300<sup>0</sup>C temperature, noticeable color change starts to be observed in general case.
- Spalling begins at a temperature of 300<sup>0</sup>C. Explosive spalling observed when the magnitude of temperature is 600<sup>0</sup>C. Although spalling is greater as the magnitude of temperature increases, adding glass fiber to concrete has a greater impact on resisting the occurrence of explosive spalling during high temperature. This is because of the behavior of glass fiber they melted when they get heated and fill the gap occurred during higher temperature.
- Crack also observed on plain beams at a higher temperature. Crack width for plain concrete beams is higher than that of GFRC beams for both beams inserted in furnace and remain outside. GFRC beams crack width of is smaller than that of conventional beams.

### **5.3.Recommendation**

- In order to increase the strength of both conventional and fire-exposed concrete, adding glass fiber is important, but it is recommended that smaller quantities of glass fiber be added in order to get good result on increasing of strength. The use of smaller amount of glass fiber increases the concrete strength and has economic benefit.

- In Ethiopia, the impact of fire exposure on concrete during the investigation of the mechanical properties of concrete is not that much investigated, so it is recommended that this investigation be applied during the test carried out.
- Due to the increased tensile, compressive and flexural strength of concrete, glass fiber has a greater impact. Furthermore, concrete cracks that occur due to higher tensile strength and fire exposure are minimized due to glass fiber. Both the government and higher education institutes should pay attention to use fiber as concrete reinforcement material.
- In higher education institutes, blast furnaces should be set so that they can be easily available in material laboratories and fire exposure investigation on concrete can be carried out in broader way.
- It is recommend to do further research on concrete exposed to fire by changing the cooling system of exposed concretes.
- It is recommend to do further research on concrete exposed to fire by using software.

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## APPENDIX

### Appendix A- Materials Laboratory Test Results

#### A.1. Sieve analysis for fine and coarse aggregate

Table A.1.1. Sieve Analysis result for Fine Aggregate

ASTM Sieve Designation	Sieve size	Weight retained(gm)			% retained	Cumulative % coarser	Cumulative % passing	Minimum	Maximum
		Sample 1	Sample 2	Average					
3/8"	9.5mm	0	0	0	0	0	100	100	100
No.4	4.75 mm	11	13.6	12.3	2.46	2.46	97.54	95	100
No.8	2.36 mm	36	25.4	30.7	6.14	8.6	91.4	80	100
No.16	1.18 mm	86.2	71.4	78.8	15.76	24.36	75.64	50	85
No.30	600 $\mu$ m	208.1	203.1	205.6	41.12	65.48	34.52	25	60
No.50	300 $\mu$ m	125.2	142.8	134	26.8	92.28	7.72	5	30
No.100	150 $\mu$ m	30.8	40	35.4	7.08	99.36	0.64	0	10
No.200	0.75 $\mu$ m	2.5	3.4	2.95	0.59	99.95	0.05	0	3
Pan	pan	0.2	0.3	0.25	0.05	100	0	0	0
Total		500	500	500	100	292.54			
Fineness modulus					2.9254				

Table A.1.2. Sieve Analysis result for Fine Aggregate

ASTM Sieve Designation	Sieve size(mm)	Weight retained(gm)			% retained	Cumulative % coarser	Cumulative % passing	Minimum	Maximum
		Sample 1	Sample 2	Average					
3	75mm	0	0	0	0	0	100	100	100
2	63mm	0	0	0	0	0	100	100	100
1.5	37.5mm	0	0	0	0	0	100	100	100
1	25mm	872.7	1204.3	1038.5	12.999	12.999	87.001	90	100
3/4	19mm	2574	2344.8	2459.4	30.784	43.783	56.217	40	85

1/2	12.5m m	3140 .2	3028 .3	3084. 25	38.60 5	82.388	17.612	10	40
3/8	9.5m m	1327 .2	1319 .7	1323. 45	16.56 5	98.954	1.046	0	15
No.4	4.75m m	29.7	41.3	35.5	0.444	99.398	0.602	0	5
Pan	pan	43	53.2	48.1	0.602	100.000	0.000	0	0
Total		7986 .8	7991 .6	7989. 2	100	238.123 342			

### A.2. Moisture Contain for coarse aggregate and fine aggregate

Table A.2.1. Moisture Contain for coarse aggregate

Description		Sample	
		1	2
Weight of wet(original) aggregate sample	W1(gm)	2000	2000
Weight of oven dry aggregate sample	W2(gm)	1970	1968.3
Moisture Content	%	1.522843	1.610527
Average Moisture Content of CA	%	1.566685	

Table A.2.2. Moisture Contain for fine aggregate

Description		Sample	
		1	2
Weight of wet(original) aggregate sample	W1(gm)	500	500
Weight of oven dry aggregate sample	W2(gm)	491.2	492.3
Moisture Content	%	1.791531	1.564087
Average Moisture Content of FA	%	1.677809	

### A.3. Unit weight for fine aggregate and coarse aggregate

Table A.3.1. Unit weight for coarse aggregate

Description		Sample	
		1	2
Volume of the mold	V(lit)	9	9
Weight of the mold only	W(Kg)	5.4	5.4
Weight of the mold loosely with aggregate	W1(Kg)	19	19

Weight of the mold with aggregate fully compacted	W2(Kg)	20.5	20.5
Lose unit weight	Kg/m <sup>3</sup>	1511.111	1511.111
Compacted unit weight	Kg/m <sup>3</sup>	1677.778	1677.778
Average Lose unit weight	Kg/m <sup>3</sup>	1511.111111	
Average Compacted unit weight	Kg/m <sup>3</sup>	1677.77778	

Table A.3.2. Unit weight for coarse aggregate

Description		Sample	
		1	2
Volume of the mold	V(lit)	9	9
Weight of the mold only	W(Kg)	5.4	5.4
Weight of the mold loosely with aggregate	W1(Kg)	13	13
Weight of the mold with aggregate fully compacted	W2(Kg)	14.5	14.5
Lose unit weight	Kg/m <sup>3</sup>	844.4444	844.4444
Compacted unit weight	Kg/m <sup>3</sup>	1011.111	1011.111
Average Lose unit weight	Kg/m <sup>3</sup>	844.4444444	
Average Compacted unit weight	Kg/m <sup>3</sup>	1011.111111	

#### A.4. Specific gravity and Water Absorption of CA and FA

Table A.4.1. Specific gravity and water absorption of CA

Description		Sample	
		1	2
Weight of Sample taken,(gm)	gm	4000	4000
Weight of Basket + Sample + Water	W1(gm)	4409	4419
Weight of Basket + Water	W2(gm)	1849	1859
Weight of SSD sample in air	W3(gm)	4000	4000
Weight of oven dry sample	W4(gm)	3914.4	3913.5
Specific gravity		2.718333	2.717708
Bulk Specific gravity (SSD basis)		2.777778	2.777778
Apparent Specific gravity		2.890136	2.891393
Water Absorption, dry weight WA	%	2.186797	2.210298
Average Values	Specific gravity	2.718020833	
	Apparent Specific gravity	2.89076427	
	Water Absorption	2.198547577	

Table A.4.2. Specific gravity and water absorption of FA

Description		Sample	
		1	2
Weight of Sample taken,(gm)	gm	500	500
Weight of Basket + Sample + Water	W1(gm)	1603.5	1599.3
Weight of Basket + Water	W2(gm)	1301.6	1297.2

Weight of SSD sample in air	W3(gm)	500	500
Weight of oven dry sample	W4(gm)	488.9	488.3
Specific gravity		2.467945	2.467408
Bulk Specific gravity (SSD basis)		2.523978	2.526529
Apparent Specific gravity		2.614439	2.622449
Water Absorption, dry weight WA	%	2.270403	2.396068
Average Values	Specific gravity		2.467676632
	Apparent Specific gravity		2.618443741
	Water Absorption	%	2.333235468

### A.5. Results on fresh concrete tests

Table A.5.1. Slump test result

% glass fiber	Slump(mm)			Average slump	Percentage Drop%
0%	25	38	30	31	0
0.09%	25	27	25	25.66667	17.204301
0.18%	15	15	13	14.33333	53.763441
0.27%	0	5	5	3.333333	89.247312
0.36%	0	0	0	0	100

Table A.5.2. Unit weight of fresh concrete

% glass fiber	Mass of Empty container(Kg)	Volume of Container(m <sup>3</sup> )	Mass of full container(Kg)			Average mass of full container	Unit Weight (Kg/m <sup>3</sup> )
0%	5.4	0.009	27.5	27.5	27	27.333	2437.04
0.09%	5.4	0.009	27.5	27	27	27.167	2418.52
0.18%	5.4	0.009	27	27	26.5	26.833	2381.48
0.27%	5.4	0.009	26.5	26.5	26.5	26.500	2344.44
0.36%	5.4	0.009	26.5	26	26	26.167	2307.41

## Appendix B- Specimen Laboratory Test Results

### B.1. Compressive strength results

Table B.1.1. Compressive strength results of control cubes

Fiber %	No.	Dimensions (mm)			Weight (gm)	Average weight (gm)	Temperature during test(°c)	Failure Load(KN)	Compressive Strength(Mpa)	Average Compressive Strength (Mpa)
		L	W	H						
0%	1	150	150	150	8112	8149	19.8°c	676	30.04	30.030
	2	150	150	150	8208		19.7°c	676	30.04	
	3	150	150	150	8129		19.8°c	675	30.00	
0.09%	1	150	150	150	8120	8137	19.5°c	763	33.91	33.896
	2	150	150	150	8160		19.8°c	763	33.91	
	3	150	150	150	8133		19.6°c	762	33.86	
0.18%	1	150	150	150	8081	8088	19.8°c	875	38.88	38.933
	2	150	150	150	8161		19.8°c	876	38.93	
	3	150	150	150	8022		19.8°c	877	38.97	
0.27%	1	150	150	150	7902	7919	19.8°c	770	34.22	34.237
	2	150	150	150	7994		19.7°c	771	34.26	
	3	150	150	150	7861		19.8°c	770	34.22	
0.36%	1	150	150	150	7761	7793	19.6°c	664	29.51	29.481
	2	150	150	150	7830		19.8°c	663	29.46	
	3	150	150	150	7790		19.8°c	663	29.46	

Table B.1.2. Compressive strength results of cubes exposed to fire by 150<sup>0</sup>C and 2hr

Fiber %	Specimen No.	Dimensions (cm)			Weight (gm)	Average weight (gm)	Temperature during test(°c)	Failure Load(KN)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
		L	W	H						
C0%	CN	15	15	15	8208	8208	19.4°c	681.7	30.29	30.2
F0%	1	15	15	15	8071	8036	20.4°c	627.3	27.88	27.8
	2	15	15	15	8002		20.5°c	628.1	27.91	
C0.09%	CN	15	15	15	8160	8160	19.8°c	751.4	33.39	33.3
F0.09%	1	15	15	15	8000	7989	20.4°c	705.5	31.35	31.6
	2	15	15	15	7979		20°c	717.4	31.88	
C0.18%	CN	15	15	15	8161	8161	19.2°c	875.5	38.91	38.9
F0.18%	1	15	15	15	7963	7924.5	20.4°c	849.1	37.74	37.7
	2	15	15	15	7886		20.6°c	848.3	37.70	

C0.27 %	CN	15	15	15	7994	7994	19°C	769.2	34.18	34.1
F0.27 %	1	15	15	15	7778	7769.5	20.3°C	676.6	30.07	30.0
	2	15	15	15	7761		20°C	677.4	30.10	

Table B.1.3. Compressive strength results of cubes exposed to fire by 150<sup>0</sup>C and 4hr

Fiber %	Specimen No.	Dimensions (cm)			Weight (gm)	Average weight (gm)	Temperature during test(°c)	Failure Load(KN)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
		L	W	H						
C0%	CN	15	15	15	8112	8112	26°C	680	30.222	30.22
F0%	1	15	15	15	7934	7899	30.6°C	607.75	27.011	26.99
	2	15	15	15	7865		26°C	606.9	26.973	
C0.09 %	CN	15	15	15	8133	8133	24°C	764.15	33.962	33.96
F0.09 %	1	15	15	15	7840	7832	26.5°C	693.6	30.827	30.80
	2	15	15	15	7825		26.6°C	692.75	30.789	
C0.18 %	CN	15	15	15	8030	8030	25°C	877.2	38.987	38.98
F0.18 %	1	15	15	15	7765	7757	24.7°C	816	36.267	36.36
	2	15	15	15	7750		26°C	820.25	36.456	
C0.27 %	CN	15	15	15	7981	7981	26.4°C	782	34.756	34.75
F0.27 %	1	15	15	15	7562	7611.5	25.5°C	669.8	29.769	29.76
	2	15	15	15	7661		26.4°C	669.8	29.769	

Table B.1.4. Compressive strength results of cubes exposed to fire by 300<sup>0</sup>C and 2hr

Fiber %	Specimen No.	Dimensions (cm)			Weight (gm)	Average weight (gm)	Temperature during test(°c)	Failure Load(KN)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
		L	W	H						
C0%	CN	15	15	15	8112	8112	20.8°C	675.75	30.033	30.033
F0%	1	15	15	15	7796	7757	22.5°C	488.75	21.722	21.760
	2	15	15	15	7718		22.5°C	490.45	21.798	
C0.09 %	CN	15	15	15	8120	8120	20.3°C	759.45	33.754	33.754
F0.09 %	1	15	15	15	7682	7677	21.8°C	646	28.711	28.768
	2	15	15	15	7672		21.2°C	648.55	28.824	
C0.18 %	CN	15	15	15	8081	8081	19.9°C	875.5	38.911	38.911
F0.18 %	1	15	15	15	7568	7590	21.6°C	790.5	35.133	35.171
	2	15	15	15	7612		21.2°C	792.2	35.209	

C0.27 %	CN	15	15	15	7902	7902	20°c	725.05	32.224	32.224
F0.27 %	1	15	15	15	7346	7453	21.2°c	633.25	28.144	28.088
	2	15	15	15	7561		21.6°c	630.7	28.031	

Table B.1.5. Compressive strength results of cubes exposed to fire by 300<sup>0</sup>C and 4hr

Fiber %	Specimen No.	Dimensions (cm)			Weight (gm)	Average weight (gm)	Temperature during test(°c)	Failure Load(KN)	Compressive Strength(Mpa)	Average Compressive Strength (Mpa)
		L	W	H						
C0%	CN	15	15	15	8208	8208	20.9°c	675.75	30.033	30.033
F0%	1	15	15	15	7736	7718	23.0°c	467.5	20.778	20.816
	2	15	15	15	7700		22.4°c	469.2	20.853	
C0.09 %	CN	15	15	15	8160	8160	21.1°c	759.05	33.736	33.736
F0.09 %	1	15	15	15	7690	7672.5	22.8°c	611.15	27.162	27.106
	2	15	15	15	7655		22.5°c	608.6	27.049	
C0.18 %	CN	15	15	15	8161	8161	21.6°c	874.65	38.873	38.873
F0.18 %	1	15	15	15	7650	7613	22.5°c	756.5	33.622	33.679
	2	15	15	15	7576		22.4°c	759.05	33.736	
C0.27 %	CN	15	15	15	7994	7994	21.2°c	773.5	34.378	34.378
F0.27 %	1	15	15	15	7540	7495	22.8°c	612	27.200	27.219
	2	15	15	15	7450		22°c	612.85	27.238	

Table B.1.6. Compressive strength results of cubes exposed to fire by 450<sup>0</sup>C and 2hr

Fiber %	Specimen No.	Dimensions (cm)			Weight (gm)	Average weight (gm)	Temperature during test(°c)	Failure Load(KN)	Compressive Strength(Mpa)	Average Compressive Strength (Mpa)
		L	W	H						
C0%	CN	15	15	15	8129	8129	27.2°c	681	30.267	30.267
F0%	1	15	15	15	7624	7588	32.5°c	415	18.444	18.511
	2	15	15	15	7552		33.4°c	418	18.578	
C0.09 %	CN	15	15	15	8140	8140	29°c	759	33.733	33.733
F0.09 %	1	15	15	15	7555	7527.5	33.1°c	582	25.867	25.822
	2	15	15	15	7500		32.6°c	580	25.778	
C0.18 %	CN	15	15	15	8023	8023	27.8°c	817	36.311	36.311
F0.18 %	1	15	15	15	7455	7427.5	31.6°c	707	31.422	31.444
	2	15	15	15	7400		31°c	708	31.467	

C0.27 %	CN	15	15	15	7933	7933	27.8°c	733.64	32.606	32.606
F0.27 %	1	15	15	15	7399	7352.5	30.2°c	605	26.889	26.911
	2	15	15	15	7306		30.4°c	606	26.933	

Table B.1.7. Compressive strength results of cubes exposed to fire by 450<sup>0</sup>C and 4hr

Fiber %	Specimen No.	Dimensions (cm)			Weight (gm)	Average weight (gm)	Temperature during test(°c)	Failure Load(KN)	Compressive Strength(Mpa)	Average Compressive Strength (Mpa)
		L	W	H						
C0%	CN	15	15	15	8216	8216	30.2°c	675	30.000	30.000
F0%	1	15	15	15	7526	7539	35.0°c	400	17.778	17.778
	2	15	15	15	7552		41.5°c	400	17.778	
C0.09 %	CN	15	15	15	8133	8133	30.5°c	750	33.333	33.333
F0.09 %	1	15	15	15	7442	7455.5	37.7°c	559	24.844	24.822
	2	15	15	15	7469		38.3°c	558	24.800	
C0.18 %	CN	15	15	15	7966	7966	31.1°c	815	36.222	36.222
F0.18 %	1	15	15	15	7223	7253.5	41°c	663	29.467	29.400
	2	15	15	15	7284		39.9°c	660	29.333	
C0.27 %	CN	15	15	15	7861	7861	30.2°c	722.349	32.104	32.104
F0.27 %	1	15	15	15	7177	7196.5	37.3°c	580	25.778	25.778
	2	15	15	15	7216		40.5°c	580	25.778	

Table B.1.8. Compressive strength results of cubes exposed to fire by 600<sup>0</sup>C and 2hr

Fiber %	Specimen No.	Dimensions (cm)			Weight (gm)	Average weight (gm)	Temperature during test(°c)	Failure Load(KN)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
		L	W	H						
C0%	CN	15	15	15	8216	8216	26.7°c	680	30.222	30.222
F0%	1	15	15	15	7520	7536	27.8°c	363	16.133	16.067
	2	15	15	15	7552		28.5°c	360	16.000	
C0.09 %	CN	15	15	15	8100	8100	24.4°c	760	33.778	33.778
F0.09 %	1	15	15	15	7343	7382	26.6°c	522.2	23.209	22.313
	2	15	15	15	7421		27.9°c	481.8	21.417	
C0.18 %	CN	15	15	15	7932	7932	25.8°c	830	36.889	36.889

F0.18 %	1	15	15	15	7220	7218	27.3°C	625	27.778	27.822
	2	15	15	15	7216		27.9°C	627	27.867	
C0.27 %	CN	15	15	15	8129	8129	25.6°C	730	32.444	32.444
F0.27 %	1	15	15	15	7132	7159	28.9°C	530	23.556	23.600
	2	15	15	15	7186		29.0°C	532	23.644	

Table B.1.9. Compressive strength results of cubes exposed to fire by 600<sup>0</sup>C and 4hr

Fiber %	Specimen No.	Dimensions (cm)			Weight (gm)	Average weight (gm)	Temperature during test(°c)	Failure Load(KN)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
		L	W	H						
C0%	CN	15	15	15	8206	8206	26.8°C	679	30.178	30.178
F0%	1	15	15	15	7459	7463	27.2°C	337	14.978	15.022
	2	15	15	15	7467		28.3°C	339	15.067	
C0.09 %	CN	15	15	15	8074	8074	25.1°C	755	33.556	33.556
F0.09 %	1	15	15	15	7273	7238	28°C	440	19.556	19.622
	2	15	15	15	7204		28°C	443	19.689	
C0.18 %	CN	15	15	15	8022	8022	26.1°C	820	36.444	36.444
F0.18 %	1	15	15	15	7164	7172	29.2°C	521.71	23.188	26.805
	2	15	15	15	7181		29.9°C	684.52	30.423	
C0.27 %	CN	15	15	15	7924	7924	25.4°C	730	32.444	32.444
F0.27 %	1	15	15	15	7065	7067	27.8°C	480	21.333	21.333
	2	15	15	15	7069		28.5°C	480	21.333	

## B.2. Split tensile strength results

Table B.2.1. Tensile strength results of control cylinders

Fiber %	Specimen No.	Dimensions (cm)		Weight (gm)	Average weight (gm)	Temperature during test(°c)	Failure Load(KN)	Tensile Strength (Mpa)	Average Tensile Strength (Mpa)
		D	H						
0%	1	10	20	4417	4416	19.2°C	92.781	2.955	2.939
	2	10	20	4417		19.7°C	91.768	2.923	
	3	10	20	4415		19.8°C	92.297	2.939	
	1	10	20	4398	4400.3	19.5°C	102.96	3.279	3.382

0.09 %	2	10	20	4403		19.8°C	106.93	3.406	
	3	10	20	4400		19.6°C	108.71	3.462	
0.18 %	1	10	20	4352	4350	19.8°C	114.97	3.662	3.625
	2	10	20	4349		19.8°C	110.43	3.517	
	3	10	20	4348		19.8°C	116.05	3.696	
0.27 %	1	10	20	4299	4297.3	19.8°C	123.87	3.945	3.865
	2	10	20	4297		19.7°C	120.71	3.844	
	3	10	20	4296		19.8°C	119.5	3.806	
0.36 %	1	10	20	4248	4249.7	19.6°C	100	3.185	3.291
	2	10	20	4252		19.8°C	110	3.503	
	3	10	20	4249		19.8°C	100	3.185	

Table B.2.2. Tensile strength results of cylinders exposed to fire by 150<sup>0</sup>C and 2hr

Fiber %	Specimen No.	Dimensions (cm)		Weight(gm)	Average weight (gm)	Temperature during test(°c)	Failure Load(KN)	Tensile Strength(Mpa)	Average Tensile Strength (Mpa)
		D	H						
C0%	CN	10	20	4417	4417	28.2°C	91.375	2.910	2.910
F0%	1	10	20	4389	4388	28.7°C	82.318	2.622	2.677
	2	10	20	4388		27.5°C	85.781	2.732	
C0.18 %	CN	10	20	4350	4350	26°C	115.09	3.665	3.665
F0.18 %	1	10	20	4302	4301	27.9°C	108.71	3.462	3.462
	2	10	20	4300		27°C	108.71	3.462	
C0.27 %	CN	10	20	4297	4297	27.8°C	121.62	3.873	3.873
F0.27 %	1	10	20	4270	4271	26°C	117.94	3.756	3.742
	2	10	20	4273		25.4°C	117.07	3.728	
C0.36 %	CN	10	20	4250	4250	25.8°C	101.15	3.221	3.221
F0.36 %	1	10	20	4202	4200	26.2°C	91.656	2.919	2.977
	2	10	20	4199		26.4°C	95.278	3.034	

Table B.2.3. Tensile strength results of cylinders exposed to fire by 150<sup>0</sup>C and 4hr

Fiber %	Specimen No.	Dimensions (cm)		Weight(gm)	Average weight (gm)	Temperature during test(°c)	Failure Load(KN)	Tensile Strength(Mpa)	Average Tensile Strength (Mpa)
		D	H						
C0%	CN	10	20	4417	4417	20.2°C	91.768	2.923	2.923
F0%	1	10	20	4303		27.7°C	78.981	2.515	2.546

	2	10	20	4300	4301.5	27.5°c	80.927	2.577	
C0.18 %	CN	10	20	4349	4349	25.6°c	114.97	3.662	3.662
F0.18 %	1	10	20	4253	4251	26.3°c	104.99	3.344	3.279
	2	10	20	4249		26°c	100.9	3.213	
C0.27 %	CN	10	20	4297	4297	27.8°c	120.87	3.850	3.850
F0.27 %	1	10	20	4204	4203.5	26°c	110.77	3.528	3.576
	2	10	20	4203		25.4°c	113.81	3.625	
C0.36 %	CN	10	20	4252	4252	25.8°c	100.96	3.216	3.216
F0.36 %	1	10	20	4100	4100	26.2°c	87.129	2.775	2.796
	2	10	20	4100		26.4°c	88.457	2.817	

Table B.2.4. Tensile strength results of cylinders exposed to fire by 600<sup>0</sup>C and 2hr

Fiber %	Specimen No.	Dimensions (cm)		Weight(gm)	Average weight (gm)	Temperature during test(°c)	Failure Load(KN)	Tensile Strength(Mpa)	Average Tensile Strength (Mpa)
		D	H						
C0%	CN	10	20	4410	4410	23.5°c	91.475	2.913	2.913
F0%	1	10	20	3804.5	3803	24.0°c	50.9	1.621	1.691
	2	10	20	3801.5		24.1°c	55.297	1.761	
C0.18 %	CN	10	20	4349	4349	26°c	116.935	3.724	3.724
F0.18 %	1	10	20	3594	3595	27.9°c	78.488	2.500	2.506
	2	10	20	3596		27°c	78.903	2.513	
C0.27 %	CN	10	20	4296	4296	27.8°c	121.501	3.869	3.869
F0.27 %	1	10	20	3427	3427	26°c	93.2	2.968	2.947
	2	10	20	3427		25.4°c	91.9	2.927	
C0.36 %	CN	10	20	4250	4250	25.8°c	101.435	3.230	3.230
F0.36 %	1	10	20	3390	3391	26.2°c	74.6	2.376	2.303
	2	10	20	3392		26.4°c	70	2.229	

Table B.2.5. Tensile strength results of cylinders exposed to fire by 600<sup>0</sup>C and 4hr

Fiber %	Specimen No.	Dimensions (cm)	Weight(gm)	Average	Temperature			Average
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		D	H		weight (gm)	during test(°c)	Failure Load(KN)	Tensile Strength(Mpa)	Tensile Strength (Mpa)
C0%	CN	10	20	4416	4416	23.5°c	91.475	2.913	2.913
F0%	1	10	20	3768	3768	24.0°c	48.9	1.557	1.500
	2	10	20	3768		24.1°c	45.297	1.443	
C0.18%	CN	10	20	4350	4350	26°c	114.93	3.660	3.660
F0.18%	1	10	20	3470	3469	27.9°c	68.488	2.181	2.188
	2	10	20	3468		27°c	68.903	2.194	
C0.27%	CN	10	20	4294	4294	27.8°c	120.71	3.844	3.844
F0.27%	1	10	20	3355	3356	26°c	88.2	2.809	2.772
	2	10	20	3357		25.4°c	85.9	2.736	
C0.27%	CN	10	20	4251	4251	25.8°c	102.42	3.262	3.262
F0.36%	1	10	20	3200	3201	26.2°c	65.061	2.072	2.103
	2	10	20	3202		26.4°c	67.007	2.134	

### B.3. Flexural strength results

Table B.3.1. Flexural strength results of control beams

Fiber Percentage	Failure Load(KN)		Increment of strength because of fiber	
	Control beams	Beams-exposed to fire	for control beams	for beams exposed to fire
0	131.5	88.28	0	0
0.18%	189.6	103.95	44%	18%
0.27%	191.02	124.02	45%	40%

Table B.3.2. Load vs Deformation for beams without fire exposer

0% of glass fiber		0.18% of glass fiber		0.27% of glass fiber	
Deformation (mm)	Load (KN)	Deformation (mm)	Load (KN)	Deformation (mm)	Load (KN)
0	5.41	0	5.41	0	4.92
0	7.5	0	7.5	0	5.04
0	8.25	0	8.25	0	8.51
0	8.92	0	8.92	0	9.67
0.0098	9.98	0.0098	9.98	0.001	11.72
0.0299	11.12	0.0299	11.12	0.015	12.5
0.05	12.3	0.05	12.3	0.029	13.3

0.067	13.61	0.067	13.61	0.04	14.18
0.08	15.02	0.08	15.02	0.055	15.07
0.0999	16.5	0.0999	16.5	0.069	15.97
0.115	18.03	0.115	18.03	0.08	17.2
0.13	19.54	0.13	19.54	0.092	17.94
0.145	21.06	0.145	21.06	0.108	18.89
0.158	22.52	0.158	22.52	0.123	19.88
0.172	24.2	0.172	24.2	0.131	20.95
0.185	25.84	0.185	25.84	0.141	22.02
0.199	27.54	0.199	27.54	0.151	23.18
0.212	29.25	0.212	29.25	0.16	24.4
0.224	31.05	0.224	31.05	0.169	25.66
0.242	32.84	0.242	32.84	0.175	26.94
0.252	35.13	0.252	35.13	0.183	28.3
0.261	36.54	0.261	36.54	0.189	29.66
0.273	38.5	0.273	38.5	0.195	31.05
0.3	38.85	0.283	40.51	0.2	32.43
0.304	40.1	0.294	42.53	0.208	33.91
0.305	41.81	0.303	44.51	0.211	35.42
0.309	43.55	0.313	46.62	0.219	36.99
0.32	45.28	0.324	48.67	0.225	38.53
0.331	47.89	0.329	50.8	0.23	40.06
0.343	48.81	0.34	52.95	0.239	41.57
0.353	50.7	0.345	55.09	0.244	43.19
0.365	50.9	0.35	57.29	0.251	44.86
0.369	52.59	0.357	59.34	0.26	46.56
0.376	54.38	0.365	61.61	0.27	48.33
0.387	56.66	0.373	63.86	0.28	50.15
0.399	57.95	0.381	66.13	0.297	51.92
0.41	59.87	0.388	68.39	0.296	53.79
0.423	61.62	0.395	70.66	0.304	55.65
0.433	63.49	0.405	72.78	0.313	57.55
0.455	65.34	0.409	75	0.32	59.41
0.459	67.24	0.419	77.25	0.329	61.28
0.471	69.13	0.425	79.42	0.335	63.08
0.485	71.04	0.433	81.61	0.345	64.98
0.498	72.94	0.439	83.77	0.355	67.36
0.51	74.74	0.45	85.75	0.364	68.86
0.523	76.78	0.458	87.83	0.372	70.8
0.535	78.82	0.467	89.81	0.384	72.57
0.54	78.62	0.487	91.77	0.395	74.5
0.545	80.69	0.49	93.64	0.413	76.37

0.556	88.58	0.504	95.61	0.419	78.23
0.569	84.52	0.524	95.09	0.43	80.05
0.58	86.95	0.538	96.45	0.439	81.96
0.59	88.89	0.553	98.15	0.45	83.58
0.601	90.22	0.565	99.77	0.466	85.65
0.613	92.1	0.577	101.75	0.483	86.88
0.624	93.96	0.592	102.98	0.497	88.42
0.639	95.81	0.604	104.57	0.514	89.89
0.648	97.58	0.615	106.09	0.53	91.45
0.66	99.31	0.627	107.66	0.549	93.06
0.673	101.5	0.639	109.25	0.564	95.16
0.684	102.76	0.652	110.81	0.58	96.79
0.695	104.8	0.664	112.39	0.599	98.03
0.714	106	0.679	113.95	0.612	99.75
0.732	107.26	0.69	115.5	0.629	101.36
0.755	108.85	0.704	117.26	0.643	103.37
0.769	109.29	0.719	118.31	0.658	104.61
0.79	110.71	0.733	119.6	0.67	106.26
0.799	112.18	0.753	120.21	0.685	107.85
0.813	113.67	0.778	121.21	0.69	109.42
0.827	115.16	0.783	122.55	0.7	110.94
0.841	116.57	0.787	123.96	0.729	112.47
0.853	118.03	0.802	125.37	0.74	114.02
0.869	119.26	0.818	126.74	0.751	115.52
0.889	120.29	0.834	128.1	0.765	117.07
0.903	121.61	0.85	129.49	0.779	118.54
0.924	122.38	0.869	130.79	0.791	119.88
0.937	123.37	0.879	132.14	0.8	121.44
0.945	123.47	0.891	133.48	0.81	122.85
0.967	123.84	0.908	134.84	0.82	124.33
0.97	123.64	0.928	136.41	0.829	125.75
0.978	123.96	0.935	137.36	0.836	127.17
0.98	124.27	0.95	138.62	0.841	128.52
0.987	124.66	0.969	139.78	0.849	129.87
0.993	125.09	0.98	141.01	0.85	131.21
1	125.32	0.994	142.25	0.85	132.54
1.008	125.6	1.009	143.47	0.85	133.86
1.015	125.87	1.025	144.62	0.85	135.15
1.022	125.98	1.035	145.68	0.85	136.44
1.029	126.12	1.05	146.74	0.85	137.74
1.036	126.21	1.067	147.8	0.85	139.74
1.043	126.31	1.08	148.86	0.85	139.01

1.051	126.37	1.104	149.88	0.85	140.23
1.101	126.45	1.109	150.88	0.86	141.48
1.124	126.82	1.124	151.83	0.87	142.67
1.13	126.94	1.135	152.79	0.88	143.85
1.14	127.15	1.154	153.64	0.895	145.05
1.145	127.32	1.174	154.45	0.905	146.23
1.153	127.45	1.185	155.54	0.919	147.47
1.163	127.61	1.105	155.92	0.931	148.9
1.168	127.73	1.125	156.62	0.947	149.77
1.175	127.9	1.14	157.31	0.965	150.95
1.182	128.04	1.154	157.83	0.979	152.16
1.19	128.2	1.174	158.49	0.993	153.3
1.199	128.4	1.19	159.03	0.999	154.44
1.206	128.52	1.21	159.75	1.024	155.48
1.214	128.62	1.224	160.11	1.039	156.56
1.223	128.77	1.24	160.67	1.06	157.69
1.23	128.92	1.259	161.18	1.07	158.71
1.24	129.07	1.275	161.67	1.085	159.74
1.246	129.18	1.291	162.25	1.1	160.72
1.253	129.33	1.308	162.67	1.119	161.55
1.261	129.4	1.323	163.08	1.139	162.26
1.269	129.52	1.34	163.53	1.16	162.46
1.279	129.69	1.364	163.83	1.203	162.85
1.284	129.77	1.379	164.21	1.223	163.47
1.292	129.9	1.394	164.62	1.245	163.99
1.299	130.06	1.411	165.02	1.27	164.43
1.309	130.18	1.429	165.52	1.29	164.83
1.314	130.28	1.44	165.76	1.314	165.25
1.323	130.48	1.462	166.14	1.333	165.81
1.33	130.5	1.479	166.49	1.352	166.45
1.339	130.64	1.504	166.77	1.379	166.76
1.346	130.77	1.512	167.03	1.4	166.96
1.354	130.93	1.53	167.42	1.419	167.14
1.362	131.01	1.54	167.65	1.439	167.44
1.369	131.17	1.562	167.94	1.462	167.78
1.378	131.26	1.58	168.25	1.482	168.19
1.385	131.29	1.599	168.53	1.505	168.49
1.392	131.4	1.61	168.75	1.527	168.78
1.435	131.41	1.629	168.89	1.55	169.39
1.444	131.55	1.639	169.18	1.571	169.71
1.53	131.55	1.66	169.59	1.591	169.9
1.632	130.28	1.678	169.89	1.61	170.09

1.723	128.05	1.693	170.15	1.631	170.74
1.755	128.05	1.713	170.51	1.651	171.19
1.768	128.05	1.724	170.63	1.671	171.54
		1.734	170.75	1.697	171.95
		1.755	171.04	1.713	172.34
		1.772	171.25	1.738	172.7
		1.788	171.49	1.76	173.03
		1.81	171.7	1.78	173.43
		1.818	171.86	1.796	173.79
		1.831	172.04	1.819	174.25
		1.849	172.2	1.838	174.63
		1.865	172.34	1.862	175.02
		1.881	172.52	1.875	175.29
		1.898	172.7	1.892	175.7
		1.913	172.91	1.911	175.93
		1.929	173.13	1.93	176.26
		1.94	173.36	1.95	176.52
		1.96	173.65	1.979	176.8
		1.973	173.86	2.042	177.39
		1.989	174.04	2.065	177.96
		2.003	174.22	2.082	178.41
		2.018	174.33	2.102	178.77
		2.034	174.54	2.124	179.15
		2.051	174.82	2.15	179.47
		2.064	175.05	2.168	179.82
		2.08	175.38	2.183	180.19
		2.094	175.92	2.21	180.43
		2.109	175.68	2.23	180.76
		2.129	175.92	2.252	180.97
		2.141	176.1	2.279	181.25
		2.16	176.35	2.298	181.66
		2.171	176.55	2.322	181.88
		2.189	176.68	2.342	182.12
		2.205	176.91	2.362	182.37
		2.221	177.09	2.381	182.69
		2.235	177.31	2.402	182.82
		2.251	177.49	2.429	183.01
		2.269	177.73	2.449	183.17
		2.28	177.92	2.47	183.25
		2.299	178.12	2.49	183.44
		2.313	178.33	2.511	183.54
		2.324	178.93	2.56	183.64

		2.341	178.71	2.579	184.13
		2.36	178.9	2.597	184.5
		2.371	179.1	2.62	184.77
		2.388	179.31	2.639	184.97
		2.404	179.5	2.641	185.21
		2.423	179.71	2.642	185.39
		2.433	179.91	2.643	185.62
		2.45	180.1	2.643	185.85
		2.464	180.3	2.655	186.08
		2.481	180.55	2.655	186.34
		2.498	180.65	2.655	186.57
		2.507	180.87	2.655	186.72
		2.509	181.07	2.655	186.98
		2.512	181.3	2.655	187.15
		2.526	181.44	2.655	187.32
		2.535	181.61	2.655	187.57
		2.549	181.83	2.655	187.81
		2.565	181.99	2.655	188
		2.579	182.22	2.655	188.18
		2.594	182.33	2.655	188.36
		2.603	182.51	2.655	188.58
		2.616	182.67	2.655	188.8
		2.62	182.82	2.655	188.96
		2.63	182.99	2.655	189.15
		2.643	183.15	2.655	189.33
		2.654	183.29	2.655	189.49
		2.661	183.59	2.655	189.72
		2.684	183.69	2.655	189.87
		2.696	183.82	2.655	190.06
		2.704	184.06	2.655	190.4
		2.716	184.19	2.655	190.56
		2.721	184.3	2.655	190.75
		2.729	184.48	2.655	190.86
		2.735	184.62	2.655	191.18
		2.749	184.83	2.655	191.32
		2.757	184.98	2.655	191.46
		2.769	185.11	2.655	191.61
		2.777	185.31	2.655	191.71
		2.789	185.47	2.655	191.77
		2.799	185.74	2.655	191.8
		2.8	185.9		
		2.802	186.01		

		2.84	186.19		
		2.852	186.27		
		2.885	186.42		
		2.91	186.55		
		2.929	186.66		
		2.943	186.75		
		2.963	186.89		
		2.98	187.07		
		2.99	189.6		
		3	187.07		

Table B.3.3. Load vs Deformation for beams exposed to fire under 600<sup>0</sup>Cand 4hr

0% of glass fiber		0.18% of glass fiber		0.27% of glass fiber	
Deformation (mm)	Load (KN)	Deformation (mm)	Load (KN)	Deformation (mm)	Load (KN)
0	4.38	0	6.11	0	4.38
0	4.65	0	6.54	0	4.65
0	4.97	0	8.09	0	4.97
0.009	5.29	0.005	7.09	0.009	5.29
0.015	5.69	0.019	7.7	0.015	5.69
0.025	5.99	0.035	8.34	0.025	5.99
0.035	6.41	0.05	9.01	0.035	6.41
0.044	6.8	0.07	9.69	0.044	6.8
0.05	7.23	0.08	10.4	0.05	7.23
0.053	7.79	0.098	11.18	0.053	7.79
0.059	8.2	0.125	11.82	0.059	8.2
0.06	8.86	0.144	12.62	0.06	8.86
0.07	9.31	0.163	13.41	0.07	9.31
0.083	9.86	0.172	14.82	0.083	9.86
0.095	10.57	0.199	15.23	0.095	10.57
0.105	11	0.232	15.84	0.105	11
0.125	11.61	0.24	16.88	0.125	11.61
0.146	12.46	0.27	16.72	0.146	12.46
0.169	12.96	0.29	16.92	0.169	12.96
0.19	13.76	0.295	17.48	0.19	13.76
0.21	14.26	0.31	18.97	0.21	14.26
0.225	14.8	0.335	19.26	0.225	14.8
0.23	14.91	0.36	20.16	0.23	14.91
0.245	15.54	0.382	21.08	0.245	15.54
0.258	15.95	0.409	22.05	0.258	15.95
0.265	16.45	0.436	22.99	0.265	16.45
0.27	17	0.452	23.95	0.27	17
0.294	17.73	0.47	24.87	0.294	17.73

0.31	18.59	0.492	25.87	0.31	18.59
0.325	19.67	0.512	26.9	0.325	19.67
0.34	20.32	0.532	27.88	0.34	20.32
0.354	21.21	0.549	28.89	0.354	21.21
0.365	22.14	0.569	29.8	0.365	22.14
0.375	23.06	0.584	30.98	0.375	23.06
0.386	24.02	0.61	31.88	0.386	24.02
0.399	24.94	0.615	33.26	0.399	24.94
0.414	25.94	0.619	33.27	0.414	25.94
0.429	27.14	0.629	33.8	0.429	27.14
0.439	27.17	0.635	34	0.439	27.17
0.445	27.93	0.644	35.06	0.445	27.93
0.464	28.93	0.66	36.09	0.464	28.93
0.484	30	0.679	36.2	0.484	30
0.51	31.09	0.68	37.2	0.51	31.09
0.525	32.21	0.69	38.26	0.525	32.21
0.55	33.29	0.709	39.28	0.55	33.29
0.58	34.31	0.721	40.34	0.58	34.31
0.6	35.4	0.735	41.39	0.6	35.4
0.633	36.77	0.75	42.51	0.633	36.77
0.654	37.67	0.76	43.57	0.654	37.67
0.673	38.78	0.773	44.64	0.673	38.78
0.693	39.94	0.775	45.72	0.693	39.94
0.713	41.05	0.8	46.73	0.713	41.05
0.73	42.21	0.809	47.79	0.73	42.21
0.75	43.41	0.824	48.89	0.75	43.41
0.763	44.56	0.84	49.85	0.763	44.56
0.774	45.73	0.85	50.85	0.774	45.73
0.795	46.9	0.862	51.83	0.795	46.9
0.805	48.93	0.879	53.19	0.805	48.93
0.82	49.24	0.89	53.89	0.82	49.24
0.83	50.41	0.905	55.01	0.83	50.41
0.842	51.66	0.925	56.01	0.842	51.66
0.852	52.84	0.93	57.06	0.852	52.84
0.86	54.03	0.949	58.12	0.86	54.03
0.872	55.26	0.96	59.2	0.872	55.26
0.89	56.51	0.978	60.25	0.89	56.51
0.903	57.85	0.995	61.27	0.903	57.85
0.914	59.11	1.009	62.36	0.914	59.11
0.934	60.44	1.025	63.4	0.934	60.44
0.95	61.72	1.041	64.4	0.95	61.72
0.965	63.1	1.045	64.45	0.965	63.1

0.982	64.42	1.055	65.49	0.982	64.42
1.003	65.7	1.067	66.59	1.003	65.7
1.016	67.38	1.07	67.65	1.016	67.38
1.035	68.37	1.075	68.61	1.035	68.37
1.055	69.64	1.08	68.71	1.055	69.64
1.07	70.98	1.09	69.69	1.07	70.98
1.329	81.74	1.1	69.89	1.085	72.26
1.34	82.82	1.105	70.71	1.1	73.55
1.355	83.78	1.112	71.77	1.124	74.9
1.381	84.55	1.12	73	1.136	76.5
1.4	85.36	1.129	73.73	1.155	77.52
1.42	86.06	1.14	74.64	1.175	78.83
1.44	86.45	1.149	75.58	1.193	80.11
1.47	86.97	1.165	76.41	1.205	81.42
1.485	87.28	1.186	77.39	1.227	82.66
1.495	87.51	1.19	78.34	1.246	84.26
1.52	87.65	1.204	79.27	1.268	85.22
1.525	87.67	1.219	80.11	1.275	86.82
1.54	88.01	1.233	81.19	1.296	86.94
1.565	88.1	1.248	81.79	1.312	87.74
1.589	88.2	1.264	82.49	1.327	89.27
1.615	88.28	1.28	83.15	1.346	90.15
		1.29	83.3	1.365	91.37
		1.322	85.05	1.395	92.62
		1.349	86.06	1.405	94.12
		1.368	87.03	1.425	94.98
		1.39	87.82	1.445	96.16
		1.409	87.81	1.465	97.34
		1.429	89.74	1.484	98.42
		1.45	90.7	1.504	99.48
		1.469	91.46	1.524	100.56
		1.489	92.5	1.525	101.63
		1.508	93.47	1.555	102.69
		1.528	94.47	1.574	103.9
		1.543	95.42	1.6	104.79
		1.559	96.33	1.605	105.42
		1.58	97.34	1.625	106.35
		1.599	98.08	1.655	107.22
		1.618	98.96	1.694	108.04
		1.637	99.78	1.719	109.65
		1.654	100.59	1.725	110.39
		1.679	101.4	1.754	111.08

		1.69	102.42	1.774	111.79
		1.713	102.87	1.799	112.45
		1.728	103.32	1.823	113.21
		1.8	103.32	1.828	113.76
		1.9	94.08	1.857	114.04
		2	94.08	1.874	114.44
		2.1	96.56	1.897	114.97
				1.91	115.5
				1.926	115.83
				1.95	116.21
				1.975	116.49
				1.994	116.55
				2.016	117.01
				2.026	117.23
				2.05	117.69
				2.07	118.13
				2.085	118.56
				2.104	119.05
				2.125	119.45
				2.144	119.93
				2.166	120.38
				2.185	120.8
				2.21	121.18
				2.217	121.82
				2.235	121.62
				2.236	121.99
				2.265	122.36
				2.295	122.74
				2.314	123.22
				2.335	123.47
				2.356	123.64
				2.362	123.91
				2.364	124.02

**B.4. Time vs Temperature for 150°C, 300°C, 450°C and 600°C**

Table B.4.1. Time vs Temperature for 150°C

Time(min)	Actual Temperature(°C)	Temperature based on modified equation(°C)	Temperature based on ISO equation(°C)
0	34	34	34
1	35	35	364.3006

3	40	40	522.53442
4	45	45	569.20486
5	50	50	606.7966
5	55	55	611.7966
6	60	60	643.569
6	65	65	648.569
7	70	71	676.29025
7	75	76	681.29025
8	80	81	706.02778
8	85	86	711.02778
8	90	91	716.02778
9	95	96	738.47574
9	100	101	743.47574
10	105	106	764.11099
10	110	111	769.11099
11	115	116	788.27535
11	120	121	793.27535
11	125	126	798.27535
12	130	131	816.22218
12	135	136	821.22218
12	140	141	826.22218
13	145	146	843.14451
13	150	151	848.14451

Table B.4.2. Time vs Temperature for 300<sup>0</sup> C

Time(min)	Actual Temperature( <sup>0</sup> c)	Temperate based on modified equation( <sup>0</sup> c)	Temperate based on ISO equation( <sup>0</sup> c)
0	23	23	23
1	25	25	354.2137
2	30	30	454.5049
3	35	35	517.2893
4	40	40	563.8873
4	45	45	568.8873
5	50	50	606.4104
5	55	55	611.4104
6	60	60	643.1176
6	65	65	648.1176
7	70	71	675.7768
7	75	76	680.7768
8	80	81	705.4551
8	85	86	710.4551

8	90	91	715.4551
9	95	96	737.8464
9	100	101	742.8464
9	105	106	747.8464
10	110	111	768.4273
10	115	116	773.4273
11	120	121	792.5396
11	125	126	797.5396
11	130	131	802.5396
12	135	136	820.4362
12	140	141	825.4362
12	145	146	830.4362
13	150	151	847.3103
13	155	156	852.3103
14	160	161	868.3121
14	165	166	873.3121
14	170	171	878.3121
15	175	176	893.561
15	180	181	898.561
16	185	186	913.1535
16	190	191	918.1535
16	195	196	923.1535
17	200	201	937.1686
17	205	206	942.1686
18	210	211	955.672
18	215	216	960.672
19	220	221	973.7185
19	225	226	978.7185
20	230	231	991.3549
20	235	236	996.3549
21	240	241	1008.621
21	245	246	1013.621
22	250	251	1025.551
22	255	256	1030.551
23	260	261	1042.174
23	265	266	1047.174
24	270	271	1058.517
24	275	276	1063.517
26	280	281	1080.45
29	285	286	1101.738
30	290	291	1111.796
31	295	296	1121.689
32	300	302	1131.427

Table B.4.3. Time vs Temperature for 450<sup>0</sup> C

Time(min)	Actual Temperature( <sup>0</sup> c)	Temperate based on modified equation( <sup>0</sup> c)	Temperate based on ISO equation( <sup>0</sup> c)
0	105	105	105
2	110	110	534.5049
2	115	115	539.5049
3	120	120	602.2893
4	125	125	648.8873
4	130	130	653.8873
5	135	135	691.4104
5	140	140	696.4104
6	145	145	728.1176
6	150	150	733.1176
7	155	156	760.7768
7	160	161	765.7768
8	165	166	790.4551
8	170	171	795.4551
9	175	176	817.8464
9	180	181	822.8464
10	185	186	843.4273
10	190	191	848.4273
10	195	196	853.4273
11	200	201	872.5396
11	205	206	877.5396
12	210	211	895.4362
12	215	216	900.4362
13	220	221	917.3103
13	225	226	922.3103
13	230	231	927.3103
14	235	236	943.3121
14	240	241	948.3121
15	245	246	963.561
15	250	251	968.561
16	255	256	983.1535
16	260	261	988.1535
16	265	266	993.1535
17	270	271	1007.169
18	275	276	1020.672
18	280	281	1025.672
18	285	286	1030.672
19	290	291	1043.719
20	295	296	1056.355
20	300	301	1061.355

21	305	306	1073.621
22	310	311	1085.551
26	310	311	1110.45
28	305	306	1116.503
29	300	301	1116.738
31	295	296	1121.689
33	295	297	1131.02
34	300	302	1140.476
35	305	307	1149.804
36	310	312	1159.01
37	315	317	1168.101
38	320	322	1177.083
39	325	327	1185.963
41	325	327	1193.433
43	320	322	1195.548
44	315	317	1193.982
46	310	312	1195.624
48	305	307	1196.984
50	310	312	1208.085
51	315	317	1216.045
52	320	322	1223.947
53	325	327	1231.794
54	330	332	1239.588
55	335	337	1247.331
61	330	332	1257.812
62	325	327	1255.243
64	320	322	1254.99
66	320	322	1259.592
67	325	327	1266.841
68	330	332	1274.057
69	335	337	1281.24
69	340	342	1286.24
70	345	347	1293.392
71	350	352	1300.514
75	350	352	1308.712
77	345	347	1307.648
78	340	342	1304.579
80	335	337	1303.366
82	335	337	1307.06
84	340	342	1315.665
84	345	347	1320.665
85	350	353	1327.436
86	355	358	1334.186
86	360	363	1339.186
88	365	368	1347.625

90	365	368	1350.988
92	360	363	1349.276
94	355	358	1347.494
98	350	353	1348.73
99	350	353	1350.249
100	355	358	1356.753
101	360	363	1363.242
101	365	368	1368.242
102	370	373	1374.717
103	375	378	1381.177
104	380	383	1387.623
108	375	378	1388.271
110	370	373	1386.017
112	365	368	1383.713
113	360	363	1380.044
115	365	368	1387.67
117	370	373	1395.25
117	375	378	1400.25
118	380	383	1406.524
119	385	388	1412.787
119	390	393	1417.787
121	395	398	1425.282
122	395	398	1426.514
125	390	393	1425.15
126	385	388	1421.342
128	380	383	1418.7
130	375	378	1416.021
131	375	378	1417.168
132	380	383	1423.306
133	385	388	1429.436
134	390	393	1435.557
135	395	398	1441.67
135	400	403	1446.67
136	405	408	1452.775
138	410	413	1459.96
141	405	408	1458.179
142	400	403	1454.237
145	395	398	1452.367
146	390	393	1448.396
147	390	393	1449.418
149	395	398	1456.441
150	400	403	1462.442
150	405	408	1467.442
151	410	413	1473.437
152	415	418	1479.425

153	420	423	1485.407
157	420	423	1489.271
159	415	418	1486.166
160	410	413	1482.104
162	405	408	1478.964
165	405	408	1481.711
166	410	413	1487.616
167	415	418	1493.515
168	420	423	1499.409
169	425	428	1505.298
169	430	433	1510.298
171	435	438	1517.059
173	435	438	1518.8
175	430	433	1515.521
177	425	428	1512.223
178	420	423	1508.066
181	420	423	1510.569
182	425	428	1516.394
183	430	433	1522.214
184	435	438	1528.03
184	440	443	1533.03
185	445	448	1538.841
186	450	453	1544.649

Table B.4.4. Time vs Temperature for 600<sup>0</sup> C

Time(min)	Actual Temperature( <sup>0</sup> c)	Temperate based on modified equation( <sup>0</sup> c)	Temperate based on ISO equation( <sup>0</sup> c)
0	60	60	60
3	65	65	547.2893
3	70	70	552.2893
4	75	75	598.8873
5	80	80	636.4104
5	85	85	641.4104
6	90	90	673.1176
6	95	95	678.1176
7	100	101	705.7768
7	105	106	710.7768
8	110	111	735.4551
8	115	116	740.4551
8	120	121	745.4551
9	125	126	767.8464
9	130	131	772.8464
10	135	136	793.4273
10	140	141	798.4273

10	145	146	803.4273
11	150	151	822.5396
11	155	156	827.5396
11	160	161	832.5396
12	165	166	850.4362
12	170	171	855.4362
12	175	176	860.4362
13	180	181	877.3103
13	185	186	882.3103
14	190	191	898.3121
14	195	196	903.3121
14	200	201	908.3121
15	205	206	923.561
15	210	211	928.561
16	215	216	943.1535
16	220	221	948.1535
16	225	226	953.1535
17	230	231	967.1686
17	235	236	972.1686
18	240	241	985.672
18	245	246	990.672
19	250	251	1003.719
19	255	256	1008.719
19	260	261	1013.719
20	265	266	1026.355
20	270	271	1031.355
21	275	276	1043.621
21	280	281	1048.621
22	285	286	1060.551
22	290	291	1065.551
23	295	296	1077.174
23	300	301	1082.174
24	305	306	1093.517
24	310	311	1098.517
25	315	316	1109.603
26	320	321	1120.45
28	325	326	1136.503
30	320	321	1141.796
32	315	317	1146.427
34	310	312	1150.476
36	310	312	1159.01
37	315	317	1168.101
38	320	322	1177.083
39	325	327	1185.963
39	330	332	1190.963

40	335	337	1199.744
41	340	342	1208.433
41	345	347	1213.433
44	350	352	1228.982
46	345	347	1230.624
49	340	342	1235.065
51	335	337	1236.045
52	340	342	1243.947
54	345	347	1254.588
54	350	352	1259.588
55	355	357	1267.331
56	360	362	1275.025
56	365	367	1280.025
56	370	372	1285.025
59	375	377	1297.827
61	375	377	1302.812
63	370	372	1302.636
65	365	367	1302.309
67	360	362	1301.841
68	365	367	1309.057
69	370	372	1316.24
70	375	377	1323.392
71	380	382	1330.514
72	385	387	1337.606
72	390	392	1342.606
73	395	397	1349.669
74	400	402	1356.704
76	400	402	1360.693
79	395	397	1361.484
81	390	392	1360.224
83	385	387	1358.873
84	390	392	1365.665
85	395	398	1372.436
86	400	403	1379.186
87	405	408	1385.915
87	410	413	1390.915
88	415	418	1397.625
89	420	423	1404.316
90	425	428	1410.988
92	425	428	1414.276
94	420	423	1412.494
96	415	418	1410.645
98	410	413	1408.73
100	415	418	1416.753
101	420	423	1423.242

102	425	428	1429.717
103	430	433	1436.177
104	435	438	1442.623
104	440	443	1447.623
105	445	448	1454.055
107	450	453	1461.878
109	445	448	1459.65
111	440	443	1457.371
113	435	438	1455.044
115	435	438	1457.67
117	440	443	1465.25
117	445	448	1470.25
118	450	453	1476.524
119	455	458	1482.787
120	460	463	1489.04
120	465	468	1494.04
122	470	473	1501.514
125	465	468	1500.15
127	460	463	1497.526
129	455	458	1494.865
132	460	463	1503.306
133	465	468	1509.436
134	470	473	1515.557
134	475	478	1520.557
135	480	483	1526.67
136	485	488	1532.775
137	490	493	1538.871
140	490	493	1542.114
142	485	488	1539.237
144	480	483	1536.331
146	475	478	1533.396
148	480	483	1540.433
149	485	488	1546.441
149	490	493	1551.441
150	495	498	1557.442
151	500	503	1563.437
152	505	508	1569.425
152	510	513	1574.425
155	515	518	1582.351
156	510	513	1578.314
158	505	508	1575.221
160	500	503	1572.104
162	495	498	1568.964
164	500	503	1575.801
165	505	508	1581.711

165	510	513	1586.711
166	515	518	1592.616
167	520	523	1598.515
168	525	528	1604.409
168	530	533	1609.409
171	535	538	1617.059
172	530	533	1612.932
174	525	528	1609.663
176	520	523	1606.374
178	515	518	1603.066
180	520	523	1609.739
181	525	528	1615.569
181	530	533	1620.569
182	535	538	1626.394
183	540	543	1632.214
184	545	548	1638.03
184	550	553	1643.03
186	555	558	1649.649
188	550	553	1646.25
190	545	548	1642.835
192	540	543	1639.402
194	535	538	1635.954
196	540	543	1642.49
197	545	548	1648.252
200	550	554	1655.515
200	555	559	1660.515
201	560	564	1666.262
202	565	569	1672.005
203	570	574	1677.744
205	570	574	1679.212
207	565	569	1675.666
209	560	564	1672.106
211	555	559	1668.532
213	555	559	1669.945
214	560	564	1675.646
215	565	569	1681.344
216	570	574	1687.039
217	575	579	1692.731
217	580	584	1697.731
218	585	589	1703.419
219	590	594	1709.105
221	590	594	1710.466
223	585	589	1706.815
224	580	584	1702.485
226	575	579	1698.816

228	570	574	1695.136
230	575	579	1701.444
231	580	584	1707.093
232	585	589	1712.74
232	590	594	1717.74
233	595	599	1723.384
234	600	604	1729.026

## Appendix C- Photographs



Figure C.1. Mixing of concrete with glass fiber



Figure C.2. Cubes casted for compressive strength test



Figure C.3. Cylinders casted for split tensile strength test



Figure C.4. Curing of specimens



Figure C.5. Beams casted for flexural strength test



Figure C.6. Specimens after curing of 28 days



Figure C.7. Specimens inserted in furnace



Figure C.8. Specimens after exposed to fire



Figure C.9. Compressive strength test for cubes after exposed to fire



Figure C.10. Split tensile strength test of cylinders after exposed to fire



Figure C.11. Flexural strength test for RC beams