# BEHAVIOUR OF CONCRETE CONTAINING SLAG UNDER DIFFERENT CURING REGIMES

A Thesis Submitted
in Fulfillment of the Requirement
for the Award of the Degree of

**MASTER OF ENGINEERING**
**IN**
**STRUCTURAL ENGINEERING**

Submitted by:
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**DEPARTMENT OF CIVIL ENGINEERING**
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## DECLARATION

I Dev Langer, hereby declared dissertation entitled **"Behaviour of Concrete Containing Slag Under Different Curing Regimes"** in fulfilment of the requirement for the award of Degree of **Master of Engineering in Structural Engineering** and submitted in Civil Engineering Department, Thapar Institute of Engineering & Technology, Patiala is an authentic record of my work carried out during a period from from January 2018 to July 2018 under the supervision of **Dr. Maneek Kumar, Professor and Dr. Shweta Goyal, Associate Professor,** Department of Civil Engineering, Patiala

The matter presented in this dissertation has not been submitted by me for the award of any other degree of this or any other university

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## CERTIFICATE

This is to certify that above statement made by the student concerned is correct and true to the best of my knowledge and belief.

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**DEV LANGER**

# ABSTRACT

Problems are frequently encountered in producing good quality concrete in hot climates. Inadequate curing results in early cracking or porous and permeable concrete, or both; these effects, in turn, make structures prone to reinforcement corrosion and other processes of degradation. The research investigated that Ordinary Portland cement is one of the main ingredients used for the production of concrete. Unfortunately, production of cement involves emission of large amounts of carbon-dioxide gas into the atmosphere, a major contributor for greenhouse effect and global warming. Hence, it is inevitable either to search for another material or partially replace it by some other material. Ground granulated blast slag (GGBS) is a by-product from the blast-furnace of iron and it is very beneficial in the concrete production. This research investigated the effect of curing on the performance of Ordinary Portland Cement (OPC) and GGBS concretes in a hot climate. Moreover, the effect of cement replacement materials on concrete durability was studied. GGBS was used in three different percentages namely 30%, 50% and 70%. Three curing methods such as water curing, fully sealed with plastic sheet, and wet burlap curing were applied to cure the cube specimens until the days of testing.

The cube specimens were tested to determine the compressive strength and initial surface absorption of the concrete. Test results indicate that water curing as well as sealed with plastic sheet curing provided much better results than wet burlap curing. The rate of moisture movement was significant when the specimens were subjected to wet burlap curing. It restricted the hydration process, and thus affected the compressive strength and other properties of the GGBS concrete. The overall findings of this study suggest that GGBS concrete should be cured by water curing to achieve good hardened properties. The mixes (OPC and GGBS concretes) used in this research were designed to have equal 28-day strength under hot weather conditions. The performance of GGBS concrete was found to be beneficially affected by high curing condition. The strength of GGBS concretes was at all testing ages (3, 7 & 28 days) higher than that of OPC when good curing was provided. The durability of GGBS was also improved, in that the permeability and water absorption considerably decreased with an increase in the percentage of slag and with the application of a good curing. The disadvantage of GGBS concretes is that they proved to be more sensitive to poor curing than OPC concrete. In this case both their strength and permeability, and hence their durability were seriously impaired. Therefore, special care must be taken when using this type of concrete. especially on site where the working conditions and the application of curing are not as easy to control as in the laboratory.

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# INTRODUCTION

## 1.1 GENERAL

Concrete is typically the most widely used individual material element in the built environment. If the embodied energy of concrete can be reduced without decreasing the performance or increasing the cost, significant environmental and economic benefits may be realized. Concrete is primarily comprised of Portland cement, aggregates and water. Although Portland cement typically comprises of only 12% of the concrete mass, it accounts for approximately 93% of the total embodied energy of concrete and 6% to 7% of the worldwide $CO_2$ emissions *(Pandey, et. al, 2016)*. Some remedial measures can be taken to minimize negative effect of concrete on environment.

Waste is one of the main challenges to dispose and manage. It has become one of the major environmental, economical and social issues. Recycling is the most promising waste management process for disposal of materials like agricultural waste and Industrial by-products. Some of the waste materials that can be used in concrete are GGBS, fly ash, silica fume, rise husk, phosphogypsum etc. The use of these waste materials in concrete serve the dual purpose of waste management and reduction in embodied energy of concrete.

The Ground Granulated Blast Slag is a by-product of iron manufacturing industry. Iron ore, coke and limestone are fed into the furnace and the resulting molten slag floats above the molten iron at a temperature of about 1500ºC to 1600ºC. The molten slag has a composition of about 30% to 40% $SiO_2$ and about 40% CaO, which is close to the chemical composition of Portland cement *(www.ggbsreviewgroup.blogspot.in)*. After the molten iron is tapped off, the remaining molten slag, which consists of mainly siliceous and aluminous residue is then water-quenched rapidly, resulting in the formation of a glassy granulate. This glassy granulate is dried and ground to the required size, which is known as Ground Granulated Blast Slag (GGBS). The Fig. 1.1 shows the layout of manufacturing plant of GGBS.

The production of GGBS requires little additional energy as compared with the energy needed for the production of Portland cement. The replacement of Portland cement with GGBS will lead to significant reduction of carbon dioxide gas emission. It is therefore an environmentally friendly construction material. GGBS from modern thermal power plants generally does not require processing prior to being incorporated into concrete and is therefore considered to be an environmentally free input material. It can be used to replace as much as 80% of the Portland cement used in concrete *(Pandey et. al, 2016)*. It has better water impermeability characteristics as well as improved resistance to corrosion and sulphate attack. It enhances lower heat of hydration which reduces the risk of thermal cracking. It has higher durability, workability, reduces permeability to external agencies, which helps in making, placing and compaction easier. As a result, the service life of a structure is enhanced and the maintenance cost reduced.

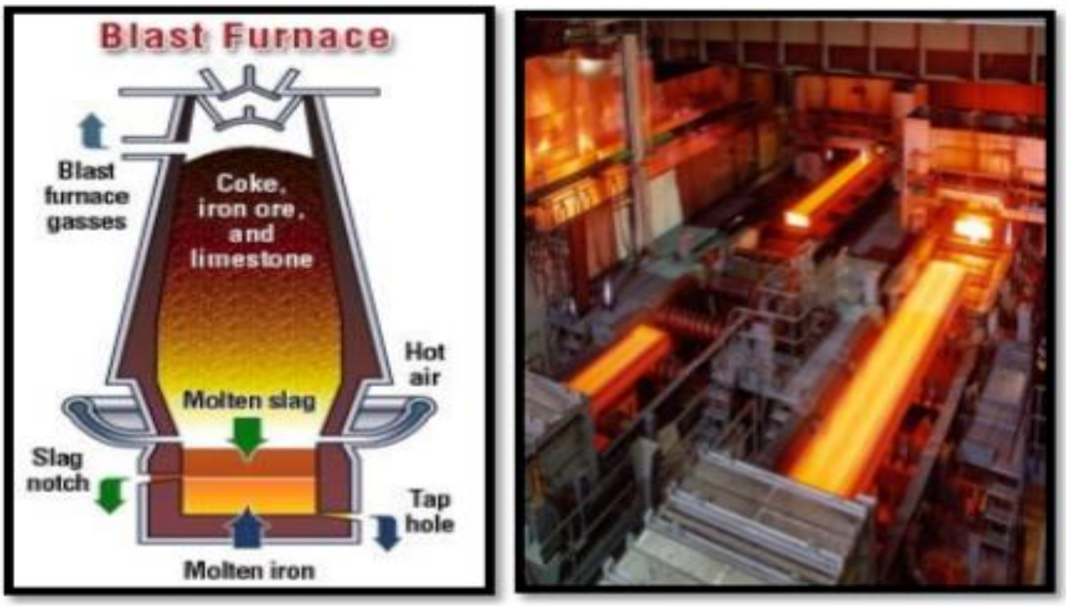


**Figure 1.1: Layout of manufacturing plant of GGBS *(Suresh, D. et. al, 2015)***

## 1.2 PHYSICAL PROPERTIES AND CHEMICAL COMPOSITION OF GGBS

The chemical composition of slag varies considerably depending on the composition of the raw materials in the iron production process. Silicate and aluminate impurities from the ore and coke are combined in the blast furnace with a flux which lowers the viscosity of the slag. In the case of pig iron production, the flux consists mostly of a mixture of limestone and forsterite or in some cases dolomite. In the blast furnace the slag floats on top of the iron and is decanted for separation. Chemical composition and physical composition of GGBS as shown in Table 1.1 and Table 1.2 respectively.

**Table 1.1: Typical chemical composition of GGBS**

| S.No | Composition | Value (%) |
|---|---|---|
| 1. | Calcium oxide | 40% |
| 2. | Silica | 35% |
| 3. | Alumina | 13% |
| 4. | Magnesia | 8% |

The glass content of slag’s suitable for blending with Portland cement typically varies between 90-100% *( Garg, E.K et. al, 2016)* and depends on the cooling method and the temperature at which cooling is initiated. The glass structure of the quenched glass largely depends on the proportions of network-forming elements such as Si and Al over network-modifiers such as Ca, Mg and to a lesser extent Al. Increased amounts of network-modifiers lead to higher degrees of network de-polymerisation and reactivity. It is a granular product with very limited crystal formation, is highly cementitious in nature and, ground to cement fineness, and hydrates like Portland cement.

**Table 1.2 Typical physical properties of GGBS**

| S.No | Characteristics | Value |
|---|---|---|
| 1. | Colour | off white |
| 2. | Specific Gravity | 2.9 |
| 3. | Bulk density | 1200 kg/m$^3$ |
| 4. | Fineness | 350 m$^2$/kg |

## 1.3 EFFECTS OF USING GGBS IN CONCRETE

GGBS hardens very slowly and for use in concrete, it needs to be activated by combining it with Portland cement. A typical combination is 50% GGBS with 50% Portland cement, but percentages of GGBS anywhere between 20 and 80 % are commonly used *(www.ggbsreviewgroup.blogspot.in)*. The greater the percentage of GGBS, the greater will be the effect on concrete properties. The effects of using GGBS on basic properties of concrete can be summarized below.

1. **Sustainability:** Ground granulated blast slag (GGBS) is one of the greenest of construction materials. Its only raw material is a very specific slag that is a by-product from the blast furnaces manufacturing iron. Manufacturing of GGBS utilises all of the slag and produces no significant waste. It offers the environmental benefit of utilising a by product, GGBS replaces something that is produce by a highly energy intensive process. By comparison with Portland cement, manufacture of GGBS requires less than a fifth the energy and produces less than a fifteenth of the carbon dioxide emissions. Further, green benefits are that manufacture of GGBS does not require the quarrying of virgin materials, and if the slag was not used as cement it might have to be disposed of to tip.

**2. Colour:** GGBS is off-white in colour and substantially lighter than Portland cement. This whiter colour is also seen in concrete made with GGBS *(Garg, E.K. et. al, 2016)* especially at addition rates of 50% and above as shown in Fig. 1.2. The more aesthetically pleasing appearance of GGBS concrete can help soften the visual impact of large structures such as bridges and retaining walls. For coloured concrete, the pigment requirements are often reduced with GGBS and the colours are brighter.

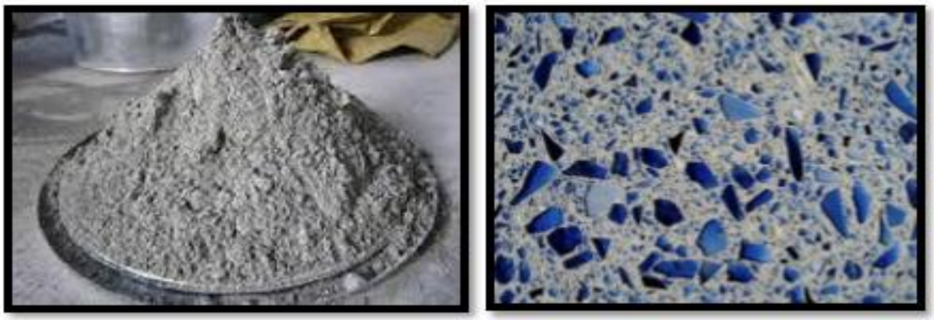


**Figure 1.2: Colour of GGBS** ***(Suresh, D. et. al, 2015)***

**3. Setting time:** The setting time of concrete is influenced by many factors, in particular temperature and water/cement ratio. With GGBS, the setting time will be extended slightly, perhaps by about 30 minutes *( Garg, E.K. et. al, 2016).* The effect will be more pronounced at high levels of GGBS and/or low temperatures as shown in Fig. 1.3. An extended setting time is advantageous in that the concrete will remain workable longer and there will be less risk of cold joints. This is particularly useful in warm weather.

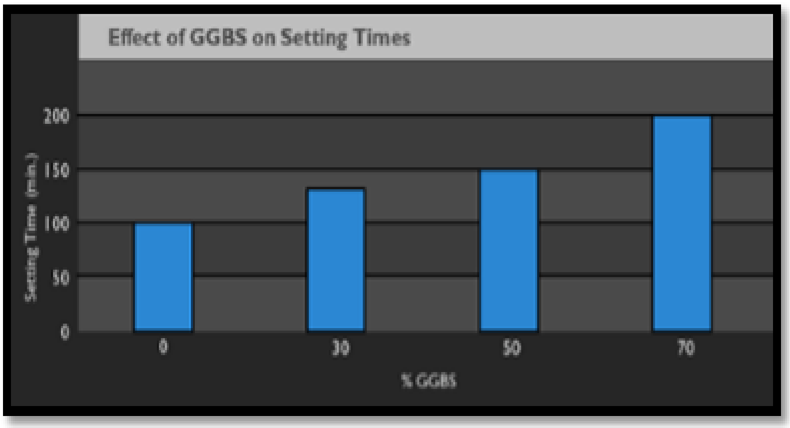


**Figure 1.3: Effect of GGBS on setting time** ***(Suresh, D. et. al, 2015)***

**4. Consistency:** While concretes containing GGBS have a similar, or slightly improved consistence to equivalent Portland cement concrete, fresh concrete containing GGBS tends to require less energy for movement. This makes it easier to place and compact, especially when pumping or using mechanical vibration as shown in Fig.1.4. In addition, it will retain its workability for longer *(Suresh, D. et. al, 2015).*

**Figure 1.4: Showing that the workability is more and pumping is easier *(Suresh, D. et. al, 2015)***

**5. Early age temperature:** The reduction involved in the setting and hardening of concrete generates significant heat and can produce large temperature rises, particularly in thick section pours. This can result in thermal cracking. Replacing Portland cement with GGBS reduces the temperature rise and helps to avoid early age thermal cracking as shown in Fig. 1.5. The greater the percentage of GGBS, the lower will be the rate at which heat is developed and the smaller the maximum temperature rise *( Suresh, D. et. al, 2015).*

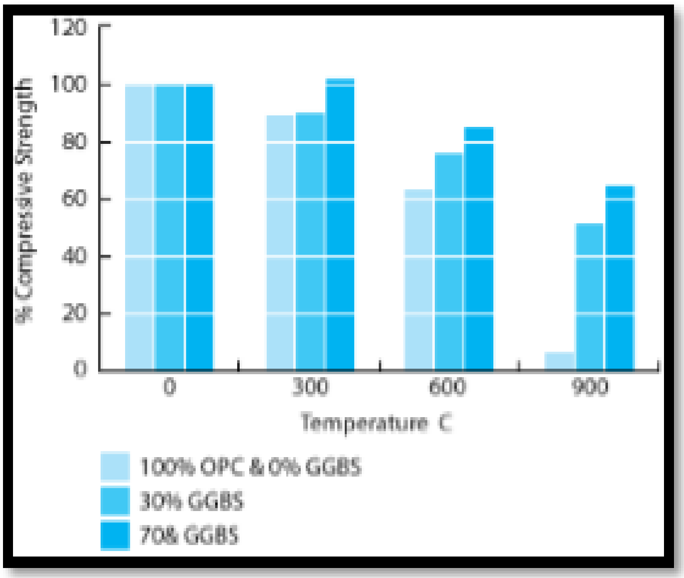


**Figure 1.5: Strength variation of temperature *(Suresh, D. et. al, 2015)***

**6. Permeability and Chemical stability:** The reaction between GGBS, Portland cement and water are complex. When Portland cement reacts with water, the insoluble hydration products (mainly calcium silica hydrates) form close to the cement particle. The more soluble product of hydration (Calcium hydroxide) migrates through the pore solution and precipitates as discrete crystals, surrounded by large pores. When GGBS particles are also present, both the GGBS and Portland cement hydrate to form calcium silicate hydrates.

Additionally, the GGBS react with the excess of calcium hydroxide to form a finely dispersed gel, which fills the larger pores. The result is a hardened cement paste, which contains far fewer calcium hydroxide crystals and therefore has fewer large capillary pores. The reduction in free calcium hydroxide makes concrete chemically more stable, and the finer pore structure limits the ability of aggressive chemicals to diffuse through the concrete.

**7. Corrosion of Reinforcement by Chloride:** Steel embedded in concrete is normally protected against corrosion by the alkalinity created inside concrete by hydrated cement. In such conditions, a passive layer forms on the surface of the steel and rusting is inhibited. However, if significant amounts of chloride are able to penetrate the concrete this protection can be destroyed and the embedded steel will rust and corrode. Because of its finer pore structure, GGBS concrete is substantially more resistant to chloride diffusion than Portland cement concrete. For reinforced concrete structures exposed to chlorides, the use of GGBS will give enhanced durability and a longer useful life. This applies in many situations, including highway structures (particularly bridge parapets), car parks subjected to de-icing salts and coastal environments. Generally, the higher the proportion of GGBS, the greater will be the resistance to chloride penetration.*( Suresh, D. et. al, 2015)*

**8. Alkali-Silica Reaction (ASR):** Alkali ions (sodium and potassium) are present in Portland cement. They are readily soluble in water and are released into the pore solution of concrete when the cement hydrates. Here they can slowly react with certain types of silica in the aggregate to produce an alkali-silicate gel. In wet conditions this gel can absorb water, swell and exert sufficient pressure to crack the concrete. In some cases, the resultant cracking is sufficient to endanger structural integrity. The consequences of ASR can be severe and there is no reliable cure for affected structures. Addition of appropriate percentages of GGBS is an effective means of minimising the risk of damaging ASR *(www.vcem-global.com).*

### 1.4 ADVANTAGES AND DISADVANTAGES OF GGBS

The major use of GGBS is in ready mixed concrete, and it is utilised in a third of all UK, ready-mix deliveries. Specifiers are well aware of the technical benefits, which GGBS imparts to concrete, including:

- Better workability, making placing and compaction easier.

- Lower early age temperature rise, reducing the risk of thermal cracking in large pours.
- Elimination of the risk of damaging internal reactions such as ASR.
- High resistance to chloride ingress, reducing the risk of reinforcement corrosion.
- High resistance to attack by sulphate and other chemicals.
- Considerable sustainability benefits.

In the production of ready mixed concrete, GGBS replaces a substantial portion of the normal Portland cement concrete, generally about 50%, but sometimes up to 70% *(www.ukcsma.co.uk)*. The higher the portion, the better is the durability.

The disadvantage of the higher replacement level is that early age strength development is somewhat slower. The effect of curing in hot climate condition proved that GGBS concrete are more sensitive to poor curing than OPC concrete. In this case both their strength and permeability, and hence their durability, are seriously damaged.

## 1.5 CURING OF CONCRETE

Curing is the maintaining of an adequate moisture content and temperature in concrete at early ages so that it can develop properties the mixture was designed to achieve. Curing begins immediately after placement and finishing so that the concrete may develop the desired strength and durability. Without an adequate supply of moisture, the cementitious materials in concrete cannot react to form a quality product. Drying may remove the water needed for this chemical reaction called hydration and the concrete will not achieve its potential properties.

Temperature is an important factor in proper curing, since the rate of hydration, and therefore, strength development, is faster at higher temperatures. Generally, concrete temperature should be maintained above 50°F (10°C) *(Burg et. al 1996)* for an adequate rate of strength development. Further, a uniform temperature should be maintained through the concrete section while it is gaining strength to avoid thermal cracking.

For exposed concrete, relative humidity and wind conditions are also important; they contribute to the rate of moisture loss from the concrete and could result in cracking, poor surface quality and durability. Protective measures to control evaporation of moisture from concrete surfaces before it sets are essential to prevent plastic shrinkage cracking.

The major benefits of curing are as follows:

1. Concrete strength gain: Concrete strength increase with age as moisture and a favorable temperature is present for hydration of cement. Concrete placed under high temperature conditions will gain early strength quickly but later strengths may be reduced. Concrete

placed in cold weather will take longer to gain strength, delaying form removal and subsequent construction. Fig.1.6 illustrates a comparison of the strength of concrete at 180 days of moist curing with various periods of moist curing (0, 3, 7, 14 and 28 days) and then allowing it to dry out *(Gonnerman and Shuman 1928)*. From the graph, it can be observed that concrete allowed to dry out immediately, achieves only 40% of the strength of the same concrete water cured for the full period of 180 days.

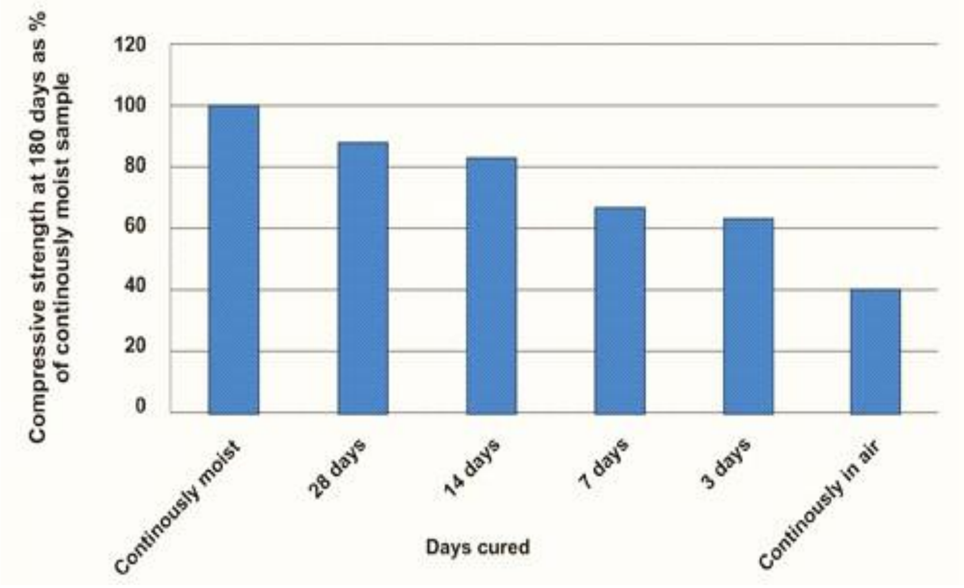


**Figure 1.6: Effect of duration of water curing on strength of concrete *(Gonnerman and Shuman 1928)***

2. Improved durability of concrete: The durability of concrete is affected by a number of factors including its permeability, porosity and absorptivity. Well cured concrete can minimize thermal, plastic and drying shrinkage cracks, making concrete more water tight, thus preventing moisture and water borne chemicals from entering into the concrete and thereby increasing its durability.

3. Enhanced serviceability: Concrete that is allowed to dry out quickly undergoes considerable early age shrinkage. Inadequate curing contributes to weak and dusty surfaces having a poor abrasion resistance.

4. Improved microstructure: Material properties are directly related to their microstructure. Curing assists the cement hydration reaction to progress steadily and develops calcium silicate hydrate gel, which binds the aggregates leading to a rock solid mass, makes the concrete denser, decreases the porosity and enhances the mechanical properties of concrete.

### 1.5.1 Duration of Curing and Right Time to Cure Concrete

The duration of curing of concrete depends on the grade and type of cement, mix proportion, desired concrete strength, shape and size of the concrete member and environmental and exposure conditions. The duration may vary from few days to a month. IS-456:2000 provisions for duration of Curing (Indian Standard-Plain and Reinforced Concrete-Code of Practice). Exposed surfaces of concrete shall be kept continuously damp or in a wet condition by ponding or by covering with sacks, canvas, hessian or other similar material and kept continuously wet for at least 7 days from the date of placing, in case of Ordinary Portland Cement (OPC) and at least 10 days when mineral admixtures or blended cements are used. In case of concrete where mineral admixtures or blended cements are used, it is recommended that the above minimum periods may be extended to 14 days, for assisting the secondary reaction.

After concrete has been placed in its final position and during the initial set, bleed water rises to the concrete surface as plastic settlement occurs. During this period, if the rate of evaporation of bleed water is greater than the rising water, plastic shrinkage of the concrete occurs. Initial moist curing is necessary to keep the surface moist to prevent the surface from drying out.

Between initial set and final set, intermediate curing would be needed if the finishing is complete prior to final set. This may be in the form of a barrier which prevents the loss of moisture from the concrete surface. e.g. covering the concrete surfaces with plastic sheets, waterproof paper, etc. After final set, meticulous curing will have to be done as per the procedures selected.

### 1.5.2 Curing Methods and Materials

Concrete can be kept moist (and in some cases at a favorable temperature) by three curing methods:

- Methods that maintain the presence of mixing water in the concrete during the early hardening period. These include ponding or immersion, spraying or fogging, and saturated wet coverings. These methods afford some cooling through evaporation, which is beneficial in hot weather.
- Methods that reduce the loss of mixing water from the surface of the concrete. This can be done by covering the concrete with impervious paper or plastic sheets, or by applying membrane-forming curing compounds.
- Methods that accelerate strength gain by supplying heat and additional moisture to the concrete. This is usually accomplished with live steam, heating coils, or electrically heated forms or pads.

The method or combination of methods chosen depends on factors such as availability of curing materials, size, shape, and age of concrete, production facilities (in place or in a plant), esthetic appearance, and economics. As a result, curing often involves a series of procedures used at a particular time as the concrete ages. For example, fog spraying or plastic covered wet burlap can precede application of a curing compound. The timing of each procedure depends on the degree of hardening of the concrete needed to prevent the particular procedure from damaging the concrete surface.

The various methods of curing are as follows:

1. **Ponding and Immersion:** On flat surfaces, such as pavements and floors, concrete can be cured by ponding. Earth or sand dikes around the perimeter of the concrete surface can retain a pond of water. Ponding is an ideal method for preventing loss of moisture from the concrete; it is also effective for maintaining a uniform temperature in the concrete. The curing water should not be more than about 11°C (20°F) cooler than the concrete to prevent thermal stresses that could result in cracking. Since ponding requires considerable labor and supervision, the method is generally used only for small jobs.

**2. Wet coverings:** Fabric coverings saturated with water, such as burlap, cotton mats, rugs, or other moisture-retaining fabrics, are commonly used for curing. Treated burlaps that reflect light and are resistant to rot and fire are available.

**3. Fogging and Sprinkling:** Fogging and sprinkling with water are excellent methods of curing when the ambient temperature is well above freezing and the humidity is low. A fine fog mist is frequently applied through a system of nozzles or sprayers to raise the relative humidity of the air over flat-work, thus slowing evaporation from the surface. Fogging is applied to minimize plastic shrinkage cracking until finishing operations are complete. Once the concrete has set sufficiently to prevent water erosion, ordinary lawn sprinklers are effective if good coverage is provided and water runoff is of no concern. Soaker hoses are useful on surfaces that are vertical or nearly so.

**4. Impervious Paper:** Impervious paper for curing concrete consists of two sheets of craft paper cemented together by a bituminous adhesive with fiber reinforcement. The efficient means of curing horizontal surfaces and structural concrete of relatively simple shapes. An important advantage of this method is that periodic additions of water are not required. Curing with impervious paper enhances the hydration of cement by preventing loss of moisture from the concrete.

**5. Plastic Sheets:** Plastic sheet materials, such as polyethylene film, can be used to cure concrete. Polyethylene film is a lightweight, effective moisture retarder and is easily applied to complex as well as simple shapes. Its application is the same as described for impervious paper. Curing with polyethylene film (or impervious paper) can cause patchy discoloration, especially if the concrete contains calcium chloride and has been finished by hard-steel troweling. This discoloration is more pronounced when the film becomes wrinkled, but it is difficult and time consuming on a large project to place sheet materials without wrinkles. Flooding the surface under the covering may prevent discoloration, but other means of curing should be used when uniform colour is important.

**6. Membrane-Forming Curing Compounds:** Liquid membrane-forming compounds consisting of waxes, resins, chlorinated rubber, and other materials can be used to retard or reduce evaporation of moisture from concrete. They are the most practical and most widely used method for curing not only freshly placed concrete but also for extending curing of concrete after removal of forms or after initial moist curing. However, the most effective methods of curing concrete are wet coverings or water spraying that keeps the concrete continually damp. Curing compounds should be able to maintain the relative humidity of the concrete surface above 80% for seven days to sustain cement hydration.

**7. Internal Moist Curing:** Internal moist curing refers to methods of providing moisture from within the concrete as opposed to outside the concrete. This water should not affect the initial water to cement ratio of the fresh concrete. Lightweight (low-density) fine aggregate or absorbent polymer particles with an ability to retain a significant amount of water may provide additional moisture for concretes prone to self-desiccation. When more complete hydration is needed for concretes with low water to cement ratios (around 0.30 or less), 60 kg/m$^3$ to 180 kg/m$^3$ (100 lb/yd$^3$ to 300 lb/yd$^3$) of saturated lightweight fine aggregate can provide additional moisture to extend hydration, resulting in increased strength and durability. All of the fine aggregate in a mixture can be replaced with saturated lightweight fine aggregate to maximize internal moist curing. Internal moist curing must be accompanied by external curing methods.

**8. Steam Curing:** Steam curing is advantageous where early strength gain in concrete is important or where additional heat is required to accomplish hydration, as in cold weather. Two methods of steam curing are used: live steam at atmospheric pressure (for enclosed cast-in-place structures and large precast concrete units) and high-pressure steam in autoclaves (for small manufactured units). Only live steam at atmospheric pressure will be discussed here. A typical steam-curing cycle consists of (1) an initial delay prior to steaming, (2) a period for increasing the temperature, (3) a period for holding the maximum temperature constant, and (4) a period for decreasing the temperature.

**9. Insulating Blankets or Covers:** Layers of dry, porous material such as straw or hay can be used to provide insulation against freezing of concrete when temperatures fall below 0°C (32°F). Formwork can be economically insulated with commercial blanket or insulation that has a tough moisture proof covering. Suitable insulating blankets are manufactured of fiberglass, sponge rubber, cellulose fibers, mineral wool, vinyl foam, and open-cell poly-urethane foam. When insulated formwork is used, care should be taken to ensure that concrete temperatures do not become excessive. Framed enclosures of canvas tarpaulins, reinforced polyethylene film, or other materials can be placed around the structure and heated by space heaters or steam.

## 1.6 IMPORTANCE OF CURING FOR GGBS CONCRETE

Curing temperature has an important effect on the curing duration required to achieve the designed strength or durability. The curing temperature affects the rate of hydration of cement, which affects the strength development of concrete *(Meeks & Nicholas, 1999)*. *(Neville, 1981)* reported that the rate of hydration increased with a rise in the curing temperature. This is beneficial to the early strength development of concrete up to the age of seven days. When the curing temperature is about 30ºC or above, the strength of seven days onwards may be adversely affected. It explained that a high initial temperature might cause the initial hydration rate to be too high such that there would be insufficient time available for the hydration products to diffuse away from the cementitious grain and precipitate uniformly in the interstitial space. As a result, a high concentration of the hydration products was built up around the hydrating grains retarding the subsequent hydration process and adversely affected the long-term strength of concrete *(Neville, 1981).*

Concrete containing GGBS has slower reaction rates. A longer curing duration is essential for proper development of the properties of GGBS *(Neville, 1996).* Some researchers *(Meeks & Nicholas, 1999)* recommend a minimum curing period of three days for high performance or durable GGBS concrete. The reason is that durability is controlled mainly by the quality of the concrete at surface and good curing is important for the quality of concrete at surface.

High GGBS replacement concrete is more susceptible to poor curing conditions than Portland cement concretes probably due to the reduced formation of hydrate at early ages. Researchers found that curing in air lowered the strength by 21% and 47% for 50% and 65% GGBS replacement concrete respectively as compared to moist-cured samples at 180 days *(Richardson, 2006).* The strength for a 50% GGBS replacement mix with an initial seven days moist curing followed by air curing is not significantly affected as compared to the moist-cured sample of the same GGBS replacement level.

## 1.7 OBJECTIVES

On the basis of study done uptil now, the objectives for the dissertation work have been fixed and details of which are as follows:

Firstly, this project has studied the effect of three curing methods on the performance of GGBS concrete in a hot climate, in an attempt to derive the most appropriate curing regimes suitable to minimise the adverse effects of such climates.

Secondly, the research investigated the effects of different percentages of GGBS i.e. 30%, 50%, and 70% used as cement replacement in concrete on the workability, compressive strength and durability properties of GGBS concrete specimens.

## 1.8 FORMAT OF THESIS

The dissertation report consists of five chapters:

**Chapter 1**: Provides introduction and defines GGBS concrete. This chapter enlists the advantages, limitations and applications of the GGBS concrete. Furthermore, fresh and hardened properties of GGBS concrete has also been discussed.

Chapter 2: Deals with the study of past research done on GGBS concrete.

**Chapter 3:** Details the scheme of experimentation, materials used in this study. Information about test methods and mixes used for GGBS concrete have been discussed in this chapter.

**Chapter 4:** Presents the results and discussion of control and GGBS concrete specimens under different curing regimes in hot climate conditions.

**Chapter 5:** Summarizes and concludes the findings of the inspect. Few recommendations for further studies are also discussed.

# CHAPTER-2

# LITERATURE REVIEW

## 2.1 GENERAL

The hydraulic potential of GGBS was first discovered in Germany in 1862. In 1880 GGBS was first used in combination with Portland cement *(Concrete Society, 1991)*. In Europe, GGBS has been used for over 100 years. In North America, the history of the use of GGBS in quality concrete dates back about 50 years *(Yazdani, 2002).* In Southeast Asian countries including Mainland China and Hong Kong, GGBS was used in concrete in around 1990. Between 1955 and 1995, about 1.1 billion tonnes of cement was produced in Germany, about 150 million tonnes of which consist of slag *(Geiseler et al, 1995)*. In China, the estimated total GGBS production was about 100 million tonnes in 2007 *(Chen, 2006).*

GGBS has been widely used as a partial replacement of Portland cement in construction projects. In Western Europe, the amount of GGBS used accounts for about 20% of the total cement consumed, whereas in the Netherlands it accounts for 60% of the total cement consumption *(Tsinghua University, 2004).*

There are abundant examples of the use of GGBS concrete in construction projects. In New York, the concrete used in the construction of the World Trade Centre has about 40% GGBS replacement *(Slag Cement Association, 2005)*. At the Minneapolis Airport, the airfield pavements were constructed using concrete with 35% GGBS replacement. Other projects using GGBS include the world’s largest aquarium - the Atlanta’s Georgia Aquarium which used 20% to 70% GGBS replacement. The Detroit Metro Airport Terminal Expansion used concrete with 30% GGBS replacement. The Air Train linking New York's John F. Kennedy International Airport with Long Island Rail Road trains used concrete with 20% to 30% GGBS replacement.

In China, GGBS has been widely used in major construction projects such as the Three Gorges Dam, Beijing-Shanghai Express Rail, and Cross-bay Bridge of Hangzhou Bay. The GGBS replacement level is generally around 40% *(China Cements, 2009; ChinaBiz, 2009).*

In Hong Kong, GGBS was used in the construction of the Tsing Ma Bridge, which requires a design life of 120 years. For this project, the GGBS replacement levels were from 59% to about 65%, with a maximum water/(cement+GGBS+silica fume) ratio of about 0.39.

GGBS was also used in the construction of the Stonecutter Island Bridge with GGBS replacement of between 60% and 70%.

For reinforced concrete in a marine environment, the SCCT endorsed in year 2000 a specification, which allows the use of GGBS. The specified replacement level for normal application is in the range of 60% to 75% by mass of the cementitious content whilst for low heat applications it ranges from 60% to 90% *(Standing Committee on Concrete Technology, 2000).*

In India the usage of GGBS for producing concrete at RMC plants is increasing day by day in the southern and western markets due to availability of product and technical superiority. As per survey it is estimated that average consumption of GGBS in the southern RMC industry markets is near to one million mt per year and about 0.4 million mt in the western India and it is continuously growing every year due to merit and availability of product *(L.R. Manjunatha, et. al, 2013).* It is widely used in India for RCC in all types of foundations and super structure works. General building construction, mass concrete works in dams, canals, retaining walls, culverts, underground works, sewage treatment plants, marine work and many more.

## 2.2 EARY AGE STRENGTH DEVELOPMENT

General literature review indicates that GGBS concrete has lower early strengths because the rate of initial reaction of GGBS is slower than that of Portland cement. GGBS is therefore generally grounded to a finer state than Portland cement. Researcher reported that, as the fineness of GGBS increased from around 4000 $cm^2/g$ to 6000 $cm^2/g$, the 28-day strength increased significantly *(Hamling, 1992).*

Lane & Ozyildirum (1999) reported that the early strengths (up to 28 days) of concrete mixes (with 25%, 35%, 50%, and 60% GGBS replacements) were lower than that of Portland cement concrete mixes. By 56 days, the strength of 50% and 60% GGBS mixes exceeded that of the Portland cement mix, and by one year all GGBS mixes were stronger than the Portland cement mixes (Lane & Ozyildirum, 1999).

## 2.3 STRENGTH AND DURABILITY CHARACTERISTICS OF GGBS

**Reshma Rughooputh and Jaylina Rana (2014)** studied the effects of partial replacement of OPC by GGBS on various properties of concrete including compressive strength and initial surface absorption. The mix proportion using GGBS as shown in Table 2.1 and Table 2.2 shows the ISAT results with varying GGBS content. Cement was partially replaced by 30 % and 50 % of GGBS by weight and test was performed at 7 and 28 days. It was found that GGBS in concrete leads to lower early compressive strength gain but higher later compressive strength gains as shown in Fig.2.1. She also observed that the initial surface absorption decreases as the

GGBS content increases because GGBS decreases the permeability of concrete. Based on the results the optimum mix was the one with 50% GGBS.

**Table 2.1 Mix proportion using GGBS *[Reshma et al. (2014)]***

| Materials(kg/m$^3$) | % GGBS | | |
|---|---|---|---|
| | A: 0% | B:30% | C:50% |
| Cement | 388 | 272 | 194 |
| GGBS | 0 | 116 | 194 |
| Coarse aggregates 14/20 | 670 | 670 | 670 |
| Coarse aggregates 6/10 | 335 | 335 | 335 |
| Fine aggregate 0/4 | 857 | 857 | 857 |
| Water | 225 | 225 | 225 |

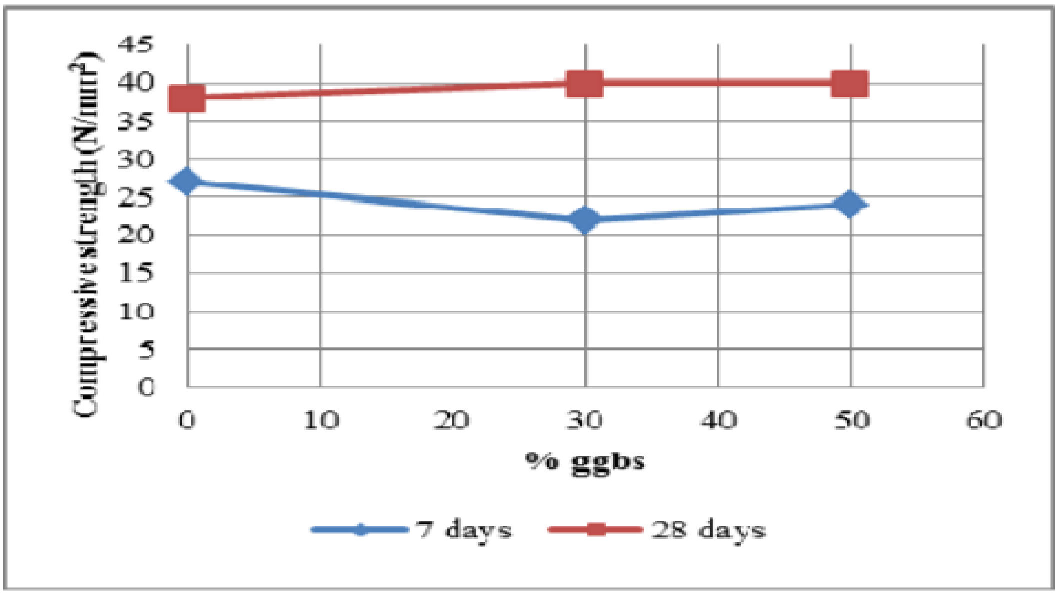


**Figure 2.1: Variation of compressive strength with GGBS content *[Reshma et al. (2014)]***

**Table 2.2: ISAT results with varying GGBS content *[Reshma et al. (2014)]***

| Mix | Initial surface absorption(ml/m$^2$s) | | |
|---|---|---|---|
| | 10 min | 30 min | 60 min |
| A | 0.0500 | 0.0400 | 0.0100 |
| B | 0.0005 | - | - |
| C | 0.000 | - | - |

**A. Oner and S. Akyuz (2007)** conducted a study in which he replaced cement partially with GGBS in various percentages from 15%-110% by weight. Compressive strength test was conducted on test specimens cured at 7, 14, 28, 63, 119, 180 and 365 days and it was found that early age strength values of GGBS concrete mix are lower than control mixtures but as the curing period is extended the strength values increases as shown in Fig. 2.2. This is because the pozzolanic reaction is slow and depends on the calcium hydroxide availability so the strength gain takes longer time for the GGBS concrete. It was also observed that as the percentage of GGBS is increased, the strength gain increases. The optimum level of GGBS content for maximizing strength was found out about 55% – 59% by Bolomey and Feret strength equation. He also found out that as the GGBS content increases, the water/binder ratio decreases for the same workability and thus, the GGBS has positive effects on the workability as shown in Fig. 2.3

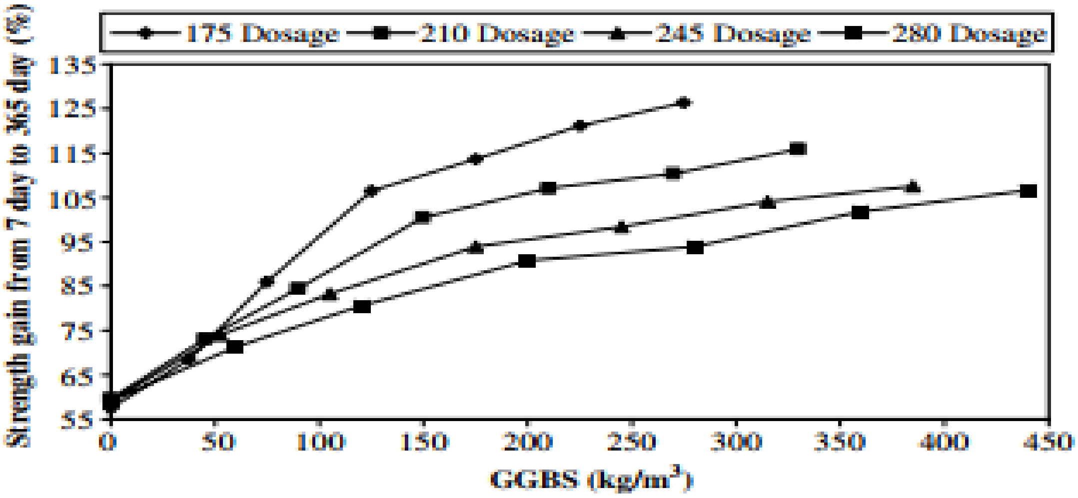


**Figure 2.2: Strength gain from 7 to 365 days in concrete containing GGBS** ***[A. Oner et al. (2007)]***

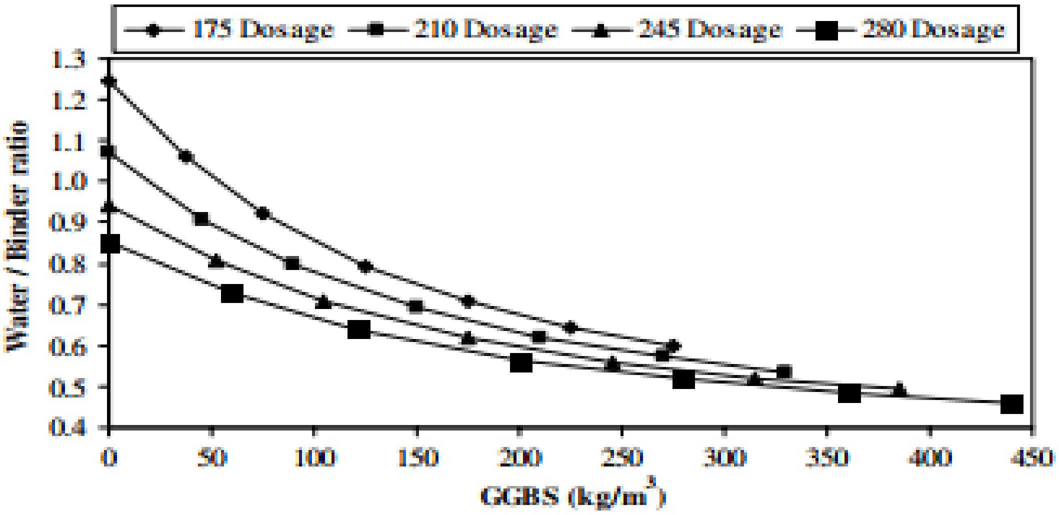


**Figure 2.3: The relation with GGBS content and water/binding ratio for equal workability.** ***[A. Oner et al. (2007)]***

**Magandeep et. Al (2015)** in there paper observed that the Slump values of various mix proportions of GGBS concretes increased when replacement of GGBS increases from 10 to 40 % as shown in Fig. 2.4. Compressive strength decreases as the percentage of GGBS increases at the age of 7 and 28 days but it increases with the increase in percentage of GGBS at the age of 56 days. He also observed that the compressive strength of the mix with 20% and 30% cement replacement better performed than control mix at 56 days where as the mix with 40% cement replacement showed a decrease in strength at 56 days as shown in Fig.2.5. The sulfate resistance and chloride resistance increased in the specimens with 30% GGBS content than the specimens without GGBS.

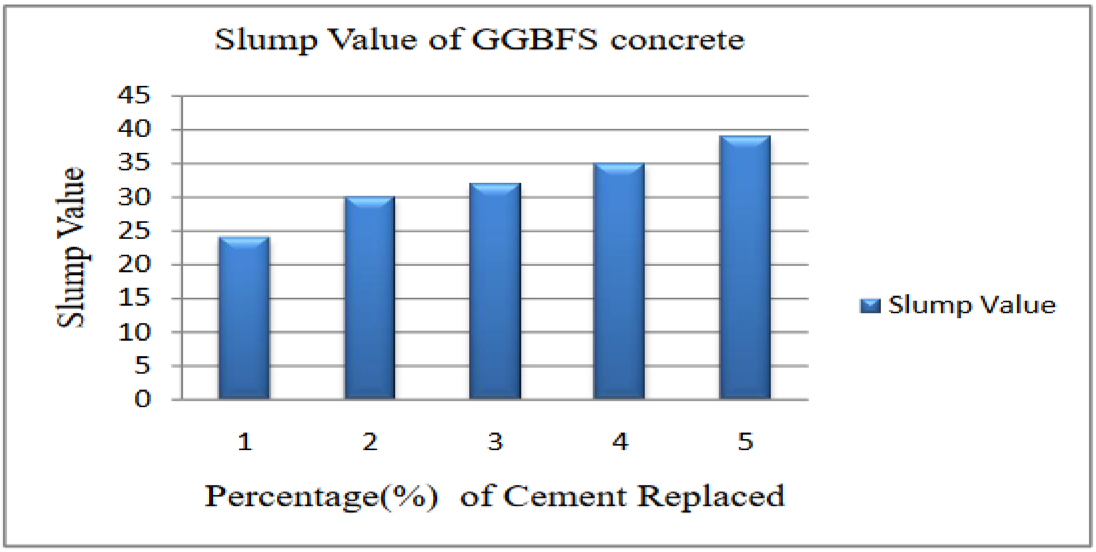


**Figure 2.4: Test result Slump test(cm) of M25 grade concrete with various percentages of GGBS. *[Magandeep et. Al (2015)]***

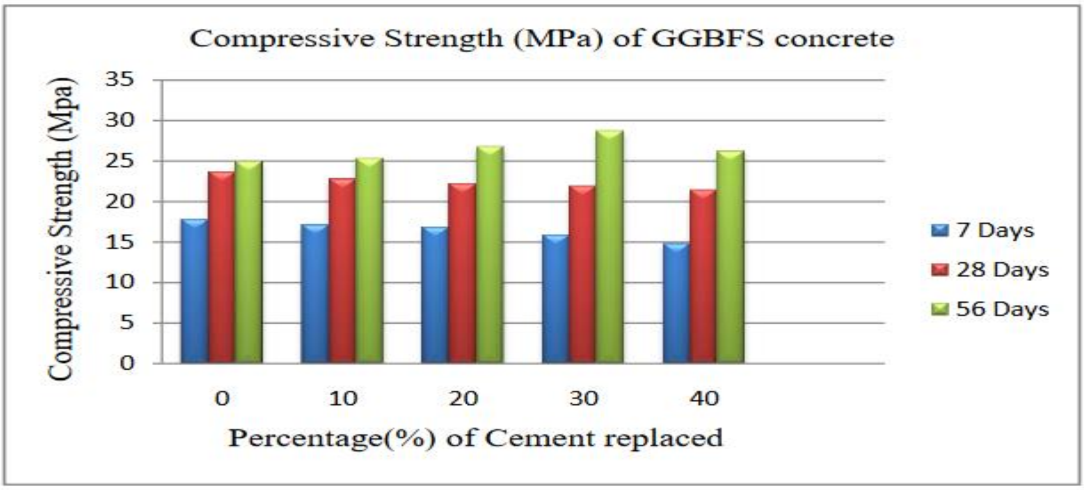


**Figure 2.5: Compressive strength of M25 grade concrete with different percentages of GGBS. *[Magandeep et. Al (2015)]***

**M. Ramalekshmi et. al. (2014)** discussed the results of partial replacement of cement with 50% - 80% of GGBS on compressive strength of concrete at 7, 14 and 28 days. She concluded that slag replacement decreases the strength of concrete in short term when compared to control OPC. However, in long term it exhibits greater final strength. Thus 50% GGBS as replacement showed maximum compressive strength at 28 days as shown in Fig. 2.6. Experiments were also conducted on beam-column with and without GGBS with 50% replacement. The specimen were tested at 28 days under constant axial load and varying lateral load which showed increase in load carrying capacity of the specimen by 6.6 %. Thus 50% GGBFS as replacement can be used in RC specimens.

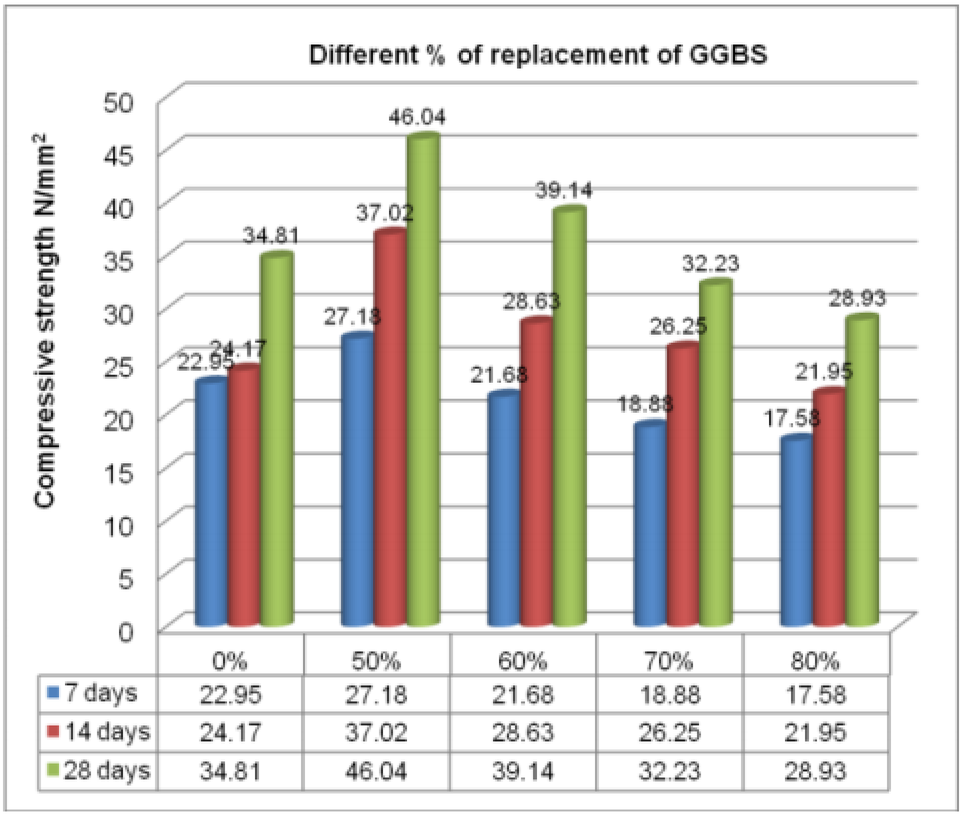


**Figure 2.6: Show the average cube strength test results *[M. Ramalekshmi et. al. (2014)]***

**Yogendra O. Patil et. al. (2013)** researched on the effects on compressive strength of concrete with partial replacement of cement with various percentages of GGBS. The tests were conducted at 7, 28 and 90 days with replacement ranging from 10 % to 40 %. It was observed that the strength of concrete is inversely proportional to the percentage of replacement of cement with GGBS. The replacement of OPC by GGBS up to 20% shows the marginal reduction of 4 – 6 % in compressive strength for 90 days curing and beyond that of more that 15% as shown in Fig. 2.7. He concluded that, GGBS as replacement of OPC by 20% results in reduction in cost of concrete at the current market rate by 14%.

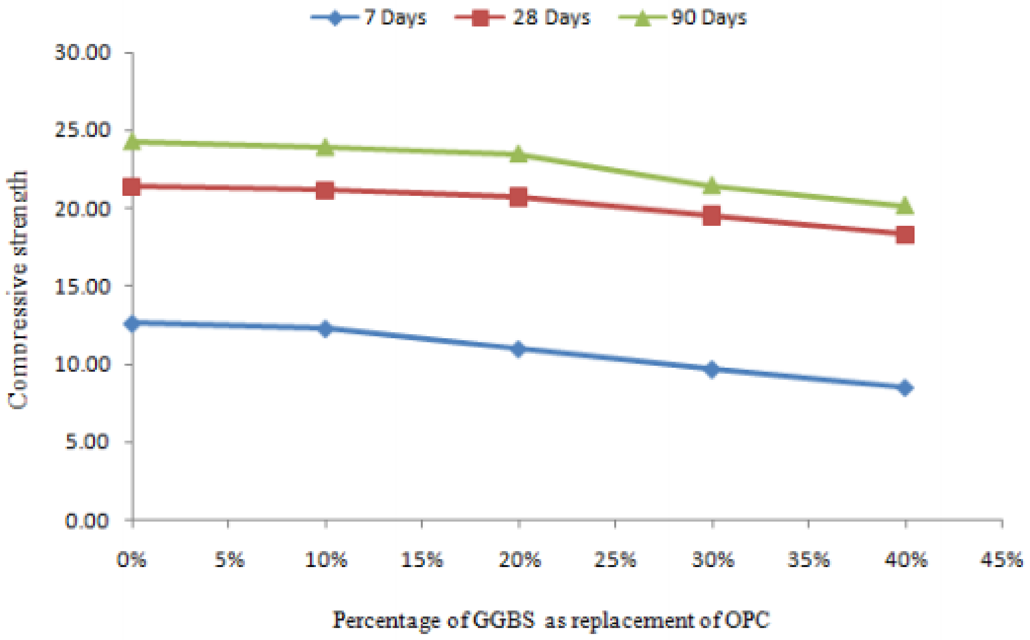


**Figure 2.7: Compression test results *[Yogendra O. Patil et. Al (2013)]***

**Veena G. Pathan et. al. (2012)** investigated on partial replacement of cement with GGBS obtained from two plants mainly Bhilai and Rourkela steel plant. She found that the fineness of slag sample was high so it was grounded further to match the fineness of the cement sample. Cement consistency was also higher at 28% of the weight of sample taken in comparison to 26% of the weight of slag sample taken. The initial setting time of slag sample was very low and the final setting time was much higher than the cement sample. Slag sample had lower specific gravity than cement sample. She also concluded that the workability of both M20 grade of concrete increased as the percentage of GGBS increased. Compressive strength test was conducted at 3, 7 and 28 days on test specimens of M20 grade of concrete with replacements varying from 30 – 50 %. Compressive strength of both grade of concretes of both plants increased at 40% and 45% cement replacements as shown in Fig 2.8 and Fig. 2.9. There are basically three strength grades (80, 100 and 120) of GGBS which are determined by their respective mortar strength when they are mixed with equal mass of OPC. She found that only 100 and 120 grade GGBS should be used because it results in greater compressive strength. She also conducted the electrical conductivity test which resulted that the slag replaced concrete is not a very good conductor of electricity.

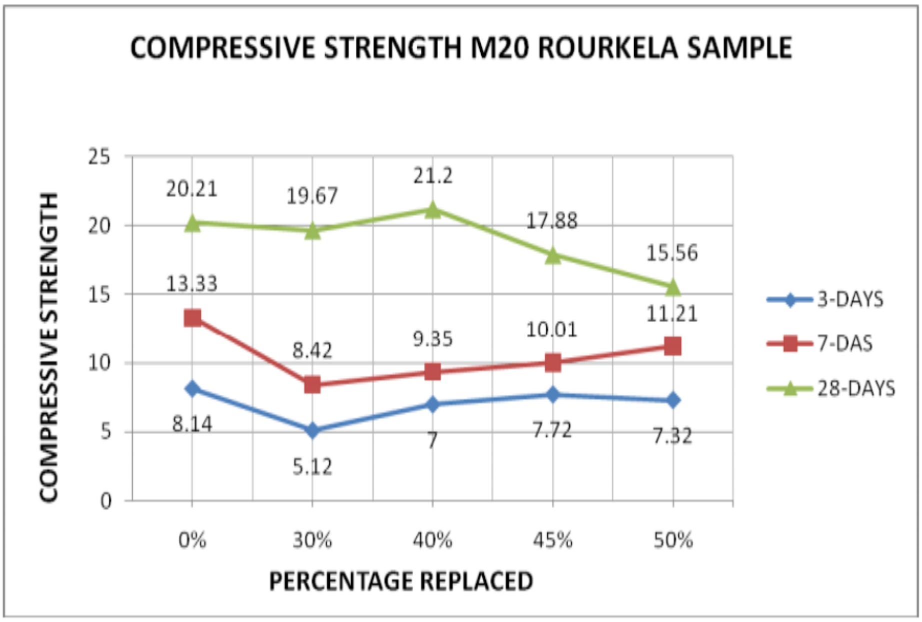


**Figure 2.8: Variation of compressive strength with varying replacement percentage *[Veena G. Pathan et. al. (2012)]***

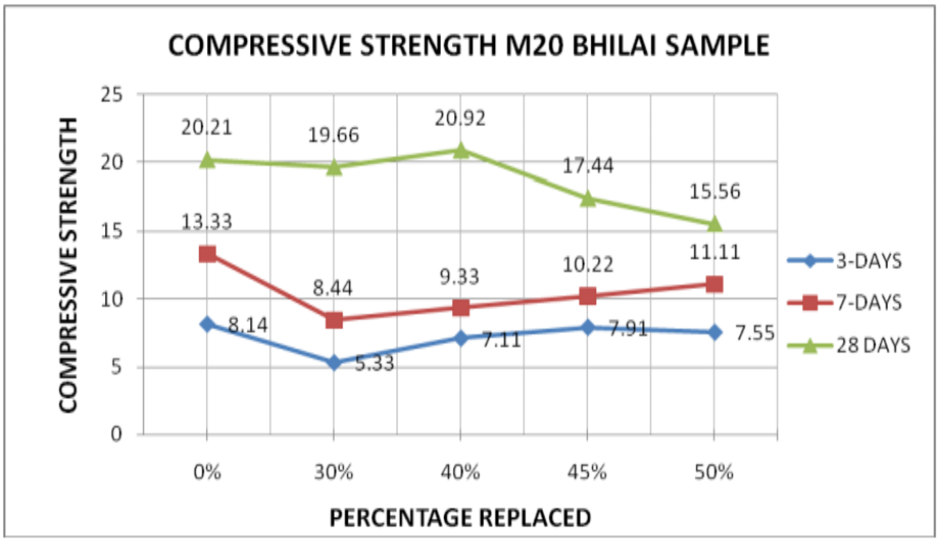


**Figure 2.9: Variation of compressive strength with varying replacement percentage *[Veena G. Pathan et. al. (2012)]***

**Atul Dubey et. al. (2012)** examined the effects of partial replacement of cement with 5 to 30 % of Blast furnace slag on compressive strength of concrete. The test was conducted at 7, 14 and 28 days on cubes made of standard size of 150 mm x 150 mm x 150 mm. He concluded that as the percentage of BFS increases, the strength tends to decrease as shown in Fig. 2.10. On replacement of OPC with 15% blast furnace slag powder, the depreciation in 28 days compressive strength is being near about only 5 %.

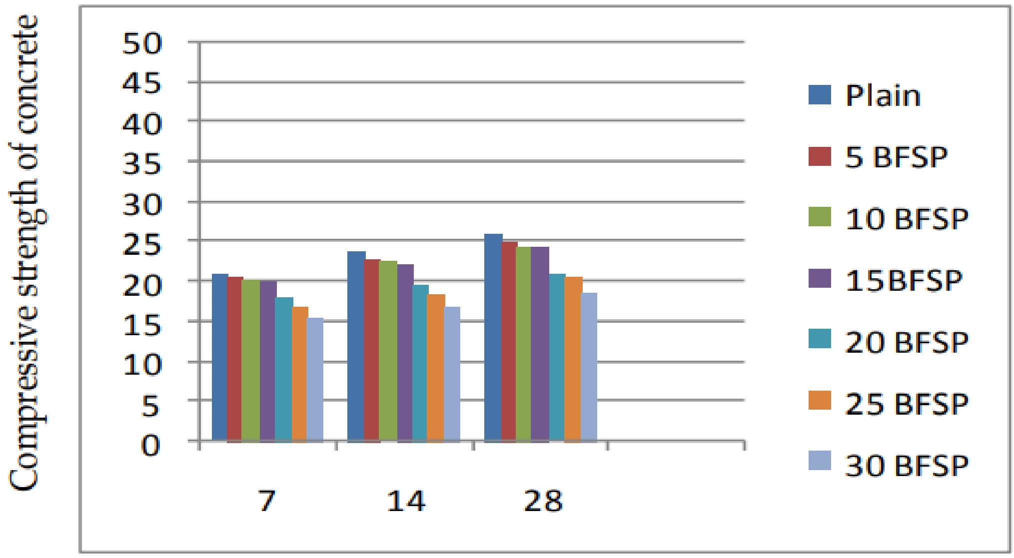


**Figure 2.10: Variation of 7, 14 and 28 days Compressive strength of concrete with % replacement of cement by blast furnace slag powder.** ***[Atul Dubey et. al. (2012)]***

**Kamran Muzaffar Khan and Usman Ghani (2004)** studied the utilization of GGBS as a cementitious constituent in concrete. He prepared four mixes namely 1:2:4, 1:1:5:3, 1:1.25:2.50 and 1:1:2 at three different replacement levels of cement i.e. 0%, 25% and 50% by GGBS and found that the workability increases with the increase in percentage of GGBS as shown in Fig. 2.11. He tested all the test specimens and concluded that there was a decrease in early age compressive strength (3 and 7 days) but an appreciable gain in strength after 7 and 28 days as the replacement level was gradually increasing. However, 50% replacement level had yielded slightly lower strengths. It was also seen that minimum percentage strength reduction was in case of mix 1:1:2 and maximum in case of 1:2:4, which meant that with the increase in the cement quantity, strength reduction can be minimized as shown in Table 2.3. He also observed that if water cement ratio is decreased using water reducers, percentage strength reduction can be minimized. Even up to 50% replacement levels, there was no substantial decrease in 28 days strength as shown in Fig. 2.12.

**Table 2.3: Results of concrete testing using GGBS** ***[Kamran Muzaffar Khan et. al (2004)]***

| **Mix ratio** | **W/C ratio** | **Water content(kg/$m^3$)** | **% replacement** | **Slump(mm)** | **Compressive strength(psi)** | | |
|---|---|---|---|---|---|---|---|
| | | | | | **3 days** | **7 days** | **28 days** |
| 1:2:4 | 0.65 | 204 | 0 | 25 | 2310 | 2966 | 4101 |
| | | | 25 | 45 | 1686 | 2467 | 3789 |
| | | | 50 | 65 | 1062 | 1592 | 2810 |
| 1:1.5:3 | 0.65 | 260 | 0 | 126 | 2435 | 3422 | 4682 |
| | | | 25 | Collapse | 2000 | 3060 | 4247 |
| | | | 50 | Collapse | 1405 | 2185 | 3528 |
| 1:1.25:2.50 | 0.45 | 208 | 0 | 65 | 3795 | 3997 | 5777 |
| | | | 25 | 87 | 2623 | 3778 | 5152 |
| | | | 50 | 103 | 2092 | 3029 | 4715 |
| 1:1:2 | 0.45 | 247 | 0 | 86 | 4340 | 5589 | 6339 |
| | | | 25 | 100 | 3029 | 4997 | 6058 |
| | | | 50 | 120 | 2536 | 4247 | 5277 |

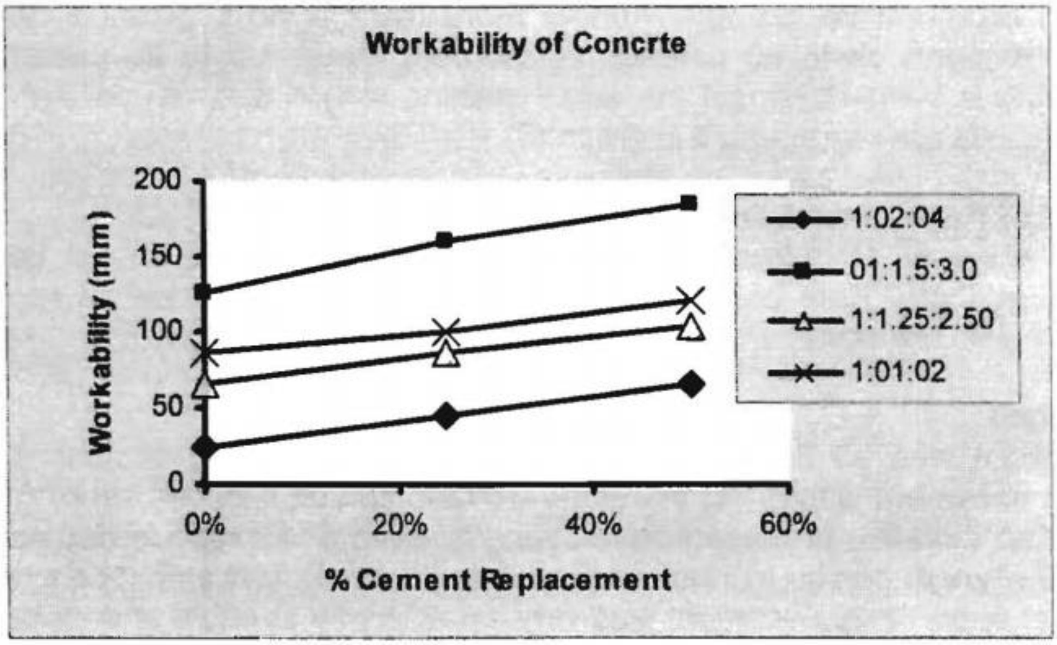


**Figure 2.11: Relation b/w Workability and % Cement Replacement** ***[Kamran Muzaffar Khan et. al (2004)]***

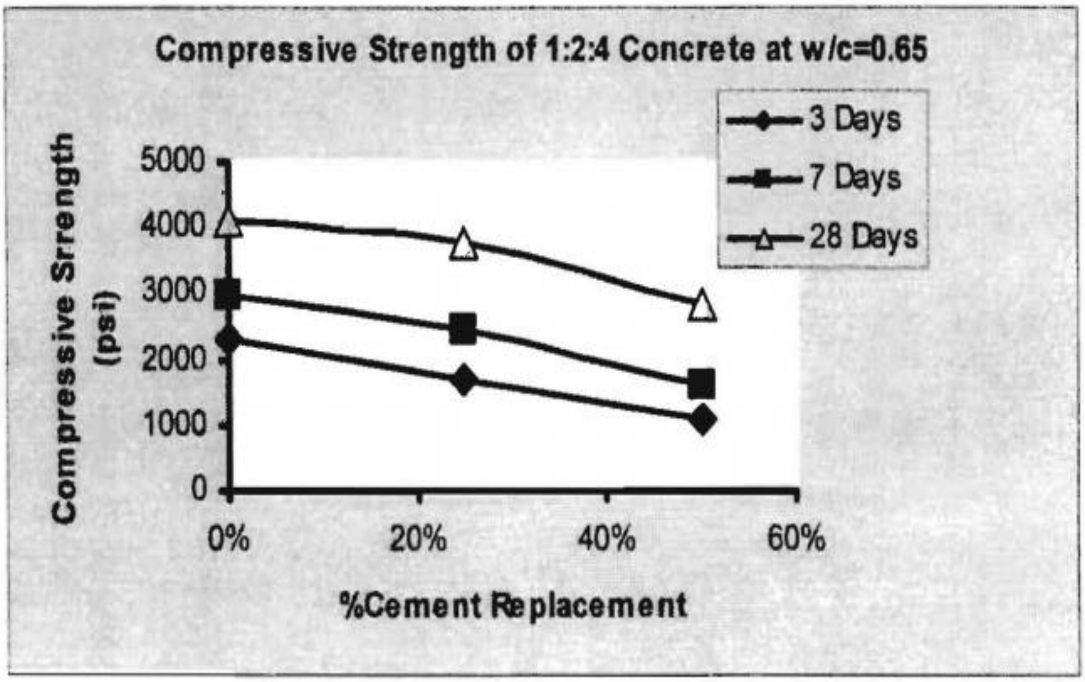


**Figure 2.12: Relation b/w Compressive Strength and % Cement Replacement** ***[Kamran Muzaffar Khan et. al (2004)]***

**Venu Malagavelli et al. (2010)** studied on high performance concrete with GGBS and robo sand and concluded that the percentage increase of compressive strength of concrete is 11.06 and 17.6% at the age of 7 and 28 days by replacing 50% of cement with GGBS and 25% of sand with ROBO sand. Compressive strength of concrete at the age of 7 and 28 days as shown in Fig. 2.13 and Fig. 2.14.

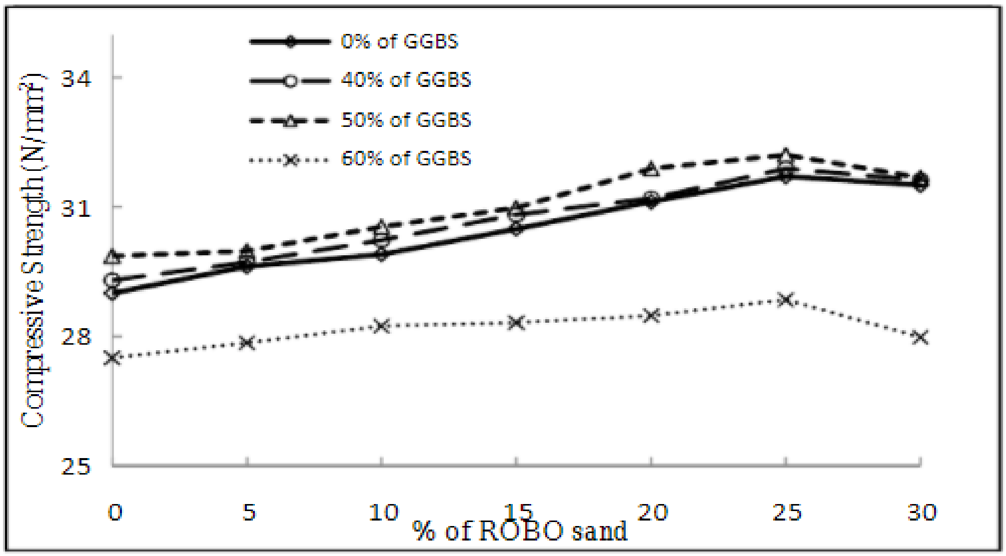


**Figure 2.13: Compressive strength of concrete at the age of 7 days** ***[Venu Malagavelli et al. (2010)]***

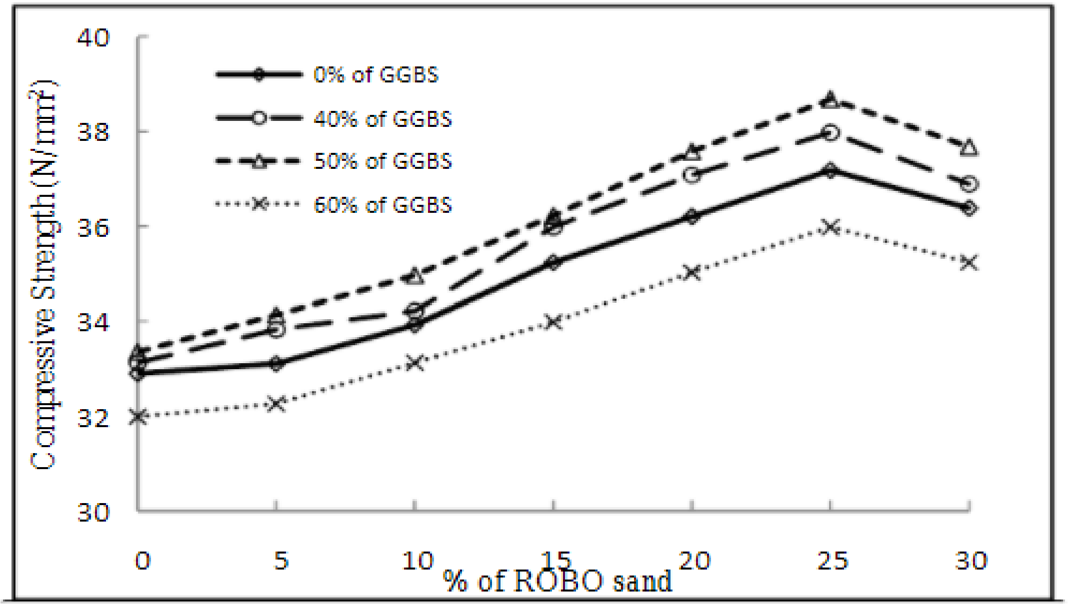
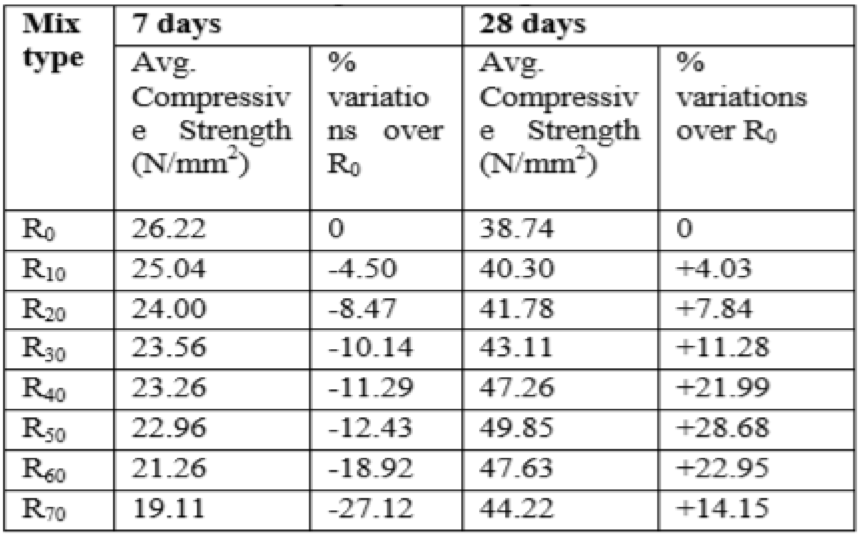


**Figure 2.14: Compressive strength of concrete at the age of 28 days [*Venu Malagavelli et al. (2010)*]**

**Ishwar Chandra Thakur et al. (2016)** This test was performed in accordance with IS 516:1959 on the cube of size 150mm × 150mm × 150mm.The average compressive strength of concrete as shown in Table 2.4 and Graph showing variation of compressive strength of the concrete with different percentage of GGBS is presented in Fig. 2.15. Compressive strength of concrete with increasing percentage of GGBS decreases after 7 days but increases after 28 days with optimum percentage of 50% replacement by GGBS. It indicates the slower value of reaction of matrix by incorporation of GGBS. At optimum percentage of GGBS the compressive strength is 28.68% higher than that of conventional cement concrete.

**Table 2.4: Compressive strength of concrete**



| **Mix type** | **7 days** | | **28 days** | |
|---|---|---|---|---|
| | Avg. Compressive Strength (N/mm$^2$) | % variations over $R_0$ | Avg. Compressive Strength (N/mm$^2$) | % variations over $R_0$ |
| $R_0$ | 26.22 | 0 | 38.74 | 0 |
| $R_{10}$ | 25.04 | -4.50 | 40.30 | +4.03 |
| $R_{20}$ | 24.00 | -8.47 | 41.78 | +7.84 |
| $R_{30}$ | 23.56 | -10.14 | 43.11 | +11.28 |
| $R_{40}$ | 23.26 | -11.29 | 47.26 | +21.99 |
| $R_{50}$ | 22.96 | -12.43 | 49.85 | +28.68 |
| $R_{60}$ | 21.26 | -18.92 | 47.63 | +22.95 |
| $R_{70}$ | 19.11 | -27.12 | 44.22 | +14.15 |

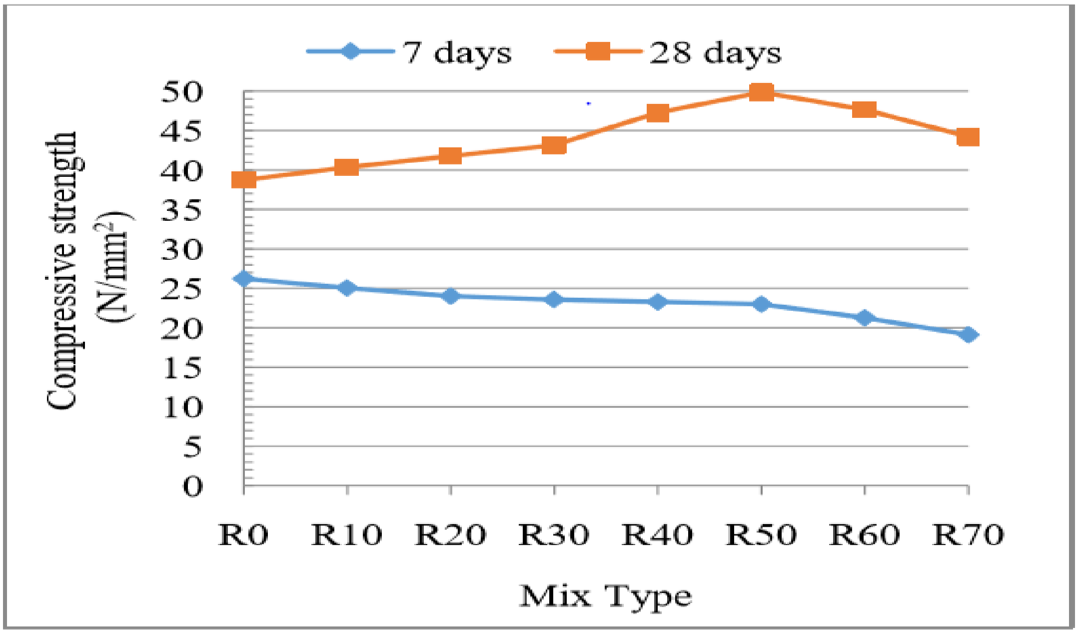


**Figure 2.15: Showing the variation of compressive strength of concrete with different percentage of GGBS is presented below in figure *[Ishwar Chandra Thakur et al. (2016)]***

Chaithra H L, Pramod K **et. Al (2015**) studied about the compressive strength development of concrete was determined at the period of 7, 28 and 56 days as presented in Fig. 2.16 showing the compressive strength of concrete along with partial substitution of OPC by slag at 0%, 30%, 40%, 50%. It is concluded that slighter reduction in strength of concrete samples at 7 days of curing periods. Increases in compressive strength observed for cement replacement at 28 and 56 curing periods. Maximum strength was achieved for 40% replacement and further it decreases.

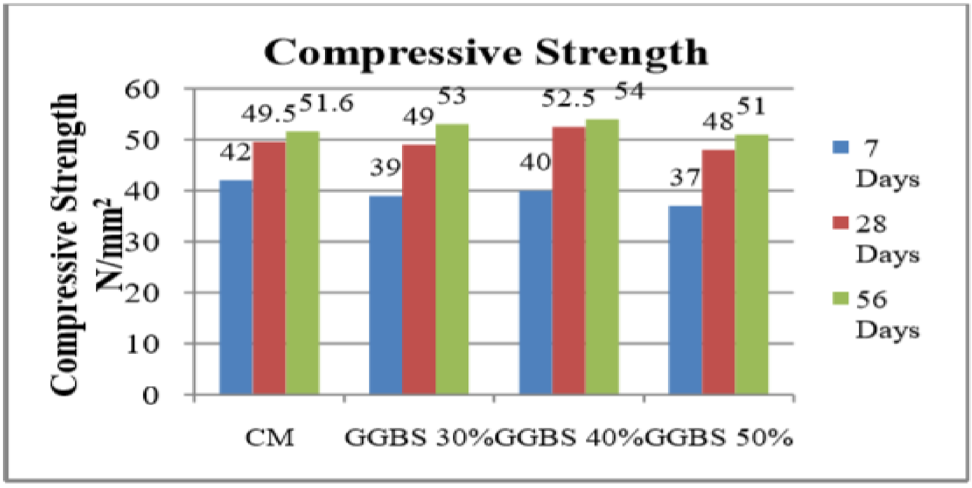


**Figure 2.16:** Compressive strength of concrete was determined at the age of 3, 7 and 28 days [Chaithra H L, Pramod K ***et. Al (2015)]***

**S. A. Austin, E J. Robins and A. Issaad (1992)** This test was performed in accordance with BS 1881 and observed that 28-day surface water absorption was affected by both the curing method and climatic conditions in the same way as the cube water absorption obtained by immersion. The influence of GGBS on 28 days ISAT values in hot and temperature condition as shown in Table 2.5. According to the Concrete Society, the burlap-protected specimen values indicate a good concrete (mostly < 0.25 $ml/m^2/s$), the polythene-wrapped an average concrete, and the air-cured a poor concrete ( > 0.5 $ml/m^2/s$). It is interesting to note that although the curing membrane substantially reduced water penetration during the initial surface absorption tests. This suggests that the curing membrane allows some evaporation of water vapour during curing.

**Table 2.5: Mean 28-days ISAT values *[S. A. Austin et. al (1992)]***

| Mix | Curing method | ISAT($ml/m^2s$) | |
|---|---|---|---|
| | | Hot condition | Temperature Condition |
| OPC | Air | 0.79 | 0.70 |
| | Burlap | 0.26 | 0.26 |
| | Polythene | 0.35 | 0.33 |
| | Membrane | 0.14 | 0.13 |
| GGBS | Air | 1.01 | 0.96 |
| | Burlap | 0.21 | 0.26 |
| | Polythene | 0.30 | 0.36 |
| | Membrane | 0.14 | 0.13 |

**Md. Moinul Islam et. al. (2011)** discussed the results of partial replacement of cement using slag in various percentages (10% – 70%). He tested various properties of concrete in which he found that the compressive strength and tensile strength of mortar mixes with slag determined at the ages of 3, 7, 14, 28, 60, 90 and 180 days decreases at early ages of curing (3 and 7 days). However, the rate of decrease diminishes with the increasing age of curing. The optimum use of slag in the mortar was observed to be 40% of cement replacement because it shows 19% higher compressive strength and 25% higher tensile strength when compared to OPC mortar. He concluded that the use of slag reduces the amount of cement content in a motar mix as well as heat of hydration which results in lower risk of thermal cracking. Thus the construction work with slag concrete becomes economical and also environmentally safe (reduced $CO_2$ emission).

**Santosh Kumar Karri et. al. (2015)** selected 30%, 40% and 50% as cement replacement levels and cured the specimens of M20 and M40 grade of concrete for 28 and 90 days. He found out that the workability of concrete increases with the increase in GGBS replacement level. He observed that the maximum compressive strength, split tensile strength and flexural strength is achieved at 40% cement replacement for both M20 and M40 grade concrete, beyond which the strength decreases slightly. Concrete cubes were also exposed to $H_2SO_4$ and HCl of 1% and 5% concentration and were tested for compressive strength at 90 days and 28 days respectively. It was observed that the resistance power increases up to 40% replacement beyond which it decreases but the compressive strength values of acid affected concrete decreases on comparison with normal concrete. It was also seen that the compressive strength of GGBS concrete affected to HCL was greater than that of $H_2SO_4$.

**Thejaskumar HM and Dr V. Ramesh (2015)** studied the effects of partial replacement of cement with BFS on various properties of concrete. Compressive strength of concrete mixtures that were kept in water, 10% HCl and 15% $H_2SO_4$ solutions were determined at the ages of 7, 28 and 56 days with cement replacement ranging between 40 – 60%. It showed that as the ages goes up, the compressive strength, split tensile strength and flexural strength soars up but it decreases with the increase in percentage of BFS. However, replacement up to 55% does not affect the strength negatively. After 56 days the samples having 53% of BFS, didn’t face a decrease in resistance, gained more compressive resistance in the solution of HCl and $H_2SO_4$.

**T. Vijaya Gowri et. al. (2014)** investigated the effects of partial replacement of cement with GGBS on compressive strength, split tensile strength and flexural strength of concrete at 28, 90, 180 and 360 days. He used 50% GGBS as replacement material of cement for various water/binder ratios i.e. 0.55, 0.50, 0.45, 0.40, 0.36, 0.32, 0.30 and 0.27. He observed that the High Volumes of slag concrete gains appreciable amount of strength at later ages (90 days onwards) and it increases with decrease in water/binder ratios. He found out that the strength of high volume of slag concrete is more at later ages because of slower hydration of slag with $Ca(OH)_2$ and water. He concluded that on replacement of cement by 50% GGBS helps to reduce the cement content of concrete, thereby reducing the cost of concrete and also protecting the environment from pollution.

**Sabeer Alavi.C et. al. (2013)** studied the effects of partial replacement of cement with 10 - 50% of GGBS and found that 30% GGBS replacement is good as beyond that the compressive strength starts decreasing. He also concluded that the split tensile strength and flexural strength conducted at 7 and 28 days increases with increase in GGBS content. It was also found that the workability increases with the increase in percentage of GGBS.

**Chao-Lung Hwang and Chao-Yin Lin (1986)** conducted a research in which he replaced cement with BFS in various percentages (0 – 80%) with three different w/c ratios (0.35, 0.47 and 0.59) and found that the use of slag lowers the strength of mortar at early age (3 days) but the strength development starts after 7 days. It was also found out that the specimens demoulded at the age of one day had significantly less strength as compared with those demoulded at one and half days. Three different temperatures were used and specimens cured under 50ºC tend to have the best results. He also concluded that the bleeding of the mortar with higher slag content is less than that of pure cement mortar during mixing. The pores tend to become smaller when slag is used in the mix. This may increases the durability of the cement mortar when it is exposed to adverse environment.

**S. Arivalagan (2014)** investigated the strength and strength efficiency factors of hardened concrete, by partially replacing cement with 20%, 30% and 40% GGBS at different ages. The specimens when tested at 7 and 28 days, showed increase in compressive strength for 20% replacement of cement. Split tensile strength and flexural strength of concrete also increased at 20% cement replacement. The increasing strength is due to filler effect of GGBS. It was also found that the degree of workability of concrete was normal and it increased with the addition of GGBS.

**Shariq et. al. (2008)** studied the effect of curing procedure on the compressive strength development of cement mortar and concrete incorporating ground granulated blast furnace slag. The compressive strength development of cement mortar incorporating 20, 40 and 60 percent replacement of GGBS for different types of sand and strength development of concrete with 20, 40 and 60 percent replacement of GGBS on two grades of concrete are investigated. Tests results show that the incorporating 20% and 40% GGBS is highly significant to increase the compressive strength of mortar after 28 days and 150 days, respectively.

# CHAPTER- 3

# MATERIALS AND DESIGN METHODOLOGY

## 3.1 GENERAL

The important purpose of this test programme was to examine the consequence of curing methods on the production of both OPC and OPC/GGBS concrete specimens cured in hot climatic conditions. More specifically, measurements were made of compressive strength and permeability to determine the relative effectiveness of the curing process used and also to identify any significant differences brought about by the use of GGBS.

The present chapter deals with the materials properties and mix proportion adopted for the development of GGBS concrete specimens. In order to attain the objective of present study, an investigation was performed to determine the workability, compressive strength and Initial surface absorption test under various curing regime in hot climate.

Therefore, experiments were carried out on 150 mm × 150 mm × 150 mm cubes to investigate the influence of different curing regimes. Four mixes were used throughout the test programme. The proportions and description of these mixes are reported in the following sections.

## 3.2 SELECTION OF MATERIALS

The properties of various materials used for making GGBS concrete mixes were established in laboratory according to IS codes of practice. The significant material used in experimental study undertaken for the development of GGBS concrete were cement, coarse aggregates, fine aggregates and water in varying proportions. The importance of study of the various properties of material is used to check the acceptance of materials with the codal provision requirements and to enable an engineer to prepared a concrete mix for the particular strength. The description of various materials along with their investigated properties which were used in this study are detailed in the following sub-sections:

### 3.2.1 Cement

It is a binding material which sets and hardened as soon as water is added to it causing initiation of hydration reaction, which further results in the formation of CSH gel around other particles which acts as link between them and can bind them together. Other additional cementation materials may also be used with cement but cement is considered necessary component for the initiation of the hydration reaction without which other pozzolonas cannot show any binding property. In the present study, 43 grade OPC Cement manufactured by JK Lakshmi Cement

Company was used. Figure 3.1 shows the cement being used for developing different mixes. Various physical and chemical properties of cement are presented in Table 3.1 and Table 3.2 respectively. It can be examined from the table that the physical properties of the cement was complying with the specifications of IS 8112: 1989.

**Figure 3.1: Cement used in present study**

**Table 3.1: Physical Properties of Cement used in the study**

| Property | Value | IS 8112:1989 Specifications |
|---|---|---|
| Grade | OPC-43 | OPC-43 |
| Specific Gravity | 3.12 | 3.10-3.25 |
| Initial Setting time | 100 min | 30 minutes, minimum |
| Final Setting time | 170 min | 600 minutes, maximum |
| Blaine Fineness | 3250 $cm^2/g$ | 2250 $cm^2/g$ |
| 28-Day Compressive Strength | 48.21 MPa | 43 MPa |

**Table 3.2: Chemical composition of cement observed present study**

| Constituent | Cement Used | IS 8112:1989 Specifications |
|---|---|---|
| $CaO$ | 63.49 % | Max 67% |
| $SiO_2$ | 21.25 % | Max 25% |
| $Al_2O_3$ | 4.74 % | Max 8% |
| $Fe_2O_3$ | 4.30 % | Max 6% |
| $SO_3$ | 2.92 % | Max 3.5% |
| $MgO$ | 1.02 % | Max 6% |
| Ratio of aluminia to iron oxide | 1.12 % | Min 0.66% |

### 3.2.2 Ground Granulated Blast Slag

GGBS is the by-product of iron making industry. Iron ore, coke as well as limestone are provided inside the furnace and the consequent molten slag floats over molten iron at the temperature of approximately 15000ºC to 16000ºC. The molten slag had a combination of almost 30% to 40% $SiO_2$ and the 40% CaO, which is near to the chemical constitution of Portland cement. Subsequently, molten iron is tapped off, and the surplus molten slag, which comprise of usually siliceous as well as aluminous residue is then water quenched quickly, resulting in the production of a glassy granulates *(Pandey, R.K. et. al, 2016)*. The glassy granulate are dried up and ground to the required sizes, which is well-known as GGBS. The GGBS used in dissertation was procured from a subsidiary of Ambuja cement group and is shown in Fig. 3.2. The product was named as ALCCOFINE-1203. The physical and chemical properties of GGBS are presented in Table 3.3 and Table 3.4 respectively.

**Figure 3.2: Actual photograph of GGBS**

**Table 3.3: Physical Properties of GGBS (Provided by the manufacture)**

| S.No | Characteristics | Value |
|---|---|---|
| 1. | Specific gravity | 2.9 |
| 2. | Bulk density | 680 kg/m$^3$ |
| 3. | Blaine fineness | 4490 cm$^2$/gm |
| 4. | Particles size distribution<br>d10 | 1.5µm |
|  | d50 | 4.2µm |
|  | d90 | 9.0µm |

**Table 3.4: Chemical Composition of GGBS**

| S.NO | Composition | Values in (%) |
|---|---|---|
| 1. | $SiO_2$ | 34.2 |
| 2. | $Al_2O_3$ | 22.7 |
| 3. | $Fe_2O_3$ | 1.0 |
| 4. | CaO | 33.8 |
| 5. | $SO_3$ | 0.13 |
| 6. | MgO | 6.6 |
| 7. | LOI | 1.71 |

**3.2.3 Fine aggregates:** The aggregates that passed throughout 4.75mm IS sieves are well-known as fine aggregate. For improved workability and for saving by use of lesser quantity of cement, the fine aggregates have to a rounded shape. The function of fine aggregates is to fill the gap in coarse aggregate and to perform as workability agent. According to IS 383:1970, fine aggregates are of following types: Natural sand i.e. the fine aggregate resultant against the natural breakdown of rocks together with crushed sand i.e. the fine aggregate formed through crushing hard stone and the crushed gravel sand. In the present work fine aggregates belonging to Anandpur Sahib area are shown in Fig. 3.3 and conforming to Grading zone II as per IS 383:1970 were collected from a local supplier. The physical properties and sieve analysis of fine aggregate was performed and the results of which are given in Table 3.5 and Table 3.6 respectively.

**Figure 3.3: River sand being used in this study**

**Table 3.5: Physical Properties of fine aggregates**

| Properties | Results obtained |
|---|---|
| Grading | Zone II |
| Specific gravity | 2.64 |
| Water Absorption | 0.87 |
| Fineness Modulus | 3.02 |

**Table 3.6: Sieve analysis of fine aggregates**

| S.NO | Sieve size | Wt. retained | %age retained | %age passing | Cumulative %age retained |
|---|---|---|---|---|---|
| 1. | 4.75mm | 31 gm | 3.1% | 96.6 | 3.1 |
| 2. | 2.36mm | 137 gm | 13.7% | 83.2 | 16.8 |
| 3. | 1.18mm | 238gm | 23.8% | 59.4 | 40.6 |
| 4. | 600µ | 168 gm | 16.8% | 42.6 | 57.4 |
| 5. | 300µ | 316gm | 31.6% | 11 | 89 |
| 6. | 150µ | 65 gm | 6.5% | 4.5 | 95.5 |
| 7. | Residue | 45 gm | 4.5% | 0 | 100 |
| | **Total** | **1000** | | | **302.4** |
| | | | **ZONE-II** | | **FM=3.024** |

**3.2.4 Coarse aggregates:** The aggregate which is retained over IS sieve 4.75 mm is termed as coarse aggregate. The basic function performed by these aggregates in GGBS concrete is to increase the strength and thus help in making a solid and hard mass of GGBS concrete. In addition to this it helps to reduce the cost of GGBS concrete mix prepared by occupying the major volume of the concrete. According to IS 383:1970 coarse aggregates are of following types: (i) Crushed gravel, stone obtained by crushing of gravel and hard stone, (ii) Uncrushed gravels, stones resulting from the natural disintegration of rocks and (iii) partially crushed gravel or stone which is obtained as a product of blending of above two types.

The coarse aggregates used in the present study were a mixture of two locally available crushed stones of 20 mm and 10 mm nominal sizes. Coarse aggregates belonging to Anandpur Sahib area were used for this dissertation work.

The specific gravity and other physical properties of coarse aggregates tested in the laboratory are given in Table 3.7. The sieve analysis of coarse aggregate was done in the laboratory and the values obtained are shown in the Table 3.8 for the 20 mm aggregate and Table 3.9 for the 10 mm aggregate.

**Table 3.7: Properties of coarse aggregates**

| S.No | Characteristics | value | |
|---|---|---|---|
| 1. | Shape | angular | |
| 2. | Nominal size | 20mm | 10mm |
| 3. | Specific gravity | 2.71 | 2.75 |
| 4. | water absorption | 0.2% | 0.35% |

**Table 3.8: Sieve analysis of coarse aggregate(20mm)**

| S.no | IS Sieve | Wt. retained (gm) | %age retained | %age passing | Cummulative % retained |
|---|---|---|---|---|---|
| 1. | 80 | 0.00 | 0.00 | 100.00 | 0.00 |
| 2. | 40 | 0.00 | 0.00 | 100.00 | 0.00 |
| 3. | 20 | 28 | 0.93 | 99.07 | 0.93 |
| 4. | 10 | 2876 | 95.87 | 3.20 | 96.8 |
| 5. | 4.75 | 75 | 3.20 | 0 | 99.3 |
| 6. | 2.36 | 0 | 0 | 0 | 100 |
| 7. | 1.18 | 0 | 0 | 0 | 100 |
| 8. | 600 | 0 | 0 | 0 | 100 |
| 9. | 300 | 0 | 0 | 0 | 100 |
| 10. | 150 | 0 | 0 | 0 | 100 |
| 11. | Pan | 21 | 0.7 | | |
| **Total** | | **3000** | | **SUM** | **697.03** |
| **Fineness Modulus (FM) = 6.97** | | | | | |

**Table 3.9 Sieve analysis of coarse aggregate(10mm)**

| S.no | IS Sieve | Wt. retained (gm) | %age retained | %age passing | Cummulative % retained |
|---|---|---|---|---|---|
| 1. | 80 | 0.00 | 0.00 | 100.00 | 0.00 |
| 2. | 40 | 0.00 | 0.00 | 100.00 | 0.00 |
| 3. | 20 | 447 | 22.35 | 77.65 | 22.35 |
| 4. | 10 | 415 | 20.75 | 56.90 | 43.1 |
| 5. | 4.75 | 1055 | 52.75 | 4.15 | 95.85 |
| 6. | 2.36 | 80 | 4.0 | 0.15 | 99.85 |
| 7. | 1.18 | 0 | 0 | 0 | 100 |
| 8. | 600 | 0 | 0 | 0 | 100 |
| 9. | 300 | 0 | 0 | 0 | 100 |
| 10. | 150 | 0 | 0 | 0 | 100 |
| 11. | Pan | 3 | 0.15 | | |
| **Total** | | **2000** | | **SUM** | **661** |
| **Fineness modulus (FM) = 6.61** | | | | | |

**3.2.5 Water:** Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Since it helps to form the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully. Potable water is generally considered satisfactory. In the present investigation, tap water was used for both mixing and curing purposes.

## 3.3 EXPERIMENTAL PROGRAMME

**3.3.1 Mix design:** In this present study, concrete mixes comprised of a OPC concrete along with three GGBS concrete mixes with varying GGBS content by 30%, 50%, and 70% respectively. Proportioning of concrete mix for M35 grade of concrete have been achieved by concrete mix design in accordance with IS 10262:2009. Composition of constituent materials per cubic meters of the concrete mix for different batches is given in Table 3.10. The cement used in the present study was OPC- 43 grade. The fine aggregate and water/cement was kept fixed for all mixes. The mix ratios used was 1:1.5:2.62 for the casting and preparation of specimens.

Table 3.10: Mix Proportions using GGBS for M35 grade concrete

| S.NO | Mix designation | GGBS % | Cement (kg/m$^3$) | GGBS (kg/m$^3$) | Coarse aggregate (kg/m$^3$) | | Fine aggregate (Kg/m$^3$) | Water (Kg) |
|---|---|---|---|---|---|---|---|---|
| | | | | | 20mm | 10mm | | |
| 1. | M 0 | 0 | 420 | 0 | 660 | 440 | 630 | 189 |
| 2. | M 30 | 30 | 294 | 126 | 660 | 440 | 630 | 189 |
| 3. | M 50 | 50 | 210 | 210 | 660 | 440 | 630 | 189 |
| 4. | M 70 | 70 | 126 | 294 | 660 | 440 | 630 | 189 |

### 3.3.2 Preparation of specimens

For carrying out this dissertation work a total of 144 cube specimens were prepared. These samples comprised of control mix and also partially replacement of cement using GGBS at 30%, 50% and 70%. Cubical sample of size 150 × 150 × 150 mm were prepared for finding compressive strength and the durability properties of GGBS concrete specimens by using Initial surface absorption test. Four different concrete mixes used were:

- M 0: 100% OPC
- M 30: 70% OPC + 30% GGBS
- M 50: 50% OPC + 50% GGBS
- M 70: 30% OPC + 70% GGBS

For each of the above specified mixes, the following set of concrete batches were cast. Totally 108 cube specimens were prepared for finding the compressive strength of control concrete and GGBS concrete mixes. In the preparation of specimens, total four sets of cube specimens were casted and in each set 27 cubes were casted by partial replacement of cement with varying GGBS content at 0%, 30%, 50% and 70%. Each set have 27 cubes, out of which nine cubes were cured in water curing tank placed in the lab, nine cubes were cured with the wet burlap and remaining nine cubes were cured with fully sealed with plastic sheet specimens placed in hot and humid conditions The compressive strength were carried out at 3, 7, and 28 days under the different curing regimes.

Furthermore, total 36 cube specimens were prepared for investigating the durability properties by ISAT and testing after 28 days of curing under three curing regimes as discussed above.

### 3.3.3 Casting of Specimens

The important features of the casting procedure followed are as follows:

- To begin with all the materials to be used were taken out and cleaned of dirt and dust if any.
- After that, all the materials were weighed in accordance with the mix proportion selected.
- Then GGBS and cement were taken in a tray and mixed properly by hand mixing for 2-3 min to form a uniform coloured blend.
- To start the drum mixer, the fine and coarse aggregates were added into the mixer and were mixed properly for 2 min followed by the incorporation of blended mixture into the mixer. To attain a uniform mix throughout the mixture, the mixer was further rotated for 4-5minutes.
- Water was added to the mix as and when required and the prepared mix was poured into moulds in three layers and vibrator layer wise.
- At last, finishing of the moulds was done with the help of a trowel. To prevent any undulation in the finished product during curing period they were placed safely on a levelled ground as shown in Fig. 3.4
- After casting and finishing is done, the cubes were stripped from the moulds after 24 hours and cured under different curing methods. In order to examine the influence of curing condition using GGBS concrete some cube specimens were put inside the water curing tank kept at 20±2ºC and the remaining OPC concrete and GGBS concrete specimens were covered with wet burlap and fully sealed with plastic sheeting curing and placed outside in hot climatic conditions after that they were left untreated until the period of testing.

**Figure 3.4: Finished mould containing GGBS concrete**

### 3.3.4 Curing Methods

The aim of the curing methods used was to replicate both conditions found in practice and best case scenario. The cubes were stripped from the moulds 24 hours after pouring, then were cured using one of the following curing methods. Description of test samples are specified in Table 3.11.

1. Water curing.
2. Fully sealed with plastic sheet curing.
3. Wet Burlap curing.

- **Water Curing**: The cubes were casted and totally immersed inside water, throughout the curing period using curing tank as shown in Fig. 3.5. The curing water was kept at the laboratory temperature of 20±2ºC to restrain the thermal stresses that may results in cracking. From every batch of concrete mixed, cubes were constantly cured in water until they were examined at the period of 3, 7 and 28 days.

**Figure 3.5: Cube specimens cured in water tank**

- **Plastic sheet Curing:** Plastic sheet materials, such as polyethylene film, were used to cure the concrete cubes. Polyethylene is a lightweight, effective moisture retarder and easily applied to simple cubes shapes**.** In this type of curing plastic sheet were first dip in water and then applied on the cube specimens as shown in Fig. 3.6

Figure 3.6: Cube specimens cured with fully sealed plastic sheet

- **Wet burlap Curing:** Hessian sac was used like a mulch to maintain water on the surface of the concrete cubes; also, it is important to ensure that the whole areas were covered. Wet covering material was placed as soon as the concrete cubes were hardened sufficiently to prevent surface damage. Throughout the curing period, the sac is kept saturated with water as shown in Fig. 3.7

Figure 3.7: Cube specimens cured with wet burlap

**Table 3.11 Description of test samples**

| Nomenclature | Description |
|---|---|
| M0WC | GGBS = 0%, Water curing |
| M30WC | GGBS = 30%, Water curing |
| M50WC | GGBS = 50%, Water curing |
| M70WC | GGBS = 70%, Water curing |
| M0WB | GGBS = 0%, Wet burlap curing |
| M30WB | GGBS = 30%, Wet burlap curing |
| M50WB | GGBS = 50%, Wet burlap curing |
| M70WB | GGBS = 70%, Wet burlap curing |
| M0PS | GGBS = 0%, Plastic sheet curing |
| M30PS | GGBS = 30%, Plastic sheet curing |
| M50PS | GGBS = 50%, Plastic sheet curing |
| M70PS | GGBS = 70%, Plastic sheet curing |

### 3.3.5 Compressive Strength Test

Compressive Strength may be defined as the capacity of a material or structure to withstand loads tending to reduce size. In other words, it is just the opposite of tensile strength. The main function of the concrete in structure is mainly to resist the compressive forces and since concrete being strong in compression and weak in tension it becomes imperative to know about its strong property so that other additions to it can be done accordingly. So this test basically aims to know about its load carrying capacity in compression.

The compressive strength of the cubical specimens of size 150mmx150mmx150mm was found out on compression testing machine of 1000 kN capacity as per the provisions of IS:516-1959 Compressive strength test was carried to calculate the strength development of OPC concrete mix, containing various percentage of GGBS at the age of 3, 7 and 28 days respectively.

However, under different curing regime placed in hot climate such as water curing, wet burlap and polythene sheet were used. After curing period was completed, three specimens of each mix from three different curing condition was taken and the test cubes were placed on the platform of a compressive testing machine without any packing between the cube and the plate of the testing machine as shown in Fig. 3.8. The cubes were tested perpendicular to the face of casting, and uniform and steady load was applied. Compressive strength of mortar cubes were tested with a pace rate of 0.5 KN/sec. Therefore, three cubes were tested for each mix and the average compressive strength of these three cubes was considered to be the compressive strength of the mix.

The compressive strength was then calculated according to the formula:

$$\sigma = P / A$$

Where, $\sigma$ = Compressive Strength (N/mm$^2$)

P = Peak load (N)

A = Cross-section area of cube (mm$^2$)

**Figure 3.8: Cube under compression in Automatic Compression Testing Machine**

### 3.3.6 Initial Surface Absorption Test (ISAT)

Initial surface absorption of concrete is a test to indicate the water flow into the surface of a dry, flat concrete surface. This experiment is time dependent and correlative to indicate the property of concrete surface to resist the absorption of water. The ISAT test is performed to obtain an indication of durability of the concrete surface when exposed to the external chemical attack. The main benefit of the ISAT is that it is a fast and simple non-destructive in situ method that can be used to measure the water penetration of the normal cast concrete surface. The main use of ISAT is a quality control experiment for the precast concrete units that can be tested when they are 'dry'. The motive of test is to check the time taken for the quantity of water to flow through the calibrated glass tube above a known area of concrete surface. The ISAT test as specified in BS 1881 Part 5 code was originally developed as a laboratory method of measuring the porosity of concrete. The test consists of the measurement of water flow into the test specimen through a known surface area. The contact area is defined by a plastic cell sealed in contact with the surface, as shown in Fig. 3.9 and Fig. 3.10. A clear reservoir is connected to the ‘inlet’ of the cell. The ‘outlet’ of the cell is connected to a capillary tube with an affixed scale. A valve is fitted to the inlet side to isolate the reservoir. The cell is clamped to the test surface so as to ensure the even pressure and a good seal around the perimeter. The capillary tube as well as reservoir are mounted 200 mm above the cell. After filling the cell completely, the reservoir is closed off and the measurements taken from flow alongside the capillary tube.

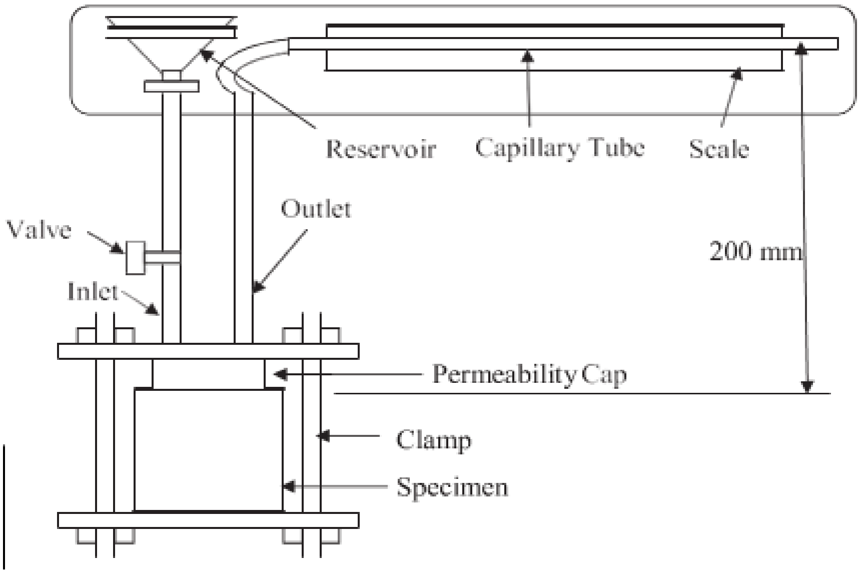


Figure 3.9: The general arrangement for ISAT

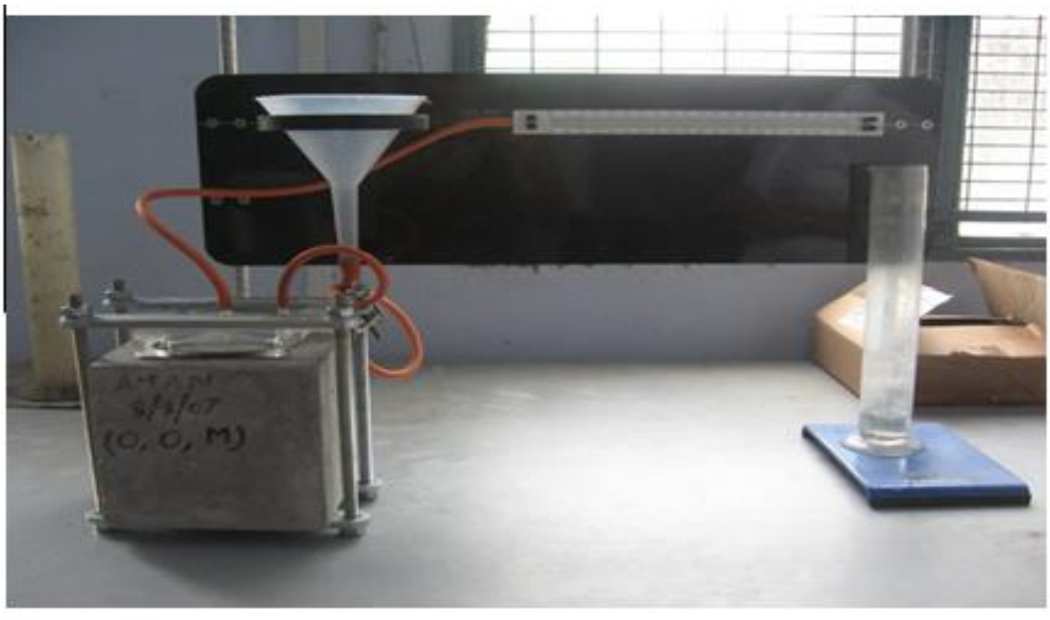


Figure 3.10: The setup for ISAT

Set of readings are taken at 10, 30 and 60 min after the first wetting of the concrete surface. For each set of readings, the reservoir is closed off and time taken for the meniscus to moved back 90 divisions is recorded. The observation on the scale is marked to indicate the rate of flow of water into the concrete at the rate of 0.01ml/$m^2$/s based on the test time of 1 minute. Tests were carried out on 150mm cube specimens which were dried in an oven at 105 ± 5 $^0$C until the difference in mass over any 24h drying period did not exceed 0.1% weight change, as detailed in BS 1881: Part 208 and results, which are the average of three nominally identical samples, are expressed as ml/ ($m^2$s). Therefore, to obtain the flow, *f* (in ml/$m^2$/s), from the data obtained we calculate:

f= 60/t×D×0.01

where t = test point time in seconds, *D* = no of scale divisions during the period t.

f= flow in millimeters/meter$^2$/second.

# CHAPTER-4

# RESULTS AND DISCUSSION

## 4.1 GENERAL

In this chapter results obtained from various tests conducted on the GGBS concrete specimens are presented and discussed to study the influence of addition of GGBS in percentages of 30%, 50% and 70% on the compressive strength and durability property using Initial surface absorption test on OPC control cubes and GGBS concrete specimens. The compressive strength tests on the specimens have been performed after 3, 7 and 28 days of curing whereas ISAT test of the specimens has been checked for 28 days only. To study the consequence of these variables on the mechanical properties various graphs and bar charts showing the relative strength in different samples have been drawn.

## 4.2 Workability Test

Workability was determined by the slump test. The test has been performed in accordance with IS 1199:1959. The cone for the test was placed on a smooth surface and filled with concrete in three equal layers. Each layer was tamped twenty-five times with a normal 16 mm dia steel rod and also the top surface was simulated by means of a spreading and rolling motion of the tamping rod. The slump was then calculated as the distance from the underneath of the steel rod to the displaced original centre of top of the specimens as shown in Fig. 4.1.

**Figure 4.1: Showing the workability of concrete mix**

To determine the workability of fresh concrete mix, the values of slump from 0% to 70% of GGBS are found by the slump cone experiment. Figure 4.2 shows variation in slump with

GGBS replacement. Therefore, all mix used had a slump varying from 75 mm to 108 mm as shown in Table 4.1

**Table 4.1: Workability of concrete with varying percentages of GGBS**

| S.No | Specimen mix | GGBS % | SLUMP(mm) |
|---|---|---|---|
| 1. | M 0 | 0 | 75 |
| 2. | M 30 | 30 | 82 |
| 3. | M 50 | 50 | 96 |
| 4. | M 70 | 70 | 108 |

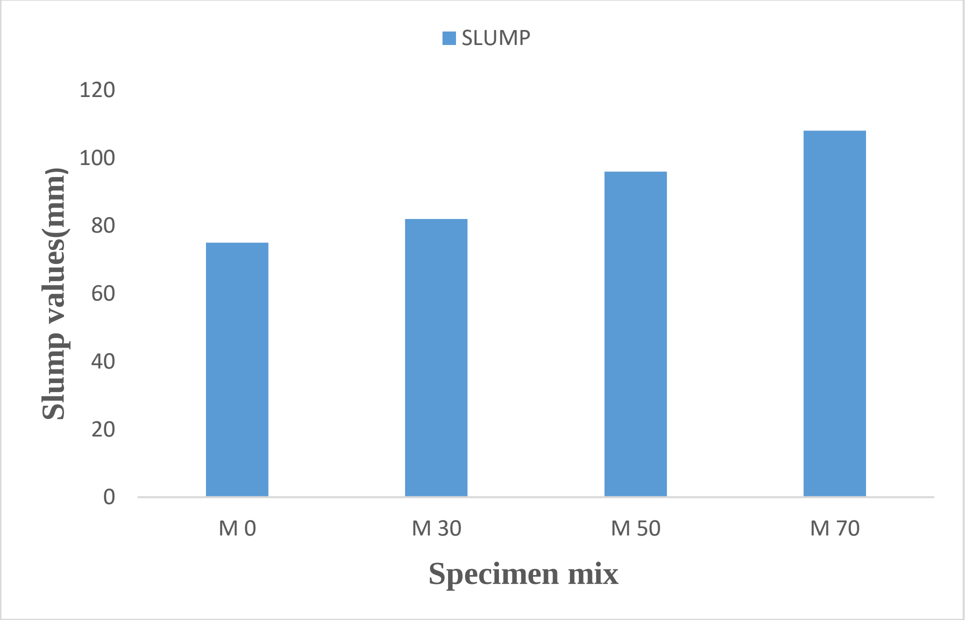


**Figure 4.2: Variation in Slump with GGBS replacement**

From the Fig. 4.2, it is found that the slump values of concrete increases with increase in the percentage of GGBS used as replacement of cement concrete. The increase in slump value is due to the higher smoothness and fineness of slag, that increases the entrainment of air in the matrix, subsequently increasing the volume of paste. It is also known that the GGBS particles are lesser water absorptive than the OPC particles and therefore GGBS concrete is better workable as compared to OPC concrete. For equivalent workability, there is reduction in water content of up to 10% is possible *(Richardson 2006)*. Several researchers reported that this was because of smooth and denser surface of the slag that produced slag particles slighter less water absorptive than OPC concrete *(ACI Committees-233R, 1995)*. Furthermore, some researchers investigated that slag concrete mixes attained 20% to 50% higher slump than the control concrete with the same water/cement ratio *(Duos and Eggers, 1999)*. It is observed that percentage increase in slump is upto 70% replacement of cement with GGBS.

## 4.3 COMPRESSIVE STRENGTH

The compressive strength is a general property used to describe a concrete. Since other properties of concrete often correlate well with the compressive strength, it is used as the indicator of other mechanical properties. These are the average values of results achieved from three identical specimens. The effect of compressive strength tests of GGBS concrete samples are specified in Table 4.2 respectively.

**Table 4.2 Average compressive strength development in MPa of 150mm cube specimens cured in hot conditions**

| S.NO | Curing Environment | Curing Method | Specimen Mix | Mean Compressive Strength (MPa) | | |
|---|---|---|---|---|---|---|
| | | | | 3 Days | 7 Days | 28 Days |
| 1. | Curing Tank | Water | M0WC | 29.2 | 37.4 | 42.5 |
| | | | M30WC | 27.5 | 36.0 | 44.3 |
| | | | M50WC | 26.4 | 35.7 | 45.6 |
| | | | M70WC | 21.3 | 33.1 | 41.0 |
| 2. | Hot and humid | Sealed with plastic sheeting | M0PS | 28.8 | 36.2 | 40.1 |
| | | | M30PS | 26.2 | 35.8 | 42.8 |
| | | | M50PS | 24.7 | 35.0 | 43.5 |
| | | | M70PS | 19.0 | 31.4 | 39.0 |
| | | Wet burlap | M0WB | 26.5 | 35.4 | 38.1 |
| | | | M30WB | 24.9 | 34.0 | 40.0 |
| | | | M50WB | 22.0 | 33.5 | 41.5 |
| | | | M70WB | 17.5 | 30.2 | 37.4 |

Therefore, in order to examine the influence of curing on the strength development of the concrete, the compressive strength has been calculated at different ages. To facilitate the discussion, the results were drawn according to each curing process. Specimens were cured under three curing regimes namely water curing, wet burlap curing and fully sealed with plastic sheets at 3, 7 and 28 days of curing. Furthermore, specimens were prepared with the partially replacement of OPC cement by the GGBS at 0%, 30%, 50% and 70%.

### 4.3.1 Influence of GGBS on the compressive strength of cubes cured under water curing regimes

Figure 4.3 showed when the specimens cured in water tank attained higher compressive strength at all ages as compared with the other types of curing. For control specimen with water curing, M0WC mix is observed to have an increase in compressive strength of 29.2 MPa and 37.4 MPa at 3, 7 days of curing respectively and in later ages it exhibits about 42.5 MPa of 28-days compressive strength. Subsequently, when the percentage of GGBS was increased to 30%, the compressive strength for M30WC mix was recorded as 27.5 MPa and 36.0 MPa at 3 and 7 days of curing which is lower than control specimens but after 28 days of curing it attained about 44.3 MPa of strength which is higher than the control specimen. Similarly, if the percentage of GGBS mix was increased up to 50%, the compressive strength for M50WC mix at 3 and 7 days of curing was 26.4 and 35.7 MPa which is lower than OPC concrete but at 28 days it attained 45.6 MPa of compressive strength which is greater than control concrete specimen. However, when the percentage of GGBS was increased to 70%, the compressive strength for M70WC mix was recorded as 21.3 and 33.1MPa which results in lower strength than control specimens but at later ages of curing, the compressive strength at 28 days was observed as 41.0 MPa which results in decrease in strength when compared with control specimens.

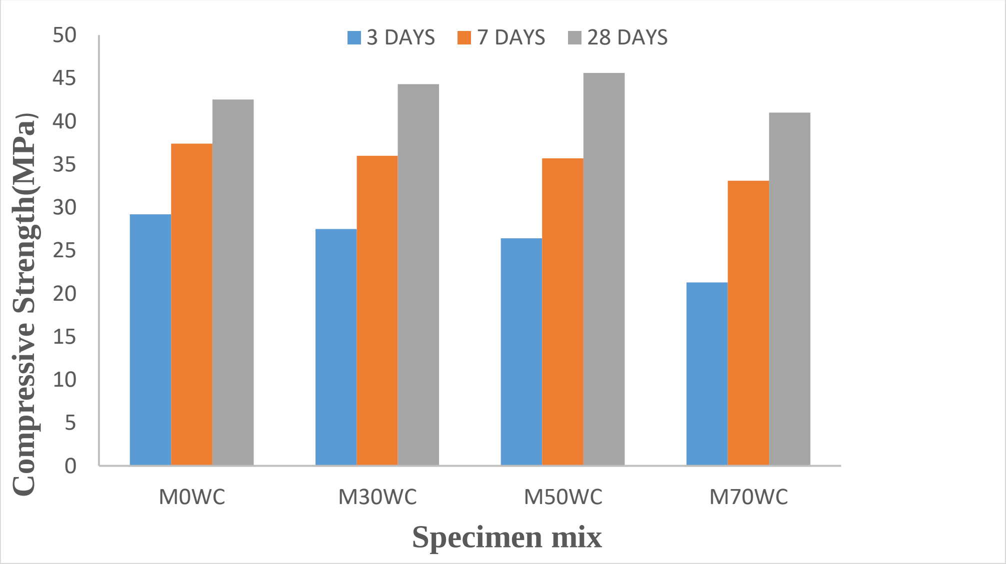


**Figure 4.3 Effect of water curing on compressive strength of concrete**

From the above recorded values, it can be seen that for M0WC mix, exhibited higher compressive strength at early age of curing than the GGBS mixes but later age of curing with increase in percentage of GGBS from 30% to 50% attained higher 28 days compressive strength than control concrete specimens. Firstly, this is because of the pozzolanic reaction is slow and depending on the calcium hydroxide($CaOH_2$) utility, so the strength attains longer time for the GGBS concrete mix. Secondly, because of initial rate of hydration of slag mix is usually lower than that of Portland cement, which results on lower rate of strength gain for concrete with additions of slag at early ages of curing but the strength development at later age of curing increases. Furthermore, with increase in percentage of slag to 70% strength decreases *(Dubey, A. et. al 2012).*

Hence, it is observed that the replacement of cement with slag from 30 to 70% results in decreasing the early age strength because of less filler effect of GGBS to fill up the voids and slower reactivity of GGBS concrete. Specimens when cured in water tank attained higher 28-days compressive strength about 45.6 MPa at 50% replacement of OPC cement with GGBS as compared with other type of curing. Water curing was the most effective and useful method of curing.

### 4.3.2 Influence of GGBS on the compressive strength of cubes cured under fully sealed with plastic sheet curing in hot climate condition

Figure 4.4 showed when the specimens cured with fully sealed plastic sheet produce compressive strength close to that of water curing. For control concrete specimen with plastic sheet curing, M0PS mix is observed to have an increased in compressive strength of 28.8 MPa and 36.2 MPa at 3 and 7 days of curing and in later ages it exhibits about 40.1 MPa of 28 days compressive strength. Subsequently when we increase the percentage of slag to 30% by replacing cement, the compressive strength for M30PS mix was recorded as 26.2 MPa and 35.8 MPa which results in decreasing strength than the control specimen at 3 and 7 days of curing but at 28 days of curing it attained about 42.8 MPa of strength which is greater than control specimen. Similarly, when we replace the cement with slag to 50%, the compressive strength for M50PS mix at 3 and 7 days was 24.7 and 35.0 MPa which is lower than OPC concrete but at 28 days it attained about 43.5 MPa of compressive strength which is greater than control concrete specimen. However, if the percentage of slag was increased up to 70%, the compressive strength for M70PS mix at 3, 7 and 28 days of curing was recorded as 19.0, 31.4 and 39.0 MPa which results in decrease in strength when compared with control specimens.

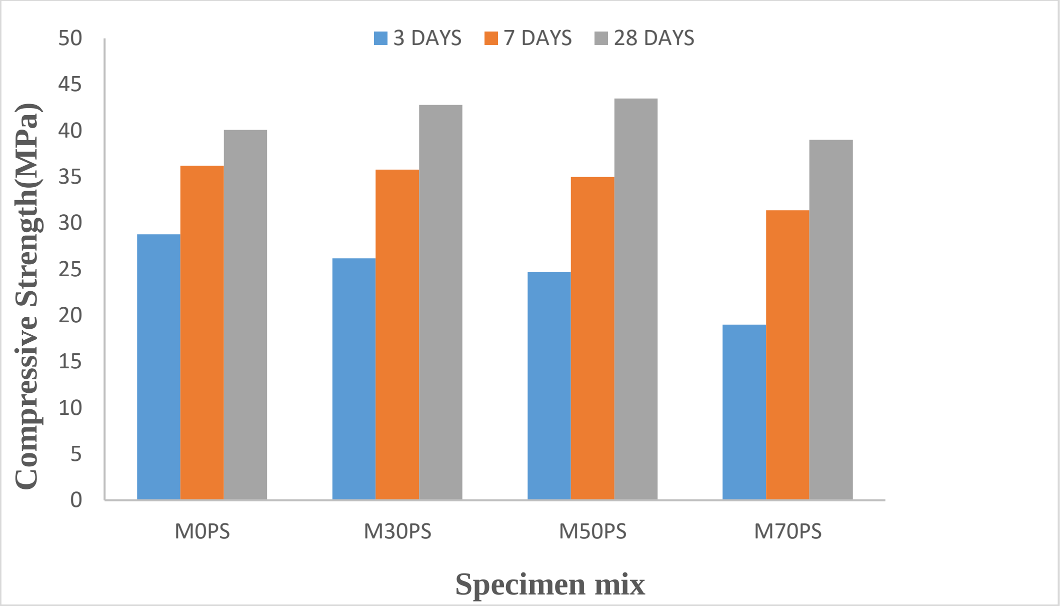


Figure 4.4 Effect of plastic sheet curing on compressive strength of concrete

From the above recorded values, the control concrete exhibited greater strength at early age of curing but later age strength development of GGBS increases after 28 days of curing in hot climatic condition because hydration rate of slag is gradually slower than that of Portland cement. So the combination of slag and OPC cement leads to slow down the rate of strength development at the initial age of curing.

However, the rate of decrease diminished with the increasing age of curing. It can be seen that compressive strength of concrete is increased with increase in there replacement level of cement by GGBS up to 50%, beyond further replacement of GGBS with cement to 70% there was a slight decrease in strength of concrete. Hence, it can be observed that if we replacing cement with slag upto 50% it exhibits higher 28 days compressive strength about 43.5 MPa. When the specimen cured with fully sealed plastic sheet gave us intermediate results.

### 4.3.3 Influence of GGBS on the compressive strength of cubes cured under wet burlap curing regimes in hot climatic condition

Fig. 4.5 showed when the specimen cured with wet burlap produced lowest level of compressive strength at all ages as compared with other two type of curing. For control concrete specimen M0WB mix, is observed to have an increase in compressive strength of 26.5 MPa and 35.4 MPa at 3 and 7 days of curing and in later age it exhibits about 38.1 MPa of 28 days compressive strength. Subsequently when we increase the percentage of slag to 30% by replacing cement, the compressive strength for M30WB mix was recorded as 24.9 MPa and 34.0 MPa which is lower than control specimen at 3 and 7 days of curing but at 28 days of curing it attained about 40.0 MPa of strength which is greater than control specimen. However, when we replace the cement with slag to 50%, the compressive strength for M50WB mix at 3 and 7 days was 22.0 and 33.5 MPa which is lower than OPC concrete but at 28 days it attained about 41.5 MPa of compressive strength which is greater than control concrete specimen. However, when the percentage of GGBS was increased up to 70%, the compressive strength for M70WB mix was recorded as 17.5 and 30.2 MPa which results in lower strength than control specimens at 3 and 7 days of curing but at later ages of curing, the compressive strength at 28 days was observed as 37.4 MPa which results in greatly decrease in strength when compared with control specimens.

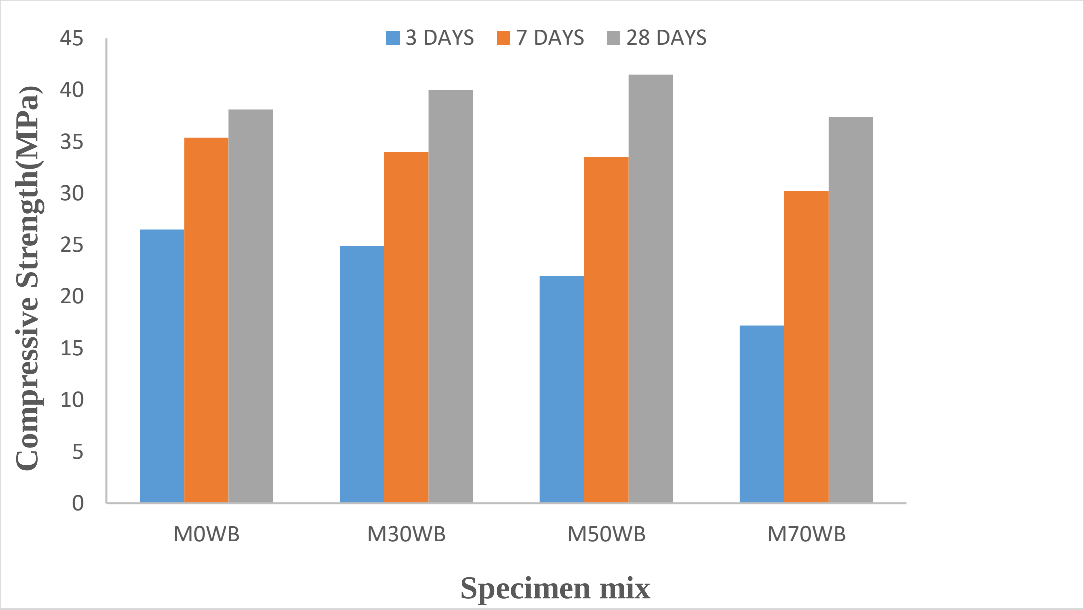


**Figure 4.5 Effect of wet burlap curing on compressive strength of concrete**

From the above recorded values, it can be seen that for M0WB mix, it exhibited higher compressive strength at the early ages of curing than the GGBS mixes but at later age of curing with increase in percentage of GGBS from 30% to 50% attained higher 28 days compressive strength than control concrete specimens. This is because of the pozzolanic reaction is slow and depending on the calcium hydroxide($CaOH_2$) utility, so the strength attains longer time for the GGBS concrete mix. Furthermore, with increased in the percentage of slag upto 70% there was a major decrease in strength at 28 days compressive strength. By using wet burlap curing as the percentage of GGBS increases results in greatly decrease in the compressive strength. As a result, when we partially replaced cement with GGBS by 50% achieved 41.5 MPa compressive strength and 70% replacement with cement was recorded as 37.4 MPa. Wet burlap curing produced the minimum compressive strength at all ages. It caused a reduction in compressive strength at 3,7 and 28 days respectively as compared to water curing and fully sealed plastic curing. Therefore, more continuously pore structures were formed that decreased the compressive strength development of concrete.

### 4.4 Initial Surface Absorption Test

Initial surface absorption of the three 150 × 150× 150mm test cubes sample was determined as per (BS 1881:Part 208:1996)- Recommendation for finding the initial surface absorption of the concrete specimen after the 28 days of curing. This experiment was carried out in order to find the permeability of the concrete surface.

The results of the initial absorption test at 10, 30 and 60 min are reported in Table 4.3. In this test we have to determine the effect of curing on ISA reading on cubes cured under three curing regimes namely water curing, wet burlap and fully sealed with plastic sheet and also observed the effect of partial replacement of cement with GGBS. The ISAT result with GGBS content varying from 0%, 30%, 50% and 70% as shown in Fig. 4.6, Fig. 4.7 and Fig. 4.8 below.

**Table 4.3 Average values obtained from ISAT 10,30 and 60 in ml/($m^2$s), of 150 mm concrete cube specimens at 28-day maturity**

| S.NO | Curing Environment | Curing method | Specimen Mix | Initial Surface Absorption, ml/(m2s) | | |
|---|---|---|---|---|---|---|
| | | | | 10 min | 30 min | 60 min |
| 1. | Curing Tank | Water | M0WC | 0.051 | 0.032 | 0.024 |
| | | | M30WC | 0.041 | 0.027 | 0.020 |
| | | | M50WC | 0.035 | 0.018 | 0.013 |
| | | | M70WC | 0.028 | 0.019 | 0.016 |
| 2. | Hot and Humid | Wet Burlap | M0WB | 0.058 | 0.037 | 0.027 |
| | | | M30WB | 0.060 | 0.043 | 0.035 |
| | | | M50WB | 0.065 | 0.048 | 0.039 |
| | | | M70WB | 0.071 | 0.037 | 0.027 |
| | | Fully sealed with plastic sheet | M0PS | 0.026 | 0.016 | 0.012 |
| | | | M30PS | 0.022 | 0.018 | 0.011 |
| | | | M50PS | 0.027 | 0.013 | 0.010 |
| | | | M70PS | 0.020 | 0.015 | 0.012 |

### 4.4.1 Influence of GGBS and wet burlap curing on the 28-day ISA of cubes cured in hot conditions

Figure 4.6 showed that the specimen when cured under wet burlap curing in hot climatic condition have higher ISA values with varying GGBS content. For control concrete M0WB mix, the average values ISA at 10, 30 and 60 min was recorded as 0.058, 0.037 and 0.027ml/m$^2$s. When we increase the percentage of slag to 30%, the ISA for M30WB mix was recorded as 0.060, 0.043 and 0.035ml/m$^2$s. However, when we replace the cement with slag at 50%, the ISA values for M50WB mix was recorded as 0.065, 0.048 and 0.039ml/m$^2$s. Moreover, further replacement of cement with slag by 70% the ISA values for M70WB mix was obtained as 0.071, 0.055 and 0.041ml/m$^2$s. It is observed that as the percentage of slag increases results in higher Initial surface absorption values than the OPC control specimen.

This is because of effect of cracks on ISA of GGBS concrete, higher reading were achieved on cubes and GGBS concretes are sensitive to poor curing an increase in the amount of GGBS in concrete merely means a pronounced adverse influence on the characteristics of the concrete surface. The initial absorption values(ISA) was considerable higher in wet burlap.

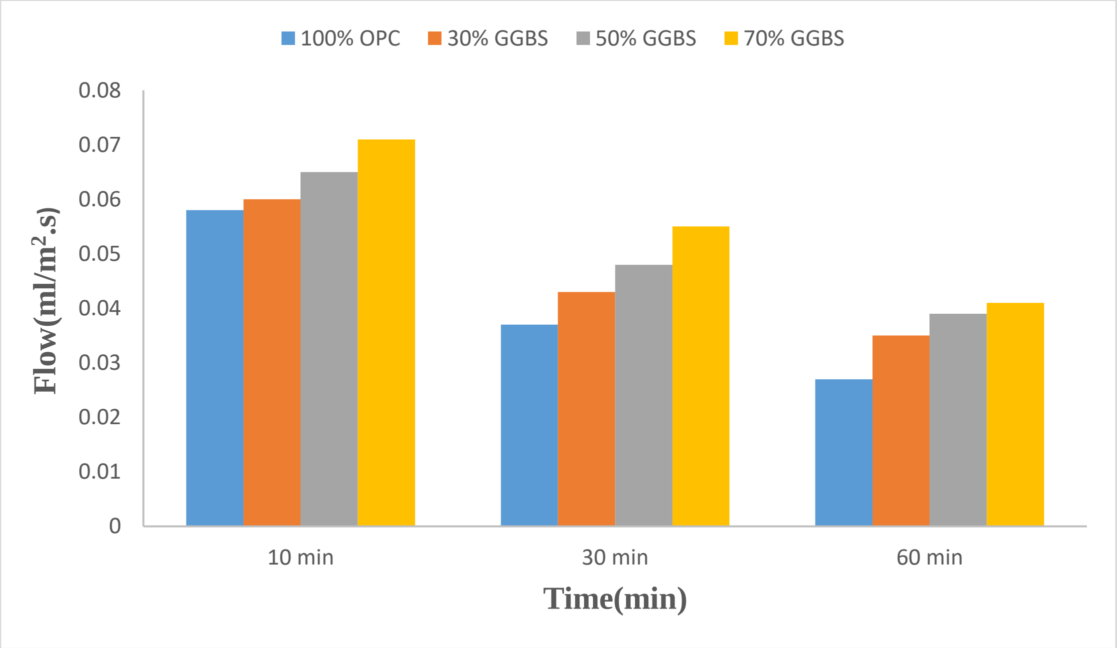


Figure 4.6 Effect of wet burlap curing on initial surface absorption of concrete

### 4.4.2 Influence of GGBS and water curing on the 28-day ISA of cubes

Figure 4.7 shows that the specimens cured inside water tank have lower ISA values with varying GGBS content. For OPC concrete specimen M0WC mix, the average values of ISA at

10, 30 and 60 min was recorded as 0.051, 0.032 and 0.024ml/m$^2$s. When we replaced the cement with slag upto 30%, the ISA values for M30WC mix was recorded as 0.041, 0.027 and 0.020ml/m$^2$s. However, at 50% replacement, the ISA values for M50WC mix were 0.035, 0.018 and 0.013ml/m$^2$s. Further with addition of slag by 70%, the ISA values for M70WC mix was recorded as 0.028, 0.019 and 0.016ml/m$^2$s. It is observed with increase in the GGBS content results in lower initial surface absorption as compared with control specimen. For M0WC mix, it is noticed that the ISA values decreases with time. This is because of production of the dicalcium silicate($C_2S$) matrix in the concrete thus preventing the water absorption in the concrete surface. It observed that with increased in GGBS content, initial surface absorption reduced significantly. Results also proved that as the slag content increases, the concrete become too much impermeable to be sensitive for the longer term test (30 and 60minutes). This can be due to the pozzolanic influence of GGBS which resulting in a considerable denser matrix than specimens consisting of 100% OPC.

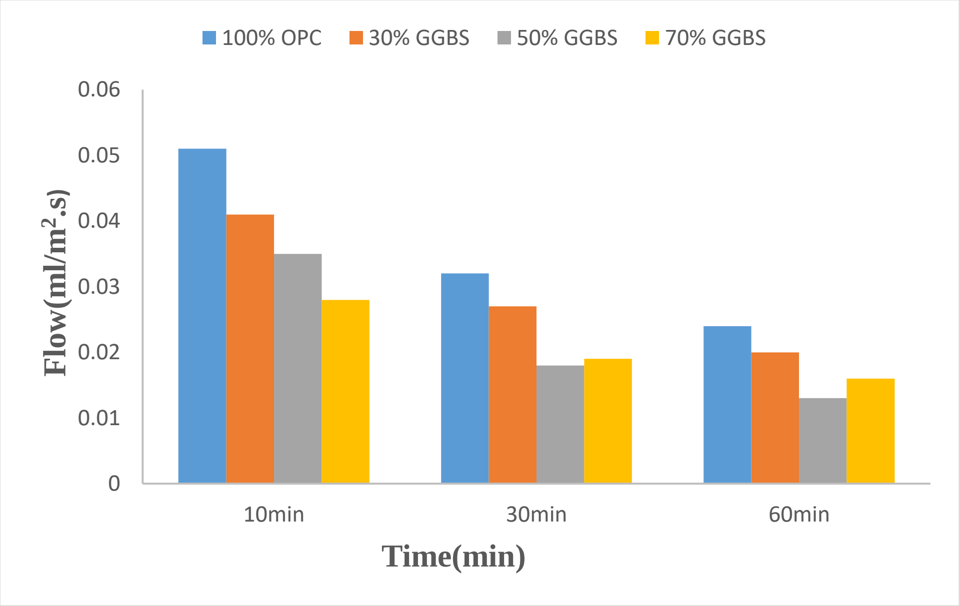


**Figure 4.7 Effect of water curing on initial surface absorption of concrete**

### 4.4.3 Influence of GGBS and sealed with plastic sheet on the 28-day ISA of cubes cured in hot conditions.

Figure 4.8 shows that the specimen cured with fully sealed plastic sheet in hot climatic condition have extremely lowest absorption values for all the mixes as compared with other type of curing. For control specimen M0PS mix, the average ISA values at 10, 30 and 60min was recorded as 0.026, 0.016 and 0.012ml/m$^2$s. When we replacing cement with slag at 30%, the ISA values for M30PS mix was recorded as 0.022, 0.018 and 0.011ml/m$^2$s. Moreover, replacing cement with slag at 50%, the ISA values for M50PS mix was recorded as 0.027, 0.013 and 0.010ml/m$^2$s. However, with addition of slag by 70%, the ISA values for M70PS mix was recorded as 0.020, 0.015 and 0.012ml/m$^2$s. It is examined that with increase in GGBS content results in lower initial surface absorption as compared with control specimen. Therefore, using plastic sheet curing durability of GGBS concrete improved as compared with other type of curing regimes.

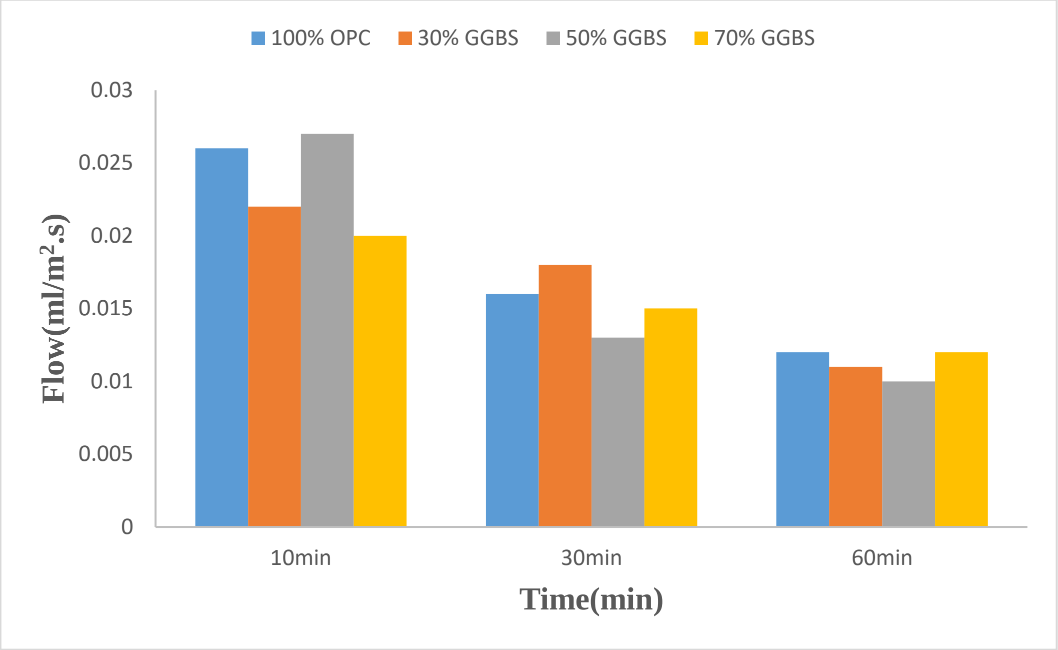


**Figure 4.8 Effect of plastic sheet curing on initial surface absorption of concrete**

## 4.5 Comparison between different curing regimes in hot climatic condition using compressive strength and Initial surface absorption test

This study presents the effect of different curing methods on several hardened properties such as compressive strength, and initial surface absorption of GGBS concrete. In addition, this study discusses the effect of moisture movement on the compressive strength, initial surface absorption and finally identifies the most effective curing process for GGBS concrete.

The results for compressive strength have been presented in Fig. 4.9. In all curing methods, the compressive strength of GGBS concrete increased with increasing age. The optimum use of slag in the concrete is observed to be 50% of cement for all three curing method. It can be observed that for control specimen exhibited higher compressive strength at early age of curing than the GGBS mixes but later age of curing with increase in percentage of slag from 30% to 50% attained higher 28 days compressive strength because hydration rate of slag is slower than that of Portland cement. So the blending of slag and Portland cement leads to retard the rate of strength development at early ages of curing but at later age hydration initiates, resulting in the creation of calcium-silicate-hydrate (CSH) and calcium hydroxide (CH). CSH is a gel that is responsible for strength development in GGBS concrete.

The highest compressive strength at all ages was produced by water curing. Plastic sheet curing produced a compressive strength close to that of water curing. The development of good compressive strength in water and plastic sheet curing is credited to sufficient moisture and suitable vapour pressure, which were maintained to continue the hydration of cement. The strength results of plastic sheet curing also indicate that a good gain in compressive strength can be achieved without applying water by external means if the moisture movement from the concrete specimens is prohibited. Furthermore, the pozzolanic reaction between GGBS and calcium hydroxide liberated from cement hydration occurred due to sufficient moisture available in water and wrapped curing. Consequently, additional amount of calcium silicate hydrate was developed, and therefore cured by water and plastic sheet curing GGBS concrete yielded increased compressive strength.

Wet burlap curing produced the lowest compressive strength at all ages. It caused a reduction in compressive strength at 3, 7 and 28 days respectively, as compared to water curing. The early drying of concrete stopped the cement hydration before the pores were blocked by adequate calcium silicate hydrate. Also, the production of secondary calcium silicate hydrate from pozzolanic reaction was hindered in absence of water. Thus, a more continuous pore structures was formed that reduced the compressive strength of the concrete.

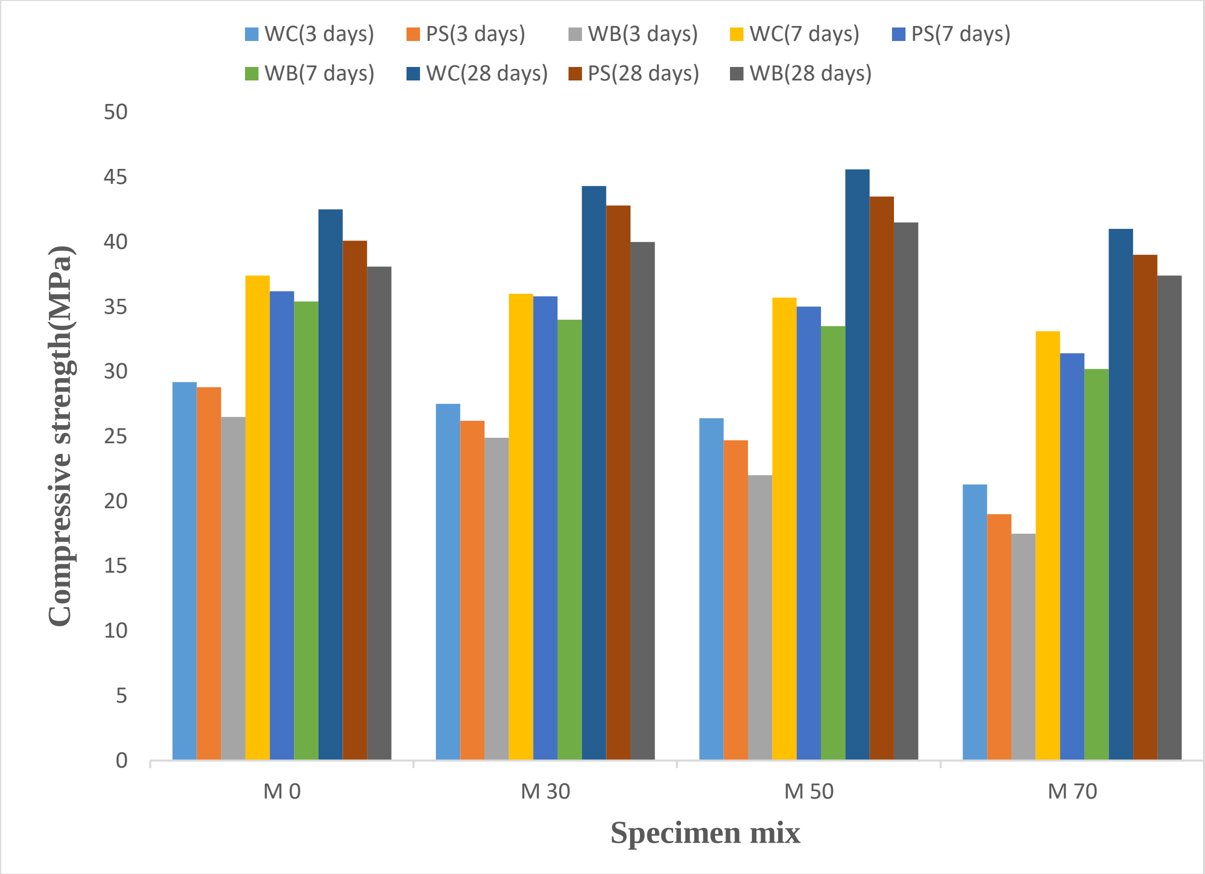


**Figure 4.9 Influence of GGBS on the compressive strength of cube cured under different curing regimes in hot climate condition**

**Initial surface absorption test**

In this test we have to determine the influence of curing on ISA of cubes cured under three curing regimes and tested at 28 days of curing. For 100% OPC, it is noticed that the ISA values decreases with time. This is because of production of the dicalcium silicate($C_2S$) matrix in the concrete thus preventing the water absorption in the concrete surface. Figure 4.8 shows that with increased in GGBS content, initial surface absorption reduced significantly. Results also proved that as the slag content increases, the concrete become too much impermeable to be sensitive for the longer term test (30 and 60minutes). This can be due to the pozzolanic influence of GGBS which resulting in a considerable denser matrix than specimens consisting of 100% OPC.

The type of curing affected the initial surface absorption of GGBS concretes, as can be seen from Fig. 4.10. The initial surface absorption under water and plastic sheet curing was much smaller than that under wet burlap curing. This indicates that the initial surface absorption was influenced by the moisture movement from the specimens. Moreover, water curing greatly enhanced the process of filling and healing the existing voids, flaws and pores due to additional hydration product evolved from pozzolanic reaction between GGBS, calcium hydroxide and moisture. Thus, GGBS concrete achieved a fine and discontinuous pore structure, and produced lower initial surface absorption.

The initial surface absorption was much higher in wet burlap curing. This is possibly because of two reasons. Firstly, the rate and degree of hydration were affected by the loss of moisture at the early age of concrete. Secondly, it might be due to microcracks or shrinkage cracks resulting from early drying out of concrete. Moreover, some microcracks might have been formed in GGBS concrete due to thermal stresses during the drying of specimens.

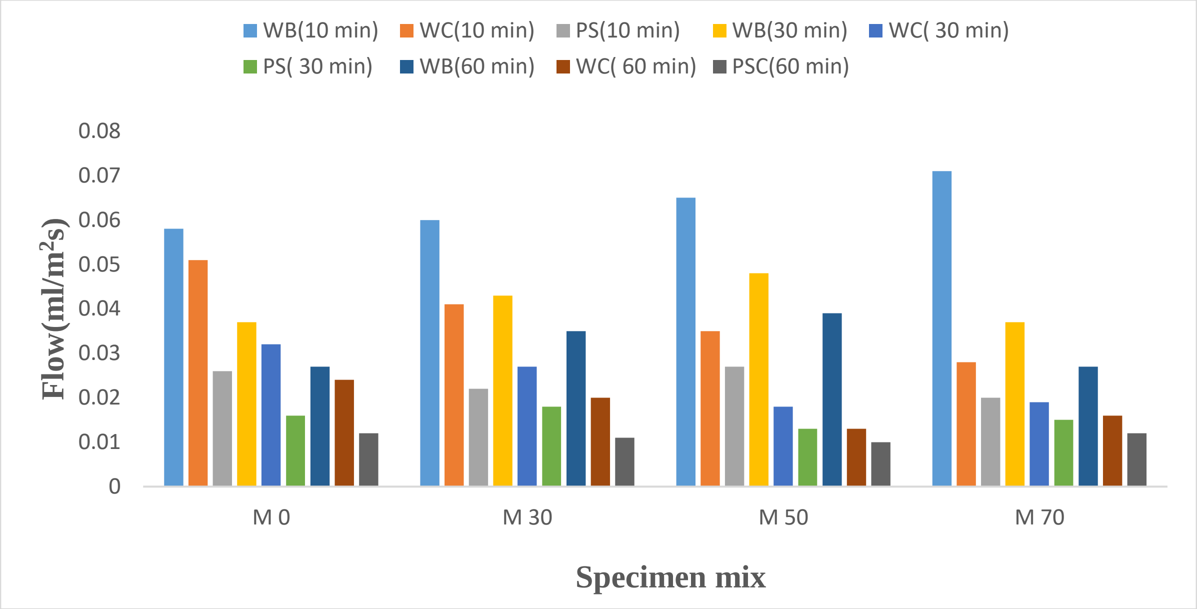


**Figure 4.10 Influence of GGBS on initial surface absorption of cubes cured under different curing regimes in hot climate condition**

By comparing the three curing regimes with varying GGBS content at 0%, 30%, 50% and 70%, it can be observed that in water curing, there was no loss of moisture from the concrete surface since the concrete specimens were immersed in water. Instead, the specimens subjected to water curing gained some moisture from surrounding water. Hence, more than sufficient water was available to maximize the extent of cement hydration. As a result, water curing produced the highest level of compressive strength and the lowest level of initial surface absorption.

The concrete specimens subjected to Plastic sheet and wet burlap curing exhibited some loss of moisture. However, the loss of moisture was minimum in case of plastic sheet curing. This is because plastic sheet curing exhibited very low rate of moisture movement, which is obvious. In plastic sheet curing, the moisture movement from concrete surface was hindered, as the specimens were sealed with poly-film. As a result, a good amount of moisture was available to be used up throughout the hydration process. For this reason, the reduction in compressive strength, and the increase in initial surface absorption were lower in plastic sheet curing. This is evident from Fig. 4.7 and Fig. 4.8 which compare the performance of plastic sheet and wet burlap curing with respect to water curing. It was understood from the performance of plastic sheet curing that the concrete properties can be improved if the moisture movement from the concrete specimens is prohibited.

The maximum loss of moisture occurred in wet burlap curing. The high moisture loss caused because of no protection against the moisture movement from concrete specimens. The moisture easily moved out of the specimens with time and caused a shortage of free water required for cement hydration. Therefore, cement hydration was stopped at a certain stage and remained incomplete. For this reason, the reduction in compressive strength, and the increase in initial surface absorption were significant in case of wet burlap curing. The poor performance of wet burlap curing is entirely due to significant moisture movement from OPC concrete and GGBS specimens.

# CHAPTER 5

# CONCLUSIONS

## 5.1 GENERAL

This investigation has shown that replacement of OPC cement by GGBS results in a considerable improvement in the properties of concrete in hot climatic conditions provided that concrete is properly cured.

The purpose of project has to study the influence of three curing regimes on the better performance of OPC and GGBS in a hot climatic condition in an attempt to gain the most suitable curing regimes to minimise the adverse effect of such climates. The following conclusions can be drawn from the experimental investigations conducted on the behaviour of concretes with GGBS as partial replacements for cement.

- Slump value of concrete increases as the percentage of GGBS increases up to 70% replacement with cement than the control concrete mixes. The increase in slump value is due to the higher smoothness and fineness of slag increases the entrainment of air in the matrix, subsequently increasing the volume of paste.
- In hot climatic condition, replacement of cement with GGBS varying between 30% to 50%, tends to decrease the early age strength decreases as compared with control concrete. This is due to less filler effect of slag to fulfill the voids and slower reactivity of GGBS.
- Though, the age of concrete is prolonged beyond 28 days, the gain in compressive strength is higher for GGBS concrete. This is because of initial rate of hydration of slag is usually lower than that of Portland cement, which results on lower rate of strength gain for concrete with additions of slag at early ages of curing but the strength development at later age of curing increases. However, replacing the OPC cement with GGBS by 70% results in decreasing the compressive strength.
- Water curing was the most effective and useful method of curing. It produced the maximum level of compressive strength, and the lower values of initial surface absorption. This is because of improved pore structure and lower permeability resulting from the greater degree of cement hydration and pozzolanic reaction without any loss of moisture from the GGBS concrete specimens. Therefore, adequate curing is provided to improve the durability of GGBS concrete.
- Fully sealed with plastic sheet curing produced compressive strength close to that of water curing, and lower initial surface absorption than the wet burlap and water curing.

This is associated with decreased moisture movement from concrete specimens, due to sealing of moisture by plastic sheets that led to improved quality of cement hydration and pozzolanic reaction.

- Wet burlap curing produced the extremely lower compressive strength, as well as the maximum initial surface absorption. This is because of moisture movement from GGBS concrete specimens was very higher in wet burlap curing, which did not provide any safeguard against the early drying out of concrete. Consequently, both the cement hydration and pozzolanic reaction were affected. In the hot climate, the burlap dry out very fast. Therefore, it is difficult to maintain wet surface in burlap curing.
- The optimum use of slag in the concrete is observed to be 50% of cement for all three curing method. The GGBS concrete would require a longer curing period than that of Portland cement concrete. Insufficient curing (less than 3 and 7 days) could severely hamper the strength development.

## 5.2 SCOPE FOR FUTURE WORK

- In this investigation the influence of curing and GGBS on the performance of concrete in hot conditions was measured up to the age of 28 days. More information is needed on the long-term effect of these parameters on the durability of concrete.
- Similar studies can be conducted by varying the grade of concrete.

# REFERENCES

- Pandey, R.K., Kumar, A. and Khan, M.A., 2016. Effect of ground granulated blast furnace slag as partial cement replacement on strength and durability of concrete: a review. *International Journal of Engineering Research & Technology,* Vol. 3, ISSN: 2395-0072.
- Suresh, D. and Nagaraju, K., 2015. Ground Granulated Blast Slag (GGBS) In Concrete–A Review. *IOSR Journal of Mechanical and Civil Engineering, Vol. 12,* pp.76-822, ISSN: 2320-334.
- Garg, E.K. and Kapoor, E.K., 2016. A Review on Ground Granulated Blast-Furnace Slag as a Cement replacing material. *International Journal of Engineering Research And Management (IJERM),* ISSN: 2349- 2058, Vol.03.
- Burg, R.G., 1996. *The influence of casting and curing temperature on the properties of fresh and hardened concrete* (No. R&D Bulletin RD113T), Portland Cement Association.
- Gonnerman, H.F., 1928. Compression, flexure and tension tests of plain concrete. Major series 171, 209, and 210. Report of Director of Research, Portland Cement. *Proc. ASTM, Part II*, *28*, pp.527.
- Rughooputh, R. and Rana, J., 2014. Partial replacement of cement by ground granulated blast furnace slag in concrete. *Journal of Emerging Trends in Engineering and Applied Sciences*, *Vol.*5, pp.340-343, ISSN: 2141-7016.
- Patil, Y.O., Patil, P.N. and Dwivedi, A.K., 2013. GGBS as partial replacement of OPC in cement concrete–An experimental study. *International Journal of Scientific Research*, *Vol. 2* pp.189-91, ISSN: 2277-8179.
- Pathan, V.G., Ghutke, V.S. and Pathan, G., 2012. Evaluation of concrete properties using ground granulated blast furnace slag. *International journal of innovative research in science, Engineering and technology, Vol.1,* pp. 71-79.
- Ramalekshmi, M., Sheeja, R. and Gopinath, R., 2014. Experimental Behaviour of Reinforced Concrete with Partial Replacement of Cement with Ground Granulated Blast Furnace Slag. *International Journal of Engineering Research & Technology (IJERT), Vol. 3*, pp.525-534, ISSN: 2278-0181.
- Dubey, A., Chandak, R. and Yadav, R.K., 2012. Effect of blast furnace slag powder on compressive strength of concrete. *International Journal of Scientific & Engineering Research*, *Vol. 3,* pp.I094-I098, ISSN: 2229-5518.

- Oner, A. and Akyuz, S., 2007. An experimental study on optimum usage of GGBS for the compressive strength of concrete. *Cement and Concrete Composites*, doi:10.1016/j.cemconcomp.2007.01.001, *29*(6), pp.505-514.
- Khan, K.M. and Ghani, U., 2004, August. Effect of blending of portland cement with ground granulated blast furnace slag on the properties of concrete. In *Proceedings of the 29th conference on our world in concrete & structures, premier PTE LTD, Singapore* (pp. 329-334).
- Thakur, I.C., Kisku, N., Singh, J.P. and Kumar, S., 2016. Properties of Concrete Incorporated with GGBS. *International Journal of Research in Engineering and Technology*, *5*(08), pp.275-281, ISSN: 2321-7308.
- Malagavelli, V. and Rao, P.N., 2010. High performance concrete with GGBS and ROBO sand. *International journal of engineering science and technology*, *2*(10), pp.5107-5113, ISSN: 2120-7450.
- Chaithra, H.L., Pramod, K. and Chandrashekara, A., 2015. An Experimental Study on Partial Replacement of Cement by GGBS and Natural Sand by Quarry Sand in Concrete. *Ijert: International Journal of Engineering Research & Technology, ISSN*, pp.2278-0181, ISSN: 2297-5318.
- Karri, S.K., Rao, G.R. and Raju, P.M., 2015. Strength and durability Studies on GGBS Concrete. *SSRG International Journal of Civil Engineering (SSRG-IJCE)*, *2*(10), pp.34-41, ISSN: 2348-8352.
- Thejaskumar, H.M and Dr. Ramesh, V, 2015 Experimental Study on Strength and Durability of Concrete with Partial Replacement of Blast Furnace Slag. Vol. 3, pp. 134-140, *ISSN:* 2348-7607.
- Gowri, T.V., Sravana, P. and Rao, P.S., 2014. Studies on Strength Behavior of High Volumes of Slag Concrete. *International Journal of Research in Engineering and Technology (IJRET)*, *3*(4), pp.227-238, ISSN: 2319-1163.
- Arivalagan, S., 2014. Sustainable studies on concrete with GGBS as a replacement material in cement. *Jordan journal of civil engineering*, *8*(3), pp.263-270.
- Islam, M., Islam, S. and Rahman, A., 2011. Strength Behavior of Mortar Using Slag As Partial Replacement of Cement, Vol.10, pp: 264-282, ISSN: 2450-1264.
- Alavi, S., Baskar, I. and Venkatasubramani, D.R., 2013. Strength and durability characteristics of GGBFS based SCC. *International Journal of Emerging Trends in Engineering and Development*, *2*(3), pp.510-519, ISSN: 2249-6149.

- Nataraja, M.C. and Das, L., 2010. Concrete mix proportioning as per IS 10262: 2009– Comparison with IS 10262: 1982 and ACI 211.1-91. *The Indian Concrete Journal*, pp.64-70.
- IS:516-1959: (Reaffirmed 2004): Methods of Test for Strength of Concrete, Bureau of Indian Standard, New Delhi – 2004.
- IS:383-1970: Specification for Coarse and Fine Aggregates from Natural Sources for Concrete, Bureau of Indian Standard, New Delhi - 1970.
- IS:1999-1959: (Reaffirmed 1999): Methods of Sampling and Analysis of Concrete, Bureau of Indian Standard, New Delhi - 1999.
- IS:2386(Part I, III), 1963: Methods of Test for Aggregates for Concrete, Bureau of Indian Standard, New Delhi - 1963.
- IS:12089-1987: Specification for granulated slag for manufacture of portland slag cement, Bureau of Indian Standard, New Delhi - 1987.
- BS 1881: Part 208: 1996: Recommendations for the determination of the initial surface absorption of concrete, BSI: London.
- P.J Robbins, S. A. Austin., (1992). Suitability of GGBS as cement replacement in Hot arid climates. *Cement & Concrete Composites*, Vol 25, pp. 598-612.
- Jin, Y. and Yazdani, N., 2002. Substitution of Fly Ash, Slag, and Admixtures in FDOT. Department of Civil Engineering, Florida State University, USA, 10 p. Concrete Mixture Proportions. *Special Publication*, *209*, pp.347-368.
- Geiseler, J., Kollo, H. and Lang, E., 1995. Influence of blast furnace cements on durability of concrete structures. *ACI Materials Journal*, *92*(3), pp.252-257.
- Chen, E.Y., 2006, April. Detecting DoS attacks on SIP systems. In *VoIP Management and Security, 2006. 1st IEEE Workshop on* (pp. 53-58). IEEE.
- Standing Committee on Concrete Technology (2000). Recommended Specification for Reinforced Concrete in Marine Environment. Hong Kong SAR Government.
- Hamling, J.W. and Kriner, R.W., 1992. Evaluation of granulated blast furnace slag as a cementitious admixture—A case study. *Cement, concrete and aggregates*, *14*(1), pp.13-20.
- Lane, D.S. and Ozyildirum, H.C., 1999. Evaluation of the effect of Portland cement alkali content, fly ash, ground slag, and silica fume on alkali-silica reactivity. *Cement, concrete and aggregates*, Virginia Department of Transportation, USA, 189 p. *21*(2), pp.126-140.

- Meeks, K.W. and Carino, N.J., 1999. *Curing of high-performance concrete: Report of the state-of-the-art*. US Department of Commerce, Technology Administration, National Institute of Standards and Technology, Gaithersburg, MD 20899, U.S. Department of Commerce, pp 56-57, 76.
- Neville, A., 1996. Suggestions of research areas likely to improve concrete. *Concrete International*, Properties of Concrete (3rd Edition). Pitman Publishing Ltd., *18*(5), pp.44-49.
- Richardson, D.N., 2006. Strength and durability characteristics of a 70% ground granulated blast furnace slag (GGBFS) concrete mix, Missouri Transportation Institute and Missouri Department of Transportation, USA.
- www.ukcsma.co.uk/what_is_ggbs.html.
- www.ggbsreviewgroup.blogspot.in.
- www.en.m.wikipedia.org/wiki/Cement.
- www.vcem-global.com/technical.html.