DURABILITY STUDY OF BLENDED CEMENT CONCRETE USING GGBFS WITH RESPECT TO SULPHATE ATTACK

Thesis submitted to Faculty of Engineering and Technology, Jadavpur University
In the partial fulfillment of the requirements for the degree of

MASTER OF CONSTRUCTION ENGINEERING

with specialization in

STRUCTURAL REPAIR AND RETROFIT ENGINEERING

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This is to certify that the thesis entitled ***"Durability study of blended cement concrete using GGBFS with respect to sulphate attack"*** *has been prepared by Ruma Halder (Examination Roll No. M6CNE19013 and Registration No. 137346 of 2016-2017) for partial fulfillment of requirements for the award of master degree in Construction Engineering, is a record of research work carried out under our supervision and guidance. We hereby approve this thesis for submission and presentation.*

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The foregoing thesis is hereby approved as a creditable study of an engineering subject carried out and presented in a manner satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

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Declaration of Originality and Compliance of Academic Ethics

I hereby declare that the thesis entitled ***"Durability study of blended cement concrete using GGBFS with respect to sulphate attack"*** *contains literature survey and original research work done by the undersigned candidate, and have been submitted for the partial fulfillment of the continuous assessment of the course of* ***Master of Construction Engineering,*** *specialization in* ***"Structural Repair and Retrofit Engineering"*** *of* ***Jadavpur University.***

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

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(*RUMA HALDER*)

ABSTRACT

Humans have been using concrete in their pioneering architectural feats for millennia. Modern concrete was born in the early ninetieth century with the discovery of Portland cement, the key ingredient used in concretes today. Production of cement has a major environmental impact." The rule of thumb is that for every tone of cement you make one tone of CO_2 is produced" says Marious Soutsos, who studies concrete at the University of Liverpool, UK. Several ways of reducing the environmental impact of concrete are now being investigated. Replacing Portland clinker either partially or entirely with alternative cement is being investigated as an approach to tackling concretes CO_2 emissions. Waste material such as pozzolanic or cementitious materials like fly ash or ground granulated blast furnace slag (GGBFS) or condensed silica fumes (CSF) etc are already being used as supplementary cementitious materials. World Commission on Environment and Development defines sustainable development as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable development seeks to achieve development in a balanced manner. Sustainable development may be economic development, social development and environmental protection. Use of These supplementary cementitious materials can act as a step towards maintaining the sustainable development. Blending of these types of materials with ordinary cement the product formed is called blended cement.

A separate approach of sustainable development is to make the structures durable. More durable structures need to be replaced less frequently and will reduce the need for cement. Such durability increase can be achieved by choosing appropriate mix designs and selecting suitable aggregates and admixtures. Many studies show that, in sufficient quantities, GGBFS is generally very effective in controlling sulfate attack. GGBFS is a latent hydraulic material and is very successful in lowering permeability of concrete. In this experiment Ordinary Portland cement is partially replaced by GGBFS by different percentage. Also comparison between market available Portland slag cement and blended cement is done. This thesis also investigates the durability of different types of concrete in sulphate exposure i.e sulphuric acid and magnesium sulphate solution. Total 135 no of 150mm ×150mm Cube specimen 75 no of 100 mm ×200 mm cylinder specimen 50 no of 100mm×100 mm×500mm beam specimen and 30 no of 50 mm× 50 mm mortar specimen have been casted for conducting various types of tests. Compressive strengths, splitting tensile strength, flexural strength of different mixes have been compared to see how the concrete strength differs from original mixes. In addition different types of non-destructive tests such as ultrasonic pulse velocity test and half-cell potential tests have also been performed on the concrete samples for better analysis of their strength and durability characteristics. Also sorptivity test of mortar has been done for better analysis of durability. Observing the experimental result it may be concluded that concrete made with up to 40% replacement of cement by GGBFS can give a durable concrete than using OPC or PSC alone. These experiments may be treated as small initiatives towards better environment and sustainable development program and economical approach in terms of durability of structure.

LIST OF CONTENTS

1.Introduction

2. Literature Review

5. Experimental Programme

5.1 Material Used

5.2Test Procedures

5.3 Material test results

6. Results and discussions

7. CONCLUSION

LIST OF TABLES

Unexposed condition (Water curing for 28 Days)

Exposed condition (Water curing for 28 Days + 4% $MgSO_4$ solution for 60 days and 120day respectively)

Exposed condition (Water curing for 28 Days + 4% H_2SO_4 solution for 60 days and 120days respectively)

LIST OF FIGUERS

Unexposed condition (Water curing for 28 Days)

Exposed condition (Water curing for 28 Days + 4% $MgSO_4$ ***solution for 60 days and 120day respectively)***

Exposed condition (Water curing for 28 Days + 4% H_2SO_4 solution for 60 days and 120days respectively)

LIST OF ABBREVIATIONS

CA	*Coarse Aggregate*
CH	*Calcium Hydroxide*
CSH	*Calcium Silicate Hydrate*
mV	*Milli-Volt*
FA	*Fine Aggregate*
GGBFS	*Ground granulated blast furnace slag*
OPC	*Ordinary Portland Cement*
PSC	*Portland slag Cement*
Sp. Gr.	*Specific Gravity*
UPV	*Ultrasonic Pulse Velocity*

CHAPTER - 1

INTRODUCTIONS

1.1 Blended cement:

When ordinary Portland cement is mixed with Pozzolanic or Cementitious materials such as fly ash ground granulated blast furnace slag or silica fume it is called blended cement.

1.2 Types of blended cement:

There are mainly two types of blended cement. The admixtures can be blended with Portland cement to produce factory blended cement

- Factory blended cement:- In a cement factory, supplementary cementitious material and Portland cement can readily be blended by feeding them simultaneously into a grinding mill.
- Site mixed blended cement:- The supplementary material used as a separate ‘addition’ and combined with the Portland cement in the concrete mixer.

Granulated Blast Furnace Slag (GGBFS) is widely used as alternative to partially replace cement, or as a cementitious material which has been found to have a relatively constant chemical composition, better workability, and higher ultimate strength compared to fly ash, and pozzolan.

1.3 Sulphate attack :

Sulfate attack is a common form of concrete deterioration. It happens when concrete comes in contact with water containing sulfates (SO_4). The use of blended slag cement is an extremely effective way of reducing the effect of sulfate attack in concrete. When concrete is exposed to different types of chemicals, the durability of concrete is quite influenced. Moreover, if sufficient research and studies have not been previously performed, the produced concrete may not meet the durability parameters for specific environmental conditions and subsequently, the result of its application may be disastrous. Although most concrete structures have considerable long life expectancies, there are also a significant number of infrastructures in the world, such as wastewater systems, which are constantly under corrosion from different types of chemicals, such as sulfuric acid. Unfortunately, this continuous invasion and ingression of acidic ions into concrete can ultimately lead to serious damages to structures, which will consequently result in costly repairs or in some cases, complete replacement of the whole structure.

It is well established in literatures that acidic environment is deleterious to concrete durability because acid neutralizes the alkalinity of concrete by reacting with the hydration products of the concrete matrix to form gypsum and ettringite. The chemical reaction of this neutralization phenomenon with sulphuric acid is given by Zivica and Bajza as in Equations (1) and (2). Both gypsum and ettringite possess little structural strength, yet they have larger volumes than the compounds they replace. This results in internal pressures, formation of cracks and eventually, the loss of strength. Consequently, the concrete becomes vulnerable to aggressive exposure.

$H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4.2H_2O$ (gypsum)……….. (1)

$3CaSO_4 + 3CaO.Al_2O_3.6H_2O + 25H_2O \rightarrow 3CaO.Al_2O_3.3CaSO_4.31H_2O$ (ettringite)…………(2)

Sulfuric acid is one of the most destructive acids to concrete and depending on its concentration and formation manner, can cause severe degradation and damage to concrete structures which come into contact with it. This acid may be produced in soils and groundwater through the oxidation of iron sulfide minerals in the form of pyrites. In the steel and iron industry, waste acids, which are used for surface preparations, may be disposed into wastewater systems which will consequently result in attacks to underground concrete facilities.

The most commonly known type of sulfuric acid corrosion in concrete takes place in sanitary sewer system infrastructures. This type of corrosion is also known by different names, such as hydrogen sulfide (H2S) corrosion, microbial induced corrosion etc. All of these names clearly imply the nature of the corrosion process. A large number of wastewater systems are made of concrete. Repair and reconstruction costs of these structures are considerable. Acid attack generally occurs in concrete sewer pipes, treatment plants, manholes, pumping stations, junction chambers, etc. These environments have the capability of providing suitable conditions for the production of H2S gas which will consequently oxidize into corrosive sulfuric acid and attacks concrete. In order to avoid the huge costs of repairs, maintenance or replacement of concrete sewer infrastructures, different solutions have been suggested for various cases. It is obvious that it would be more desirable to construct a new concrete sewage system with the capability of withstanding sulfuric acid corrosion during a long period of time without any major rehabilitation. However, in many cases, replacing an old sewage system with a new one is not an option due to the lack of sufficient funds.

It is well known that the main products of cement hydration are calcium silicate hydrate, calcium hydroxide, calcium aluminate hydrate and ettringite (Castañeda et al.,2013). However, three of these hydration products is not stable in sulfate environment. The products in chemical attack being formed under below chemical reactions:

$Ca (OH)_2 + C\text{-}S\text{-}H + SO_4^{-2} + H_2 O \rightarrow CaSO_4 + 2H_2 O$………………..(3)

$Ca (OH)_2 + C\text{-}S\text{-}H + MgSO_4 + H_2 O \rightarrow CaSO_4 + 2H_2 O\ Mg (OH)_2 + SiO_2 .x H_2$ …….(4)

$3CaO\ Al_2 O_3\ Ca (OH)_2\ (12 - 18)\ H_2 O + SO_4^{-2}.\ H_2 O + H_2 O \rightarrow 3CaO\ Al_2 O_3\ 3CaSO_{4.}\ 32H_2 O$…(5)

$Ca (OH)_2 + C\text{-}S\text{-}H + SO_4^{-2} + CO_3^{2-} + H_2 O \rightarrow CaSiO_3 .CaCO_{3.}\ CaSO_{4.}\ 2HO_2$ …………(6)

The main products in the chemical reaction are gypsum, ettringite, carbon sulfosilicate, magnesium hydroxide and silica gel .Gypsum and ettringite are the most common products of sulfate attack (Amin et al., 2008). Magnesium hydroxide and silica gel are the products of magnesium sulfate attack.

1.4 GGBFS as a supplementary cementitious material:

Ground granulated blast furnace GGBFS, a by-product of the steel manufacturing industry, being used as an effective partial cement replacement material, has already been proven to improve several performance characteristics of concrete. The reactivity of GGBFS has been found to depend on the properties of GGBFS, which varies with the source of GGBFS, type of raw material used, method and the rate of cooling. In this paper cement replacement levels of 30%, 40% and 50% were selected to study the effects of GGBFS on strength and sulfate resistance in concretes. Two solutions were used to determine the resistance of GGBFS concrete to sulfate attack. These solutions involved immersion in 4% magnasium sulfate solutions and 4% sulphuric acid solutions. Furthermore, compressive strength, splitting tensile strength, flexural strength, ultrasonic pulse velocity test, half cell potential tests of concrete mixtures that keep in water for 28 days then in magnesium sulfate and 4% sulphuric acid solutions were determined at ages up to 60 and 120 days respectively. Also mass change of concrete mixtures was determined. The experimental results show that at later ages GGBFS concrete that keeps in water got closer compressive strength to control concrete.

1.5 Type of Mix done:

This thesis work is done with three types of sustainable concrete mixes.

Mix Design Type-1 : Where design was done for M45 concrete using Ordinary Portland Cement(OPC). Then cement is partially replaced with deferent percentage of GGBFS viz. 30%, 40% and 50%.

Mix Design Type-2 : Where design was done for M45 concrete using 70% Ordinary Portland Cement(OPC) and 30% GGBFS .

Mix Design Type-3 : Where design was done for M45 concrete using 60% Ordinary Portland Cement(OPC)and 40% of GGBFS.

Mix Design Type-4 : Where design was done for M45 concrete using 50% Ordinary Portland Cement(OPC) and 50% of GGBFS .

Mix Design Type-5 : Where design was done for M45 concrete using Portland Slag Cement(PSC).

All the samples have been experimented at 7 days, 28 days (after water curing) and then after 60 days and 120days of acid exposure condition. Acid used is 4% $H2SO_4$ (having pH of solution 0.3) and 4% $MgSo_4$ solution (having pH of solution 7.6) samples are fully immersed within acid solution for 60 days and 120 days. Strength of mixes has been compared before and after acid exposure. Comparison has also been done for various replacements within same types of mixes. The aim of this research is mainly to identify and validate an optimum concrete mix design using GGBFS which is durable and sustainable in nature.

CHAPTER - 2

LITERATURE REVIEW

2.1 General:

The studies and investigations on the developments of sustainable concrete is going on since the last few years. Studies on the durability of concrete in terms of resistance to sulfuric acid attacks have also been done. Brief reviews on some of those papers are discussed here.

2.2. **Literature survey**:-

1. Newman John and Choo (2003) recorded that GGBFS is a very reactive pozzolana. In the presence of water, it reacts with calcium hydroxide to produce stable, insoluble cementitious hydrates. This pozzolanic reaction reduces the permeability and porosity of cement paste making it stronger and significantly more durable. The use of GGBFS as a partial replacement for cement in suitably designed concrete mixes improves acid resistance, sulphate resistance and freeze and thaw resistance. And it also increases the resistance to the penetration of chloride ions and eliminates alkali-silica reaction.

Newman John and Choo (2003)

2. Er. KimmiGarg, Er. KshipraKapoor studied and experimented, it is proved that GGBFS can be used as an alternative material for cement, reducing cement consumption and reducing the cost of construction. Use of industrial waste products saves the environment and conserves natural resources.

Er. KimmiGarg, Er. KshipraKapoor July 2016

3. Santosh Kumar Karri et. al. 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 GGBFS replacement level. He observed that the maximum compressive strength, splitting 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 GGBFS concrete affected to HCL was greater than that of H_2SO_4.

Santosh Kumar Karri, G.V. Rama Rao and P. Markandeya Raju, October 2015

4. Nandini S R Srinivas Raju, Dr. V Ramesh have Shown in there paper “Durability of Partially mixed GGBFS concrete exposed to acid and base attack In this paper, the cement is partially replaced by the ground granulated blast furnace slag (GGBFS) in 20% , 35% , and 50% . The results of this paper shows that, when concrete is subjected to any acid and base, losses its some properties and strength. In both Acid and base curing maximum compressive, tensile and flexural strength has been obtained for replacement of cement by 35% GGBFS.

Nandini S R SrinivasRaju, Dr. V Ramesh Vol.3 (8) Aug -2017

5. O'Connell, M, McNally, C & Richardson, MG (2010) 'Biochemical attack on concrete in wastewater applications: a state of the art review'. Cement and Concrete Composites, 32 (7):479-485.

This study found that international research to date has focussed on three distinct topics in the study of sulphate / sulphuric acid effects on concrete.

- Studies of the biological processes behind the corrosion of wastewater infrastructure, with particular reference to the role of sulphate-reducing and sulphur-oxidising bacteria.
- Studies of the chemical effects of sulphates and sulphuric acid on concrete mixes
- Laboratory-based research methodologies, especially those incorporating the biological effect on concrete.

O'Connell, M, McNally, C & Richardson, MG (2010)

6. P Lakshmaiah Chowdary , S Khaja Khutubuddin , B Vinayaka , D Saikiran , Y Induja , Y Narasappa **"**An Experimental Study on Cement Replacement by GGBFS in Concrete" Shows that the usage of GGBFS in concrete is highly improves the strength, the results carried out the strength in 28 days. GGBFS mix reduces the workability. They concluded that GGBFS can be effectively used in concrete. The inclusion of GGBFS has desirable effect on concrete mechanical properties which is comparable to normal concrete. The usage of GGBFS in concrete as cement replacement materials will lessen the CO2 is being emitted during its manufacture and acts as an eco-friendly material reducing the Greenhouse effect. Incorporation of these types of mineral admixtures in cement helps in making it more economical.

P Lakshmaiah Chowdary, April 2017

7. A.H.L.Swaroop, K.Venkateswararao, Prof P Kodandaramarao in there paper "Durability Studies On Concrete with Fly Ash & GGBFS" They evaluate changes in both compressive strength and weight reduction in different mixes with replacement of fly ash and ggfbs. They also experiment The effect of 1% of H2SO4 and sea water on these concrete mixes are determined by immersing these cubes for 7days, 28days, 60days in above solutions and the respective changes in both compressive strength and weight reduction had observed and up to a major extent we can conclude concretes made by that Fly Ash and GGBFS had good strength and durable properties comparison to conventional aggregate in severe Environment**.**

A.H.L.Swaroop, Vol. 3, Issue 4, Jul-Aug 2013

8. Liyuan Xie, Gang Wang" Study on Mechanism of Chemical Sulfate Attack on Reinforced Concrete Structures" the test studied the changes in sulfate attack resistance of the semi-soaking concrete cylinder under hydrostatic pressure and made a comparative study on the sulfate attack resistance between fly ash concrete (FAC) and sulphate-resistant cement concrete (SRC) as well as impact of different external relative humidity and external temperature on the sulfate attack to concrete.

Liyuan Xie, Gang Wang, 2017, Chemical Engineering Transactions, 62, 1087-1092 DOI:10.3303/CET1762182

9. K.A. Olonade et al. Effects of Sulphuric Acid on the Compressive Strength in there experiment they shows the Influence of sulphuric acid on compressive strength of concrete made with blended cement-cassava peel ash .A total of 90 cubes of the concrete mixture of sizes 150 mm were cast and cured in fresh water (as control), 0.5, 1.0 and 1.5 M concentrations of sulphuric acid solution (H_2SO_4) for 7, 28, 56 and 90 days. The compressive strength reduced with increase in concentrations of the acid as well as with increase in the content of the CPA.

K.A. Olonade 2014

10.Concrete Deterioration Caused by Sulfuric Acid Attack April 2005, **K. Kawai,** S. Yamaji, T. Shinmi. In this study, in order to clarify the effects of the shearing force of flowing water on the concrete deterioration due to sulfuric acid attack, concrete and mortar specimens are immersed in sulfuric acid solutions that are circulated by pumps. This circulation generates the flow of solutions and the shearing force of the flow is applied to the surfaces of the specimens. This study was performed to understand the mechanism of concrete deterioration caused by sulfuric acid. The effects of the flow of fluid, the concentration of sulfuric acid solution, the use of mineral admixtures and the difference of water cement ratio on the deterioration of concrete were investigated. As a result, the following conclusions were obtained.

a. Regarding concrete deterioration caused by sulfuric acid, the flow of fluid accelerates the deterioration and the rate of deterioration of concrete caused by sulfuric acid strongly depnds upon the concentration of sulfuric acid solution.. In an elevated concentration of sulfuric acid solution, the erosion depth of concrete is nearly proportional to the exposure time instead of the square root of the exposure time. Sulfate ions does not penetrate into concrete very much and the reaction of cement hydrates and sulfuric acid occurs in the surface portion of concrete.
b. b. When a part of cement is replaced with blast furnace slag or fly ash and the strength of concrete containing the mineral admixture is almost equal to the strength of plain concrete with the same water binder ratio, the erosion depth of concrete containing mineral admixture due to sulfuric acid attack is smaller than that of plain concrete since the content of calcium hydroxide is small.

K. Kawai April 2005

11. (Ramakrishnan *et al*. 1992; Bush *et al*.; Bleszynski *et al*. 2002 and ACI Committee 233R 1995) studied replacement of OPC by GGBFS, It results in lower early strengths, lower chloride ion permeability, greater long term strengths, greater alkali silica reactivity (ASR) durability, less greater sulfate attack resistance enhanced workability, lower heat of hydration, less bleeding and increased steel corrosion resistance. Results are combined of freeze-thaw durability and drying shrinkage somehow the use of slag seems to be non-beneficial. Moreover the hindrances of the GGBFS includes increased salt scaling, increased air entrainment required dosage, increased shrinkage cracking and increased plastic shrinkage cracking.

Ramakrishnan *et al*. 1992; Bush *et al*.; Bleszynski *et al*. 2002

12. In another experiment “The effect of attack of chloride and sulphate on ground granulated blast furnace slag concrete” they showed 20% GGBFS replacement had a considerably positive effect on the cube and cylinder compressive strength but 40% and 60% GGBFS replacements reduced the strength at the age of 28 days. The durability of GGBFS concrete increases with 20% replacement of GGBFS with cement and then started decreasing gradually for 40% and 60%. The maximum loss of strength of 0%, 20%, 40%, and 60% GGBFS concrete is due to the effect of magnesium chloride followed by magnesium sulphate.

Deepankar K. Ashish, Bhupinder Singh and Surender K. Verma*November 2, 2016*

13. N.P. Rajamane the test data indicates that on exposure to 2% and 10% sulphuric acids the losses in weight thickness and strength of geo polymer concrete are significantly much less than those for Portland pozzolana cement concrete.

14. Tao and Wei Paper 1700166 ”Effect of ground granulated blast-furnace slag on the hydration and properties of cement paste” Received 12/09/2017; revised 20/12/2017; accepted 15/01/2018

The hydration process of cement paste blended with ground granulated blast-furnace slag (GGBFS) was investigated using calorimetric and electrical methods. The effect of GGBFS on early-age hydration was studied by examining electrical resistivity curves, heat of hydration curves and their rate curves. Through comparisons of the setting time and four other critical moments in early-age hydration evolution obtained from electrical resistivity and hydration heat tests, the application of electrical resistivity to characterize the setting behavior of cement paste was proven to be effective, through the peaks on the rate curve of resistivity and the inflection point on the electrical resistivity–log time curve. The effects of GGBFS on autogenous shrinkage and compressive strength development were also studied. It was found that compressive strength at 3 d could be predicted by electrical resistivity at 1 d. A positive linear correlation between autogenous shrinkage and compressive strength before 28 d was found. A relationship relating GGBFS content to 28 d autogenous shrinkage and 28 d compressive strength was also developed. Scanning electron microscopy observations confirmed the macroscopic experimental results.

Tao and Wei 15/01/2018

15. I experiment of M. M. Amin, S. B. Jamaludin1, F. C. Pa1, K. K. Chuen "Effects of Magnesium Sulfate Attack on Ordinary Portland Cement (OPC) Mortars" Received 23 May 2007;

The spallation and cracking are produced due to sulphate ions by exposure to containing inorganic salts atmospheres. The mechanism of magnesium sulfate attack with cement hydrates as follows:

$MgSO_4$ (aq) + $Ca(OH)_2$ $CaSO_4 . 2H_2O$ + $Mg(OH)_2$

$MgSO_4$ (aq) + C-S-H $CaSO_4 . 2H_2O$ + M-S-H

The presence of high Mg in the region is indicative of carbonation and of the region where the brucite deposits. Furthermore, in the magnesium sulfate solution, the increase in concentration led to higher rate of expansion. The magnesium ions tend to attack the deeper surface and replacing the calcium. Ca2+ and OH- are provided initially by dissolution of CH and the Si/Ca ratio of the C-S-H begins to increase only when the CH has been depleted; it also implies the use of Ca2+ in the formation of gypsum .By comparing mass percentage of regions 006 and 007, it is seen that when the area with high magnesium precipitates, the percentage of calcium becomes lesser and the magnesium percentage being low, suggests a high calcium percentage.

Based on the results of this study, it is concluded: The chemical and mineralogical composition in the Ordinary Portland Cement (OPC) was determined, following SEM and EDS techniques. The formation of ettringite at the early stage causes cracking, thus being related to the expansion which is the cause of damage in the cement paste. Damage caused by the sulphate attack is attributed to decalcification, which weakens the C-S-H matrix and partly the formation of ettringite, which causes cracking and expansion. The resistance of mortars to sulfate attack was influenced by the content of the interfacial zone, which means the higher the content of interfacial zone, the faster the cement mortar expanded. In order to improve the structure of the interfacial zone, pre-treated quartz aggregate, which is composed of hydraulic surface layer and inert core, can be used. Mg2+ and SO^{-2}_4 ions make a line of attack into different regions which consists of calcium at the deeper region of the surface, resulting on the formation of the crystalline salt.

M. M. Amin 8 October 2007

16. MACPHEE D.E., ATKINS M. • GLASSER F.P. (1989) Phase development and pore solution chemistry in ageing blast furnace slag - Portland cement blends. Materials Res. Soc. Sym., 127,

475-480. The blocking of pores leads to higher strength and lower permeability (Macphee et al., 1989) which, besides other improved binding and adsorptive effects, enhances resistance of GGBFS concrete to attack from sulphates. The formation of ettringite in such systems does not necessarily result in expansion and swelling.

MACPHEE D.E., ATKINS M. • GLASSER F.P. (1989)

17. Reshma Rughooputh and Jaylina Rana studied the effects of partial replacement of OPC by GGBFS on various properties of concrete including compressive strength, tensile strength, splitting strength, flexure strength, modulus of elasticity, drying shrinkage and initial surface absorption. Cement was partially replaced by 30 % and 50 % of GGBFS by weight and test was performed at 7 and 28 days. It was found that GGBFS in concrete leads to lower early compressive strength gain but higher later compressive strength gain. Flexural strength of test specimens increased by 22% and 24%, tensile strength increased by 12% and 17% for 30% and 50% replacement respectively. Drying shrinkage increased by 3% and 4%. Static modulus of elasticity increases by 5% and 13%. She also observed that the initial surface absorption decreases as the GGBFS content increases because GGBFS decreases the permeability of concrete. Based on the results the optimum mix was the one with 50% GGBFS.

Reshma Rughooputh and Jaylina Rana, 2014

18.Effect of Alkali Content on Strength and Microstructure of GGBFS Paste By Mohd. Nadeem Qureshi & Somnath GhoshVolume 13 Issue 1 Version 1.0 Year 2013 this paper is focused on the effect of alkali content on the mechanical properties of alkali activated blust furnace slag. The experimental results have indicated that the compressive strength, splitting tensile strength and workability of the specimens is significantly affected by the alkali content of the mix.

By Mohd. Nadeem Qureshi & Somnath Ghosh Year 2013

OBJECTIVE OF STUDY

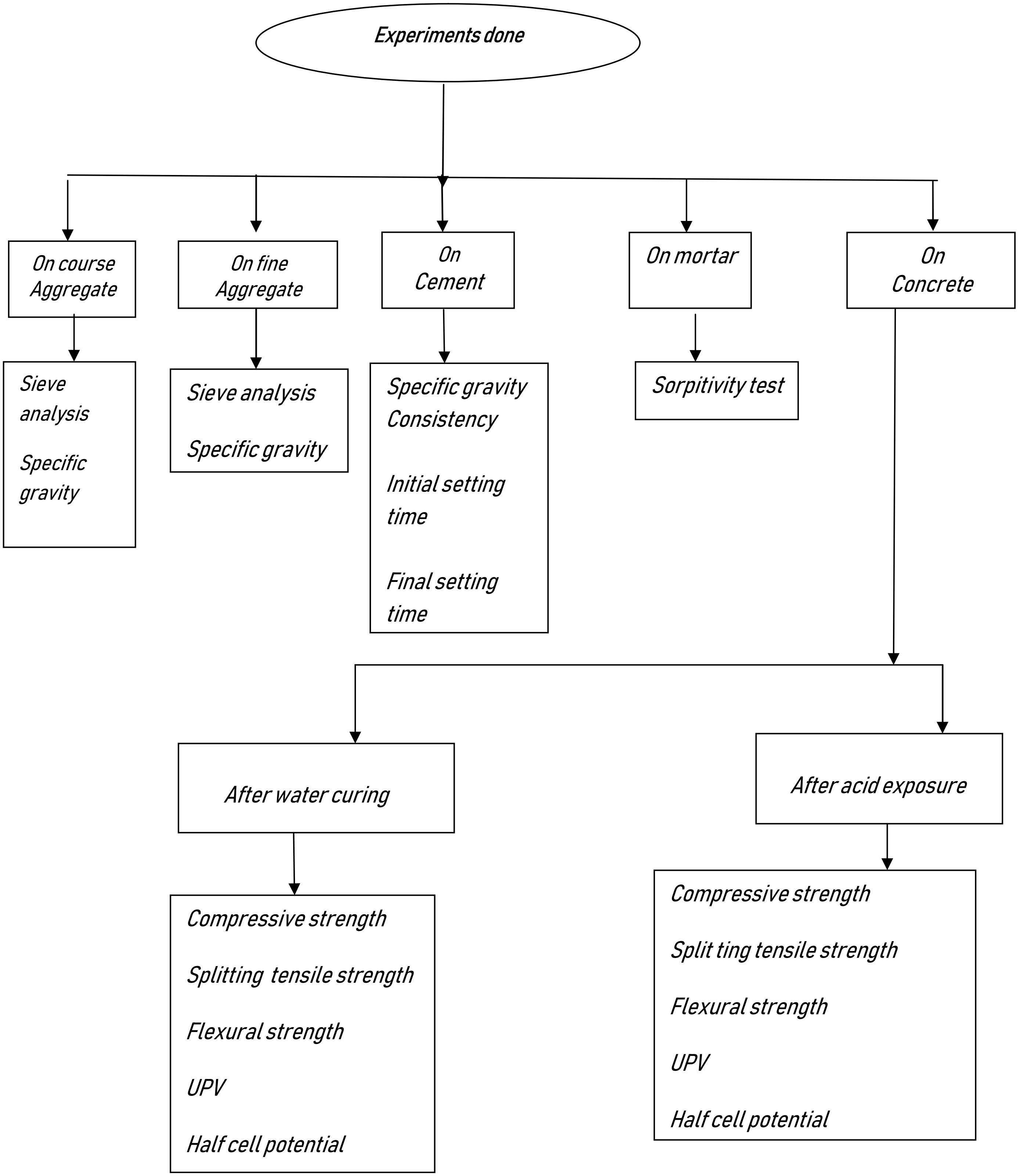
- The main objective of this study is to see whether the target strength of concrete prepared by part replacement of cement by can be achieved or not.
- To compare the strength of sustainable concrete with the strength of traditional concrete.
- To compare the durability of sustainable concrete as compared to traditional concrete in acid exposure in terms of strength.
- To compare the durability of sustainable concrete as compared to traditional concrete in salt exposure.
- It is commonly known that the pore structure of concrete plays a crucial role on its durability in different environmental conditions. Therefore, another aim of this study is to examine the permeability characteristics of original concrete specimens from different mixtures by performing water sorptivity.

SCOPE OF WORK

- To make sustainable concrete with easily available inexpensive materials.
- To compare strength of sustainable concretes with respect to traditional concrete.
- To assess durability of both traditional and sustainable concrete
- To compare durability of sustainable concrete with the durability of tradition concrete
- To investigate corrosion potential of rebar before and after acid exposure
- To study the Indian consumers awareness and knowledge on the use of industrial by products like GGBFS which are green and sustainable in Concrete.
- To study the effect of GGBFS on durable properties of concrete in acidic exposure (H_2So_4) and in $MgSo_4$ solution.
- To compare the durability and strength properties of GGBFS based concrete and market available Portland slag cement.
- To compare the durability and strength properties of GGBFS based concrete and market available Ordinary Portland cement in terms of residual strength.

CHAPTER - 5

EXPERIMENTAL PROGRAMME



5.1 Material used:

5.1.1 Cement:

Two types of cements have been used in this experimental programme:

i) Ordinary Portland Cement (53 Grade) [Conforming to IS 12269:2013] is the basic cement type with around % of clinker and 5% being gypsum which is added as an additive to regulate setting time of cement. It comes in 3 grades (OPC 33, .43 & 53). OPC 53 Grade means the minimum compression strength requirement would be 53 MPa at 28 days.

OPC is a product of four principal mineralogical phases. These phases are

i) Tricalcium Silicate-C_3S ($3CaO.SiO_2$),

ii) Dicalcium Silicate -C_2S ($2CaO.SiO_2$),

iii) Tricalcium Aluminate - C_3A ($3CaO.Al2O_3$) and

iv) Tetracalcium alumino-ferrite – C_4AF ($4CaO. Al_2O3. Fe_2O_3$).

The setting and hardening of the OPC takes place as a result of reaction between these principal compounds and water.

The reaction between these compounds is as follows:

$C_3S + H_2O = 3CaO.2SiO_2.3H_2O + Ca\ (OH)_2$ +(C-S-H gel)

$C_2S + H_2O =$ (C-S-H gel) + $Ca\ (OH)_2$

$$C_3A + H2O + \underset{\text{(Gypsum)}}{3CaSO_4.2H_2O} = \underset{\text{(Ettringite)}}{3CaO.Al2O_3.3CaSO_4{\cdot}32H_2O}$$

Above reactions indicate that during the hydration process of cement, lime is released out and remains as surplus in the hydrated cement. This surplus lime makes the concrete porous and gives chance to the development of micro- cracks.

ii) Portland Slag cement (GGBFS based) [Conforming to IS 455:.911] An intimately interground mixture of Portland cement clinker and granulated slag With addition of gypsum and permitted additives or an Intimate and uniform blend of Portland cement and finely ground granulated slag.

The composition of Portland slag cement is 40 % clinker, 5 % gypsum and 60 % blast furnace granulated slag. As per IS: 455, the quantity of GGBFS can be in the range to 25 % to 70%. The minimum compression strength requirement if 33 MPa at 28 days for PSC Cement. PSC cement has less heat of hydration as compared to OPC cement.

Portland slag cement shall be manufactured either by Intimately integrating a mixture of Portland cement clinker and granulated Slag With addition of gypsum (natural or chemical) or calcium sulphate, or by an intimate and uniform blending of Portland cement and finely ground granulated slag. So that the resultant mixture would produce a cement capable of complying with this specification. The slag constituent shall be not less than 25 percent nor more than 65 percent of the Portland slag cement.

PSC's inherent chemistry gives it several advantages over ordinary cement. Apart from being more environment-friendly, it offers;

· Resistance to Chloride & Sulphate attacks

· Low risk of cracking

· Improved workability

· Compatibility with all types of admixtures

· Resistance against alkali-silica reaction

· Minimized shrinkage cracks

5.1.2. GGBFS:

Slag In granulated form is used for the manufacture of hydraulic cement. Slag IS a non-metallic product consisting essentially of glass containing silicate and alummo-silicates of lime and other bases, as In the case of blast furnace slag, which IS developed simultaneously With Iron and blast furnace or electric pig Iron furnace. Granulated slag IS obtained by further processing the molten slag by rapidly chilling or quenching It With water or steam and air.

The reaction of GGBFS with Portland cement and water is a complex process. When Portland cement hydrates, the principal hydration products are Ca $(OH)_2$ and C-S-H gel. The GGBFS, due to its high alumina and silica content, produces somewhat more complex hydrates than ordinary Portland cement (OPC). Precipitates of calcium silicate hydrates and calcium aluminate hydrates result from the hydration reaction that ensues. This hydration reaction which is slower than the hydration of Portland cement has a 'pore-blocking' effect resulting in increased long-term hardening of the cement paste. The blocking of pores leads to higher strength and lower permeability (Macphee et al., 1989) which, besides other improved binding and adsorptive effects enhances resistance of GGBFS concrete to attack from sulphates. The formation of ettringite in such systems does not necessarily result in expansion and swelling.

Fig.5.1 GGBFS

5.1.3 Fine Aggregate:

Aggregate most of which passes 4.75-mm IS Sieve and contains only so much coarser material as permitted in table 4 of IS 383 is termed as Fine Aggregate (FA). According to clause 5.3 of IS 456, aggregates shall be suitable with regard to strength, durability of concrete and freedom from harmful effects. It should not contain more than 0.5 % of sulphates and should not absorb more than 10 % water of their own mass. River sand (yellow) conforming to Zone-III has been used in the experiment work.

Fig.5.2 River Sand

5.1.4 Coarse Aggregate:

Aggregate most of which is retained on 4.75-mm IS Sieve and containing only so much finer material as permitted in IS 383 are Coarse Aggregate. Here 20 mm nominal size crushed stone angular in shape was used as Coarse Aggregate (C.A.).No replacement was done for C.A. in this experiment. 60% of total coarse aggregate is 20mm down and 40% is 10 mm down.

Fig.5.3 Coarse Aggregate

5.1.5 Chemical admixture:

Super plasticizing admixture of a particular brand (conforming to IS 9103 : 1999) has been used in concrete mixes to make fresh concrete workable. As the mixes are stiff 0.8% high range retarding super admixture by weight of cementitious material has been used. This admixture has been added into the mix after adding normal water of 50 to 70% to the mix.

Fig.5.4 Chemical admixture

5.1.6 Sulphuric Acid: [conforming to IS 266 : 1993]

Durability of concrete has been experimented by submerging cube samples into sulphuric acid solution for 60 days and 120 days under normal room temperature. To achieve accelerated corrosion effect in short time, 4% diluted sulphuric acid solution was chosen for the experiments. Sulphuric acid of 98% was mixed with potable water at a ratio of 41gm of concentrated (98%) H_2SO_4 to 1 litre of H2O. Each of the containers was filled with 15L of potable water and then 615 gm concentrated acid added. The surface level was constantly maintained to compensate absorption or evaporation loss so that the samples remain submerged for 28 days. The acidity of prepared solution at day 1 was 0.3pH.

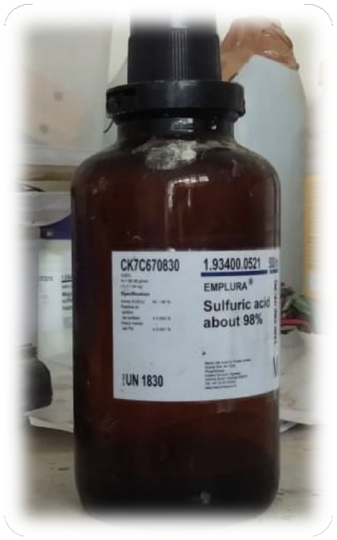


Fig.5.5 Sulphuric Acid

5.1.7 Magnesium Sulphate: [conforming to IS 266 : 1993]

Durability of concrete has been experimented by submerging cube samples into Magnesium sulphate solution for 60 days and 120 days under normal room temperature. To achieve accelerated corrosion effect in short time, 4% diluted magnesium sulphate solution was chosen for the experiments. Magnesium sulphate of 98% was mixed with potable water at a ratio of 40.5 gm of concentrated (97.5%) $MgSo_4$ to 1 liter of H2O.The surface level was constantly maintained to compensate absorption or evaporation loss so that the samples remain submerged for 28 days. The pH of prepared solution at day 1 was 7.6pH

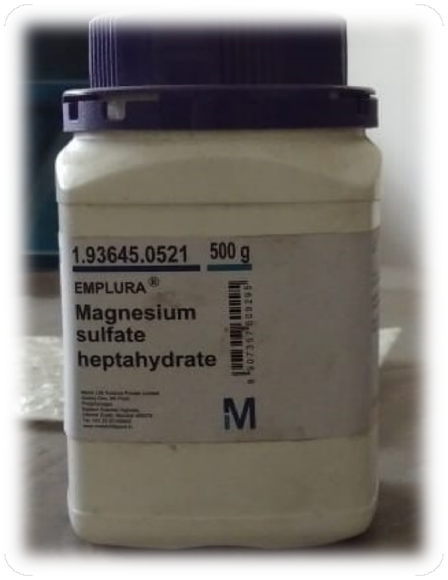


Fig.5.6 Magnesium Sulphate

5.1.8. Water:

Potable water having pH value 7.6 was used for concrete mix.

5.2. Test Procedures:

5.2.1. Specific gravity test of cement:

Specific gravity of cement was determined by Specific gravity bottle. Weight of the empty bottle with stopper was taken as W1 (say).The bottle was filled with water and weight of bottle with water = W2.Then the bottle was dried and filled with kerosene. This weight was W3. Again bottle was dried and cement was poured about half of bottle. This weight was taken as W4.Kerosene was added to cement in bottle till it flash with graduated mark. Weight was taken as W5.

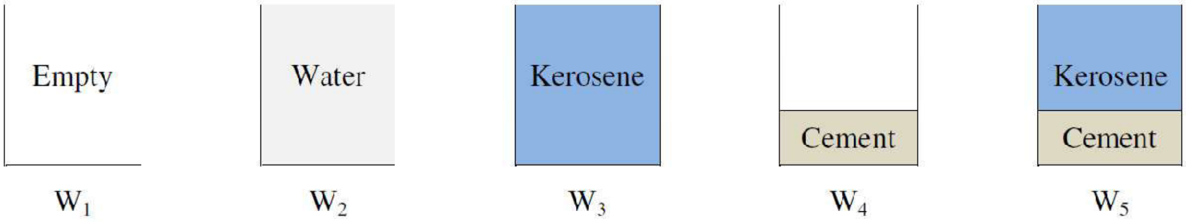


Fig.5.7 Specific gravity test of cement

Weight of the empty bottle= W1
Weight of bottle + Water= W2
Weight of bottle + kerosene=W3
Weight of bottle + Cement= W4
Weight of bottle +Cement + kerosene = W5

$$\text{Specific gravity of cement} = \frac{\text{Weight of cement}}{\text{Weight of equivalent vol. of water}}$$

$$= \frac{\text{Weight of cement}}{\text{Wt. of equivalent vol. of kerosene}} \text{ x } \frac{\text{Wt. of that vol. of kerosene}}{\text{Weight of equivalent vol. of water}}$$

$$= \frac{\text{Weight of cement}}{\text{Wt. of equivalent vol. of kerosene}} \text{ x Sp. gr. of kerosene}$$

$$= \frac{(W_4 - W_1)}{(W_3 - W_1) - (W_5 - W_4)} \text{ x } \frac{(W_3 - W_1)}{(W_2 - W_1)}$$

5.2.2 Standard consistency and setting time test of cement:

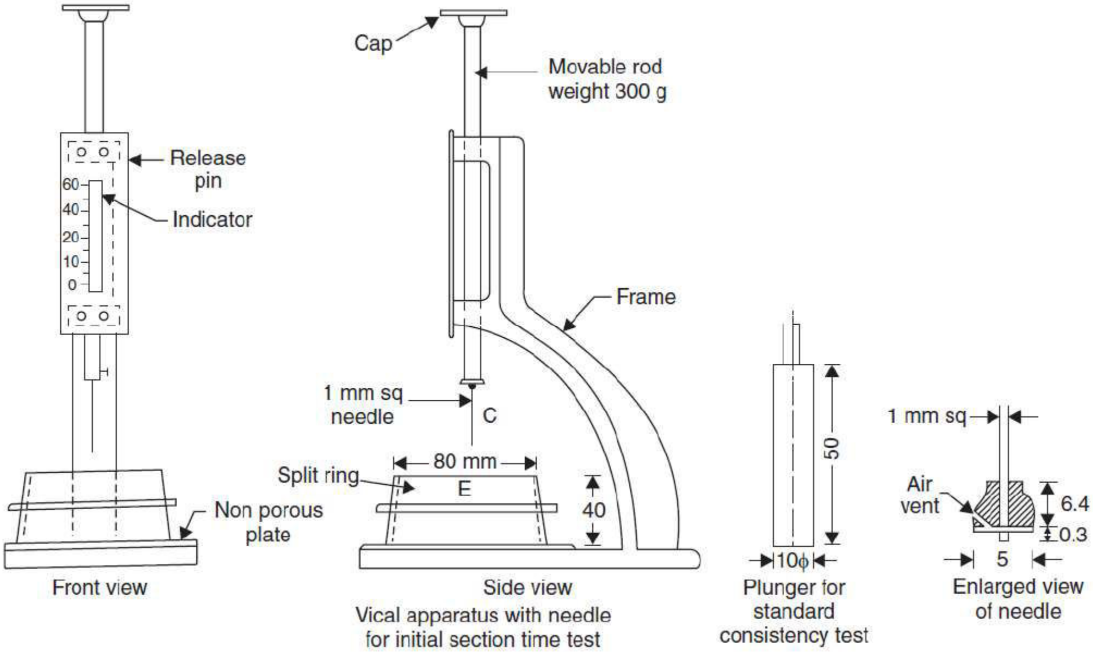


Fig.5.8 Vicat apparatus

Standard consistency, initial setting time and final setting time of cement was done with The vicat apparatus. 10mm dia Plunger was used for determining the standard consistency, 1.13mm dia needle (Needle C) was used to determine initial setting time and Needle F was used to determine final setting time. Tests have been done as per guidelines of IS 4031 (Part-4 and Part-5)

5.2.3 Specific gravity test of aggregates:

Specific gravity of stone chips, sand are determined with Pycnometer. The test procedures was as per IS : 2386 (Part III)

Weight of empty Pycnometer =W1
Weight of pycnometer +weight of Aggregates= W2
Weight of pycnometer +weight of Aggregates +Remaining quantity of water= W3
Weight of pycnometer +weight of water full of pycnometer= W4

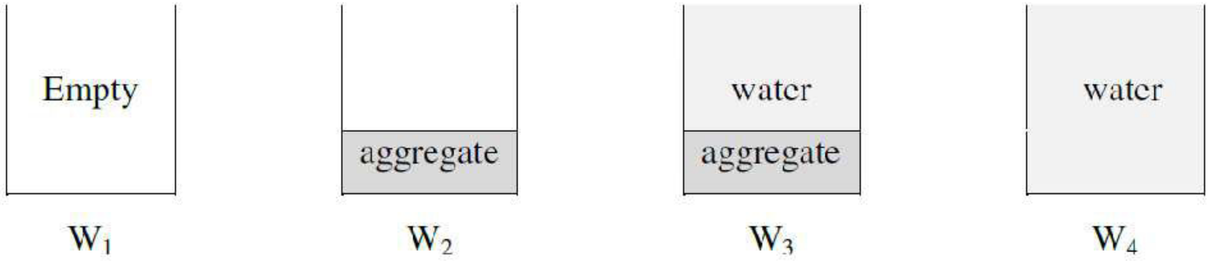


Fig.5.9 Specific gravity test of aggregates

$$\text{Specific gravity of aggregate} = \frac{\text{Weight of aggregate}}{\text{Weight of equivalent vol. of water}}$$

$$= \frac{(W_2-W_1)}{(W_4-W_1)-(W_3-W_2)}$$

5.2.4 Particle size distribution of aggregates:

To determine particle size distribution of sand and stone dust 10 mm, 4.75 mm, 2.36 mm, 1.18 mm 600micron 300 micron and 150 micron size IS sieves were used. For coarse aggregate IS Sieves used are 40mm, 20mm, 10mm and 4.75mm . The methodology was followed as laid down in IS:383

5.2.5 Acidity test of sulphuric acid and magnesium sulphate solution:

Acidity of water and acid was determined by electronic pH meter. The testing machine was switch on by pressing ON/OFF button. The electrode was immersed in the acid solution in at least 20 mm depth, and gently stirred. The pH reading was taken when the value displayed was stabilized.

Fig.5.10 Acidity test of sulphuric acid and magnesium sulphate solution

5.2.6 Cube Compressive Strength Test:

Cube compressive tests were conducted as per IS 516. 150x150x150mm size cubes have been tested. For each mix type, 3 cubes for 7 days, 3 for 28 days and 3 cubes after 60 days and 3 cubes for 120 days of sulphuric acid and magnesium sulphate exposure have been tested. Cubes are tested in compression testing machine.

Fig.5.11 Cube Compressive Strength Test in laboratory

5.2.7 Splitting Tensile Test:

The concrete is very weak in tension due to its brittle nature. Hence. it is not expected to resist the direct tension. So, concrete develops cracks when tensile forces exceed its tensile strength. Therefore, it is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack. Furthermore, splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. The procedure based on the ASTM C496 (Standard Test Method of Cylindrical Concrete Specimen) which similar to other codes lik IS 5816 1999.here in my experiment cylinder of size 10cmX20cm are used For each mix type,3 cylinders for 28 days and 3 after 60 days and 3 cylinders for 120 days of sulphuric acid and magnesium sulphate exposure have been tested.

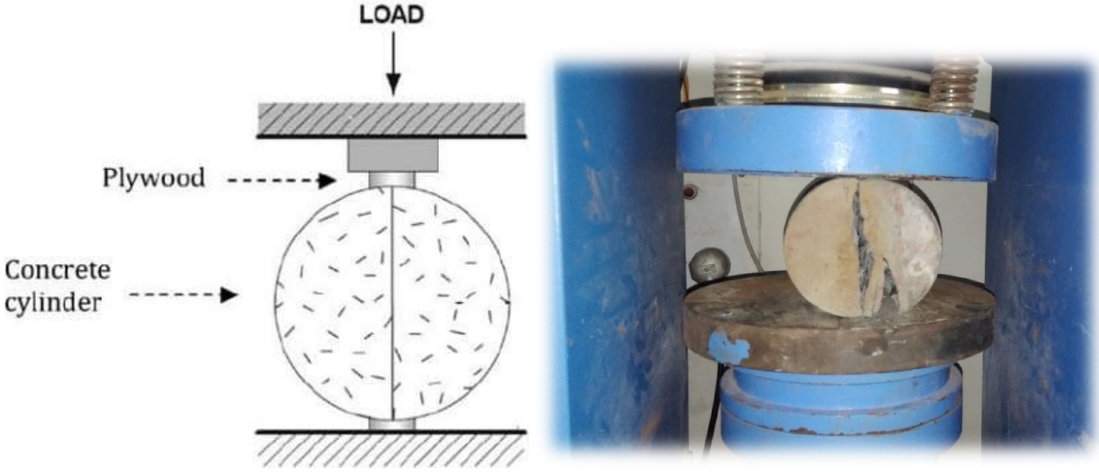
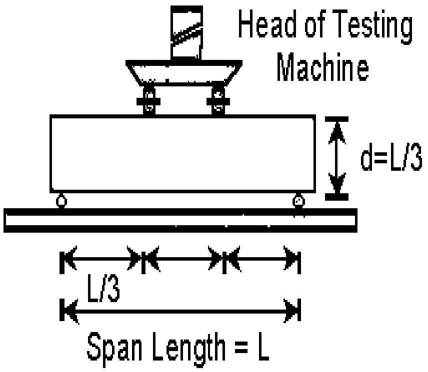


Fig.5.12 Splitting Tensile Test in laboratory

5.2.8 Flexural strength test of beam:

Flexural test evaluates the tensile strength of concrete indirectly. It tests the ability of unreinforced concrete beam or slab to withstand failure in bending. The results of flexural test on concrete expressed as a modulus of rupture which denotes as (*MR*) in MPa or psi. The flexural test on concrete can be conducted using either three point load test (ASTM C78) or center point load test (ASTM C293). The configuration of each test is shown in Figure-2 and Figure-3, respectively.



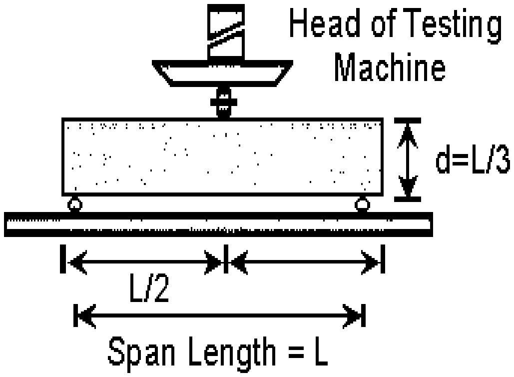


Fig.5.13. a Three-Point Load Test (ASTM C78)

Fig.5.13.b Center Point Load Test (ASTM C293)

Fig.5.14 Flexural strength Test central point loading in laboratory

The beam size which was casted for my experiment size of 100mm width, 100mm depth, and span of 500mm2 no of beams for 28 days and 3 after 60 days and 2 no for 120 days of sulphuric acid and magnesium sulphate exposure have been prepared.

5.2.9 Sorptivity Test :

Concrete is a porous material which interacts with the surrounding environment. The durability of mortar and concrete depends largely on the movement of water and gas enters and moves through it. The permeability is an indicator of concrete's ability to transport water more precisely with both mechanism that is controlling the uptake and transport of water and gaseous substances into cementitious material. Permeability is a measure of flow of water under pressure in a saturated porous medium while Sorptivity is materials ability to absorb and transmit water through it by capillary suction. Uptake of water by unsaturated, hardened concrete may be characterized by the sorptivity.

This is a simple parameter to determine and is increasingly being used as a measure of concrete resistance to exposure in aggressive environments. Sorptivity, or capillary suction, is the transport of liquids in porous solids due to surface tension acting in capillaries and is a function of the viscosity, density and surface tension of the liquid and also the pore structure (radius, tortuosity and continuity of capillaries) of the porous solid. It is measured as the rate of uptake of water. Transport mechanisms act at the level of the capillary pores and depend on the fluid and the solid characteristics. Cube mortar of size 5cm x 5cm are prepared and weight of the respective.

Fig.5.15 Mortar mould for Sorptivity Test in laboratory

5.2.10 Ultrasonic pulse velocity test :

By these test homogeneity of the concrete is determined. In this test ultrasonic pulse is produced by the transducer which is held in contact with one surface of the concrete member under test. After traversing a known path length (L) in the concrete, the pulse of vibration is converted into an electrical signal by the second transducer held in contact with the other surface of the concrete member and an electronic timing circuit enables the transit time (T) of the pulse to be measured. The pulse velocity (V) is given by V=L/T. this test was done as per IS :13311(Part 1) **.**

Table 5.1. - Concrete quality based on Ultrasonic pulse velocity test.

Pulse velocity (km/sec)	Concrete Quality (Grading)
Above 4.5	Excellent
3.5-4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

Fig.5.16 Ultrasonic pulse velocity Test in laboratory

5.2.11. Half-cell potential test:

Half-cell potential test is a non-destructive in situ test method of assessing probability of corrosion of reinforcement**.** Copper-copper sulfate electrode has been used in the instrument.(Cu/CuSO4) electrode connected to the negative end of the voltmeter placed on the surface of the concrete. And steel reinforcement connected to the positive end. Thus the potential difference between rebar and concrete surface was measured. The test procedure was followed as per ASTM C 876

Table 5.2.- Half-Cell Potential Corresponding to % Chance of Corrosion Activity (ASTM Criteria)

Half-cell Potential (mV) relative to Cu-Cu Sulphate Ref. Electrode	**% Chance of Corrosion Activity**
Greater Than -200	Low (10%)
Between -200 to -350	Intermediate (50%)
Between -350 to -500	High (More than 90%)
Less Than -500	Severe

Fig.5.17 Half-cell potential test in laboratory

5.3 Material test results:

5.3.1 Specific gravity of different materials

materials	Sp. Gr.
OPC	3.12
PSC	2.90
GGBFS	2.85
Sand (FA)	2.66
Stone Chips (CA)	2.82

5.3.2 Consistency and Setting Times of cement:

	Consistency	Initial setting time	Final setting time
100% OPC	33%	4 hr 20 min	5 hr 20 min
OPC 70% + GGBFS 30%	35%	4 hr 51 min	5 hr 21 min
OPC 60% + GGBFS 40%	36.5%	4 hr 05 min	6hr 15 min
OPC 50%+ GGBFS 50%	38%	4 hr 54 min	6 hr 44 min
PSC 100%	35%	4hr 31min	5 hr 01 min

5.3.3 Particle size distribution of Coarse aggregates:

Weight of sample taken=5000gm

Sieve Size	Weight retained(gm)	Cumulative Weight retained(gm)	Cumulative percentage retained	Cumulative percentage passing	Range as per IS 383
40	0	0	0	98.66	100%
20	180	180	3.65	95.01	95-100%
10	2603	2783	56.42	42.24	25-55%
4.75	2150	4933	98.66	1.34	0-10%
Pan	67	5000	100	0	0-10%

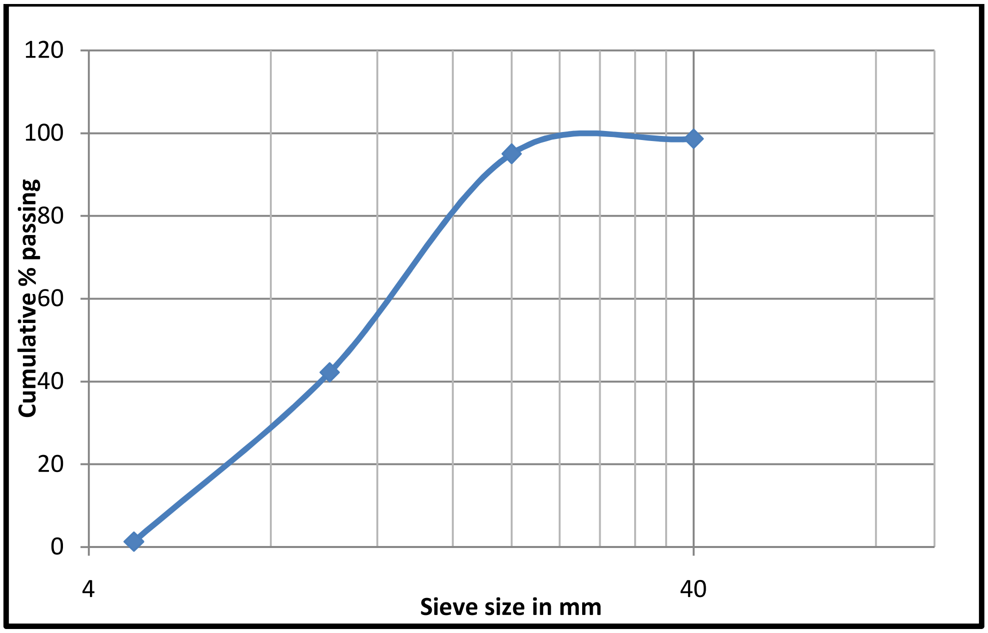


Fig.5.18 Particle size distribution of Coarse aggregates

5.3.4 Particle size distribution of Fine aggregates:

Sieve Size	Weight retained(gm)	Cumulative Weight retained(gm)	Cumulative percentage retained	Cumulative percentage passing	Range as per IS 383
10	0	0	0.00	100.00	100%
4.75	0.261	0.261	0.13	99.87	90-100%
2.36	1.48	1.741	0.87	99.13	85-100%
1.18	5.598	7.339	3.67	96.33	75-100%
0.6	45.816	53.155	26.58	73.42	60-79%
0.3	78.254	131.409	65.70	34.30	12-40%
0.15	64.721	196.13	98.07	1.94	0-10%
Pan	3.87	200.00	100.00	0.00	---

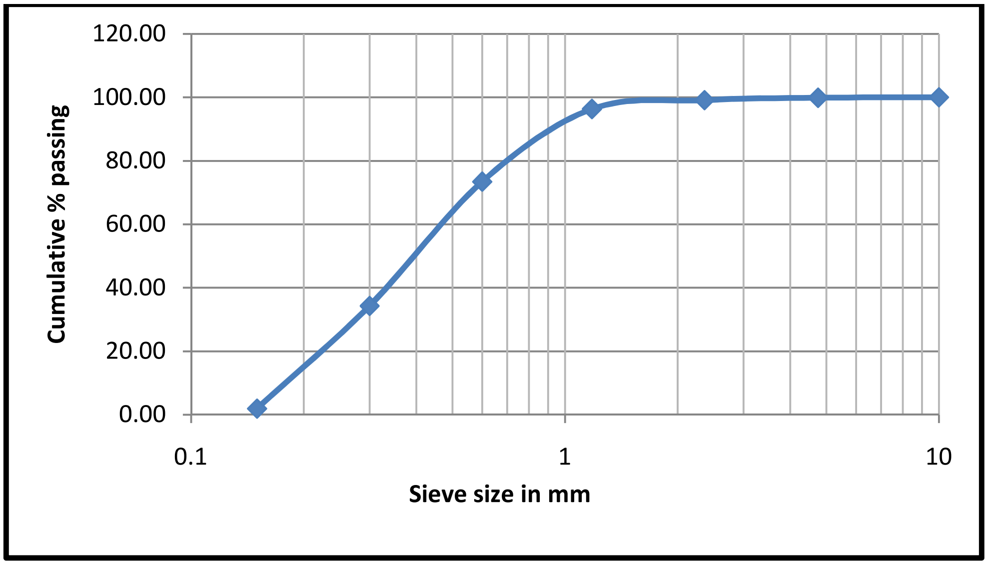
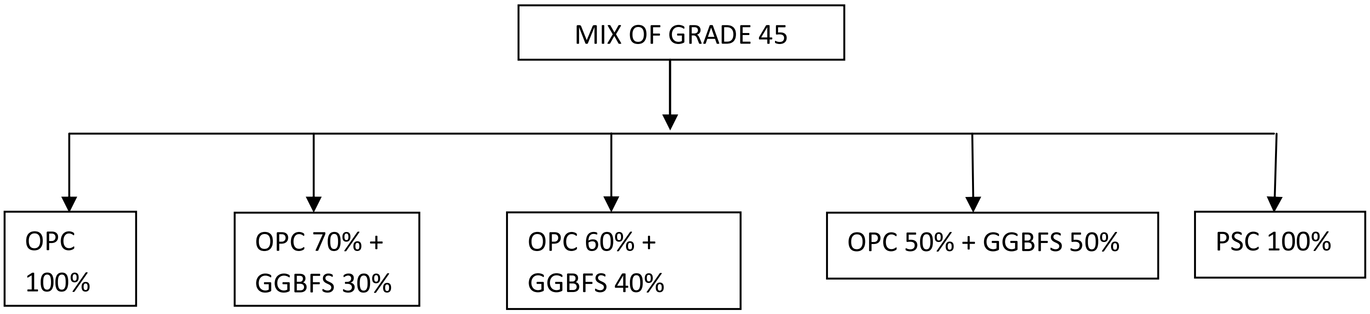


Fig.5.19 Particle size distribution of Fine aggregates

CHAPTER - 6

RESULTS AND DISCUSSIONS



All the mentioned mixed are kept in unexposed condition i.e. in water for 28 days and after 28 days curing they are placed in specific number in 4% H_2So_4 solution and 4% $MgSo_4$ solution for 60 days and 120 days respectively. Following are the results obtained.

6.1. Unexposed condition (Water curing for 28 Days)

Table 6.1: Cube compressive strengths after 3 days, 7 days and 28 days of water curing

COMPRESSIVE STRENGTH OF CUBE (N/mm^2)			
MIX	**3 Days**	**7 Days**	**28 Days**
OPC 100%	24.84	40.89	51.26
OPC 70% + GGBFS 30%	26.89	46.44	53.93
OPC 60% + GGBFS 40%	25.29	45.53	49.40
OPC 50% + GGBFS 50%	25.82	44.00	46.52
PSC 100%	38.13	43.33	47.40

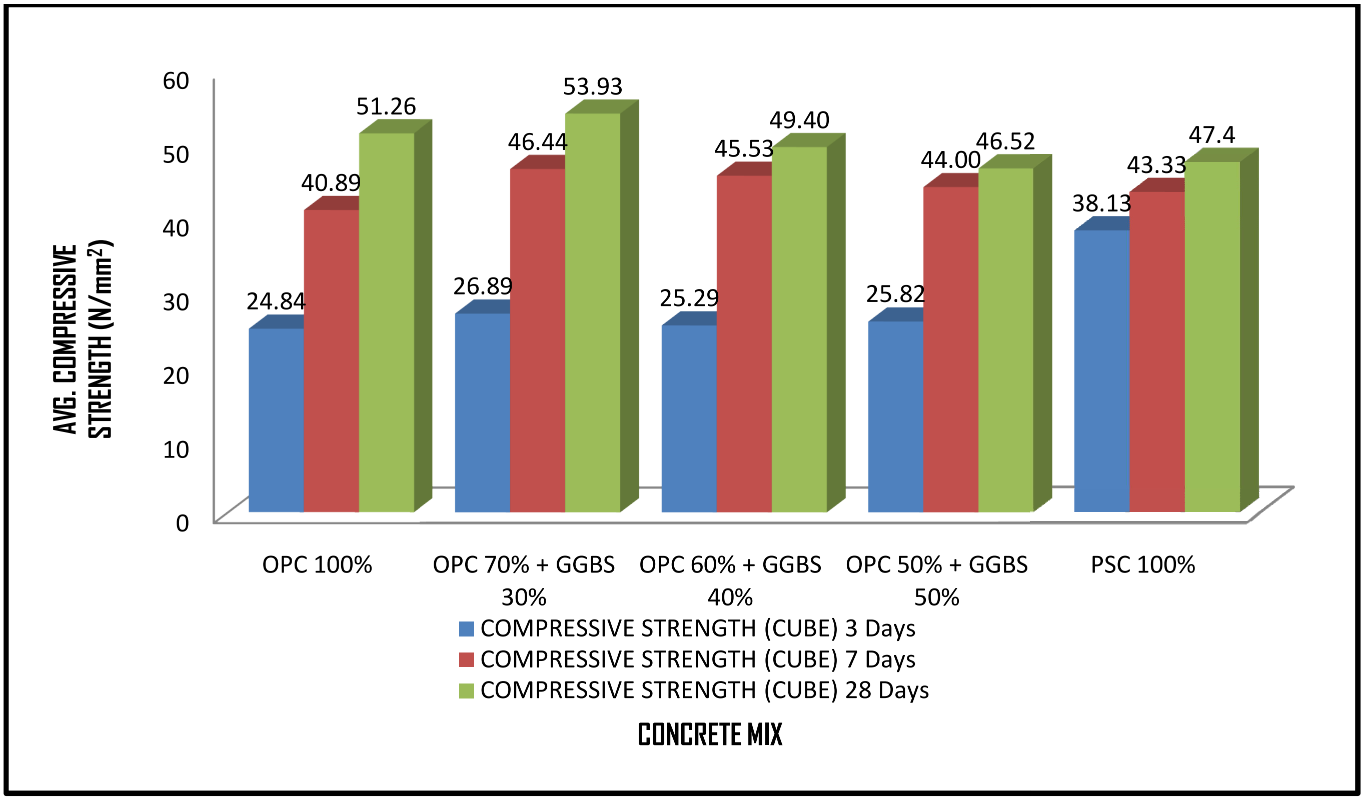


Fig.6.1.1 Graphical representation of cube compressive strengths after 3 days, 7 days and 28 days of water curing

Table 6.2: **Splitting tensile strengths of cylinder after 28 days of water curing**

SPLITTING TENSILE STRENGTH (CYLINDER)	
MIX	**28 Days**
OPC 100%	3.40
OPC 70% + GGBFS 30%	3.08
OPC 60% + GGBFS 40%	3.45
OPC 50% + GGBFS 50%	4.24
PSC 100%	3.49

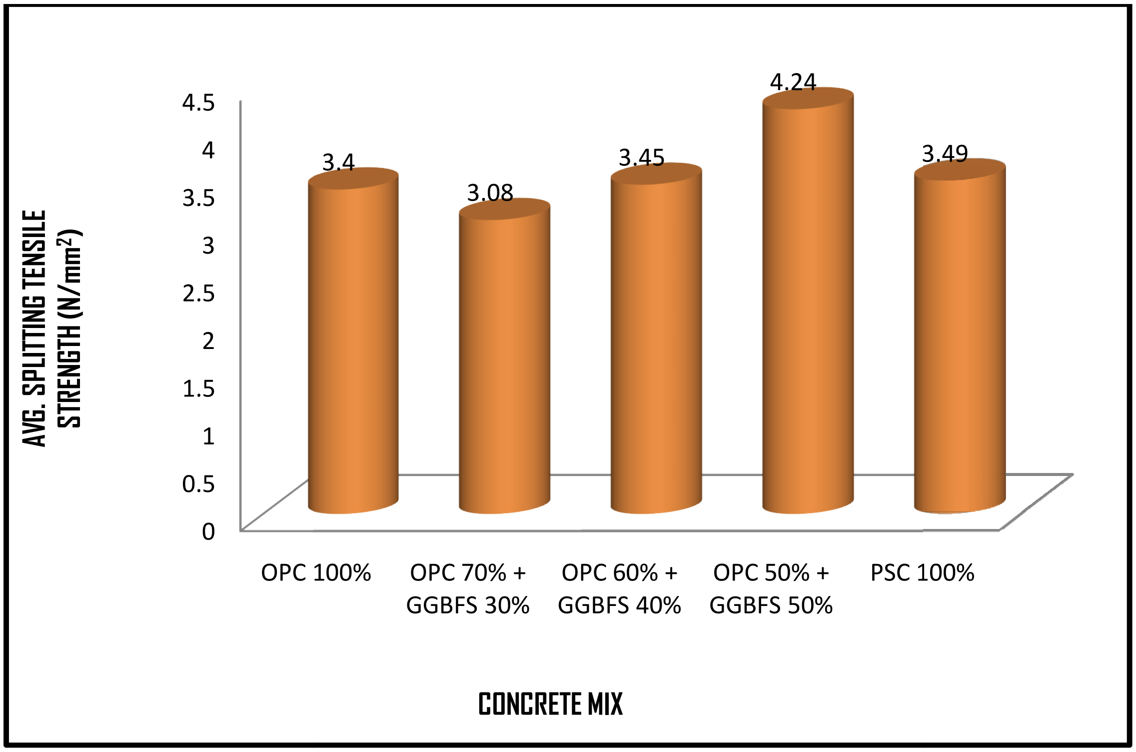


Fig.6.1.2 Graphical representation of splitting tensile strengths of cylinder After 28 days water curing

Table 6.3: Flexural strengths of beam after 28 days of water curing.

FLEXURAL STRENGTH (BEAM)	
MIX	**28 Days**
OPC 100%	8.50
OPC 70% + GGBFS 30%	7.25
OPC 60% + GGBFS 40%	7.50
OPC 50% + GGBFS 50%	8.50
PSC 100%	6.00

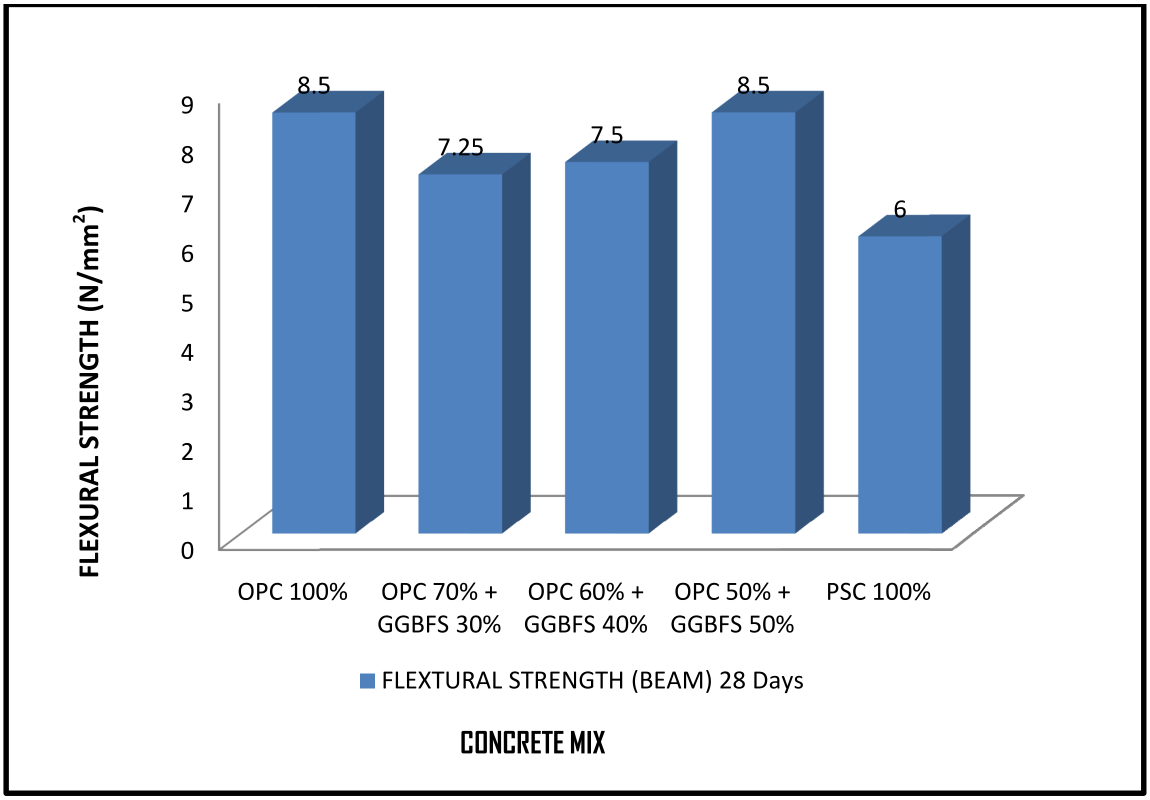


Fig.6.1.3 Graphical representation flexural strength after 28 days water curing

Table 6.4: Sorptivity index of mortar for 100% OPC .

Test Time (S)		√Time (s½)	Mass (g)	Change in mass, ΔM (g)	Area (mm²)	Density (g/mm³	I=ΔM/area/density
Days	Seconds						
	0	0	264.87	0	2500	0.001	0
	60	8	265.05	0.18	2500	0.001	0.072
	300	17	265.11	0.24	2500	0.001	0.096
	600	24	265.03	0.16	2500	0.001	0.064
	1200	35	265.05	0.18	2500	0.001	0.072
	1800	42	265.08	0.21	2500	0.001	0.084
	3600	60	265.10	0.23	2500	0.001	0.092
	7200	85	265.16	0.29	2500	0.001	0.116
	10800	104	265.22	0.35	2500	0.001	0.140
	14400	120	265.39	0.52	2500	0.001	0.208
	18000	134	265.46	0.59	2500	0.001	0.236
	21600	147	265.51	0.64	2500	0.001	0.256
	25200	159	265.55	0.68	2500	0.001	0.272
1	86400	294	266.13	1.26	2500	0.001	0.504
2	172800	416	266.15	1.28	2500	0.001	0.512
3	259200	509	266.27	1.40	2500	0.001	0.560
4	345600	588	266.43	1.56	2500	0.001	0.624
5	432000	657	266.60	1.73	2500	0.001	0.692
6	518400	720	266.84	1.97	2500	0.001	0.788
7	604800	778	266.89	2.02	2500	0.001	0.808

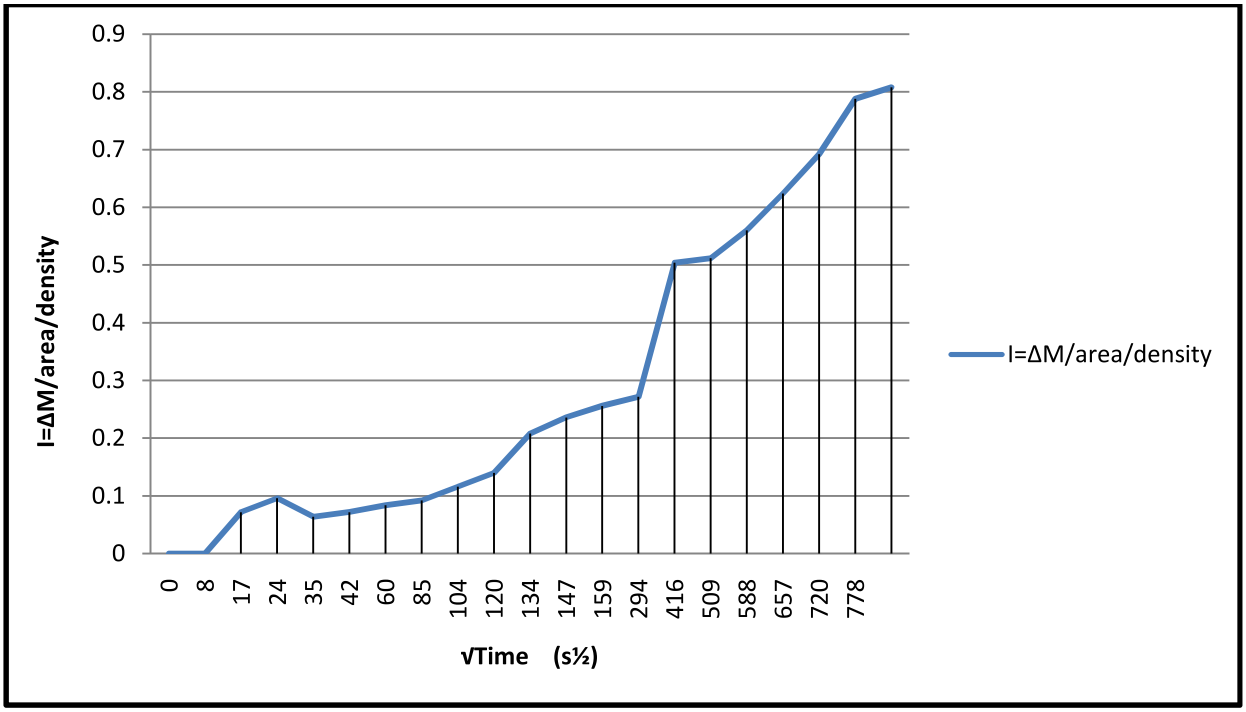


Fig.6.1.4 Graphical representation of Sorptivity index of mortar for 100% OPC

Table 6.5: Sorptivity index of mortar for OPC70% +GGBFS 30%

Test Time (S)		√Time (s½)	Mass (g)	Change in mass, ΔM (g)	Area (mm^2)	Density (g/mm^3	I=ΔM/area/density
Days	Seconds						
	0	0	274.69	0	2500	0.001	0
	60	8	274.77	0.08	2500	0.001	0.032
	300	17	274.87	0.18	2500	0.001	0.072
	600	24	274.86	0.17	2500	0.001	0.068
	1200	35	274.89	0.20	2500	0.001	0.080
	1800	42	274.90	0.21	2500	0.001	0.084
	3600	60	274.92	0.23	2500	0.001	0.092
	7200	85	274.94	0.25	2500	0.001	0.100
	10800	104	275.00	0.31	2500	0.001	0.124
	14400	120	275.02	0.33	2500	0.001	0.132
	18000	134	275.05	0.36	2500	0.001	0.144
	21600	147	275.08	0.39	2500	0.001	0.156
	25200	159	275.11	0.42	2500	0.001	0.168
1	86400	294	275.30	0.61	2500	0.001	0.244
2	172800	416	275.55	0.86	2500	0.001	0.344
3	259200	509	275.66	0.97	2500	0.001	0.388
4	345600	588	275.77	1.08	2500	0.001	0.432
5	432000	657	276.01	1.32	2500	0.001	0.528
6	518400	720	276.15	1.46	2500	0.001	0.584
7	604800	778	276.26	1.57	2500	0.001	0.628

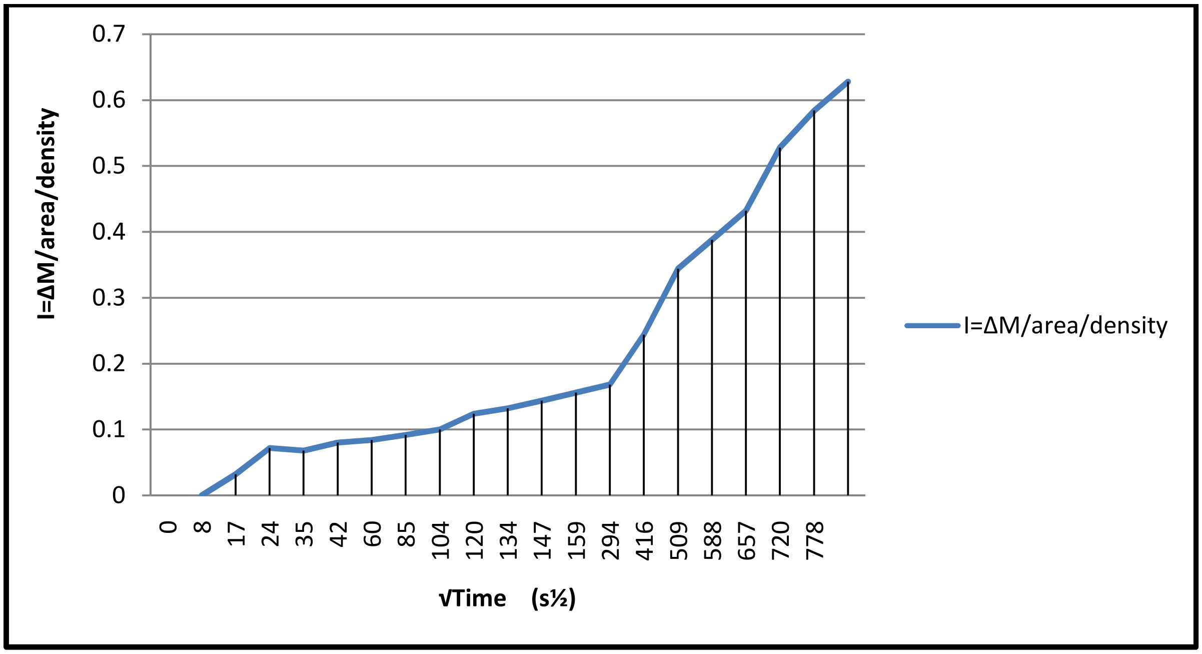


Fig.6.1.5 Graphical representation of Sorptivity index of mortar for OPC70% +GGBFS 30%

Table 6.6: **Sorptivity index of mortar for OPC60% +GGBFS 40%**

Test Time (S)		√Time (s½)	Mass (g)	Change in mass, ΔM (g)	Area (mm²)	Density (g/mm³	I=ΔM/area/density
Days	**Seconds**						
	0	0	269.81	0	2500	0.001	0
	60	8	269.96	0.15	2500	0.001	0.061
	300	17	269.98	0.17	2500	0.001	0.069
	600	24	270.04	0.23	2500	0.001	0.091
	1200	35	270.06	0.25	2500	0.001	0.099
	1800	42	270.09	0.28	2500	0.001	0.111
	3600	60	270.11	0.30	2500	0.001	0.119
	7200	85	270.20	0.39	2500	0.001	0.155
	10800	104	270.25	0.44	2500	0.001	0.176
	14400	120	270.32	0.51	2500	0.001	0.203
	18000	134	270.35	0.54	2500	0.001	0.217
	21600	147	270.44	0.63	2500	0.001	0.252
	25200	159	270.51	0.70	2500	0.001	0.279
1	86400	294	270.80	0.99	2500	0.001	0.396
2	172800	416	271.08	1.27	2500	0.001	0.509
3	259200	509	271.30	1.49	2500	0.001	0.596
4	345600	588	271.50	1.69	2500	0.001	0.676
5	432000	657	271.66	1.85	2500	0.001	0.740
6	518400	720	271.85	2.04	2500	0.001	0.816
7	604800	778	271.87	2.06	2500	0.001	0.825

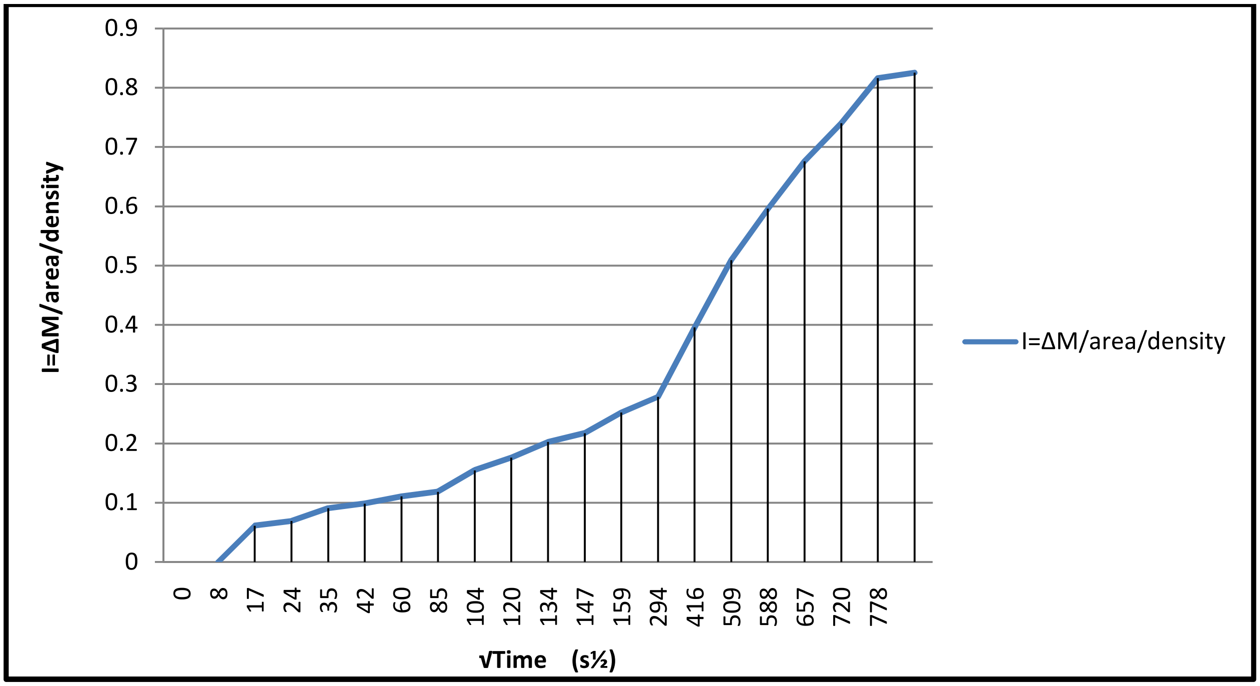


Fig.6.1.6 Graphical representation of sorptivity index of mortar for OPC60% +GGBFS 40%

Table 6.7: Sorptivity index of mortar for OPC50% +GGBFS 50%

Test Time (S)		√Time (s½)	Mass (g)	Change in mass, ΔM (g)	Area (mm²)	Density (g/mm³	I=ΔM/area/density
Days	Seconds						
	0	0	269.72	0	2500	0.001	0
	60	8	269.91	0.19	2500	0.001	0.076
	300	17	269.97	0.25	2500	0.001	0.100
	600	24	270.00	0.28	2500	0.001	0.112
	1200	35	270.02	0.30	2500	0.001	0.120
	1800	42	270.06	0.34	2500	0.001	0.136
	3600	60	270.11	0.39	2500	0.001	0.156
	7200	85	270.19	0.47	2500	0.001	0.190
	10800	104	270.33	0.61	2500	0.001	0.244
	14400	120	270.37	0.65	2500	0.001	0.260
	18000	134	270.44	0.72	2500	0.001	0.288
	21600	147	270.51	0.79	2500	0.001	0.316
	25200	159	270.60	0.88	2500	0.001	0.352
1	86400	294	270.86	1.14	2500	0.001	0.456
2	172800	416	271.01	1.29	2500	0.001	0.516
3	259200	509	271.20	1.48	2500	0.001	0.592
4	345600	588	271.40	1.68	2500	0.001	0.672
5	432000	657	271.70	1.98	2500	0.001	0.792
6	518400	720	271.80	2.08	2500	0.001	0.832
7	604800	778	271.84	2.12	2500	0.001	0.848

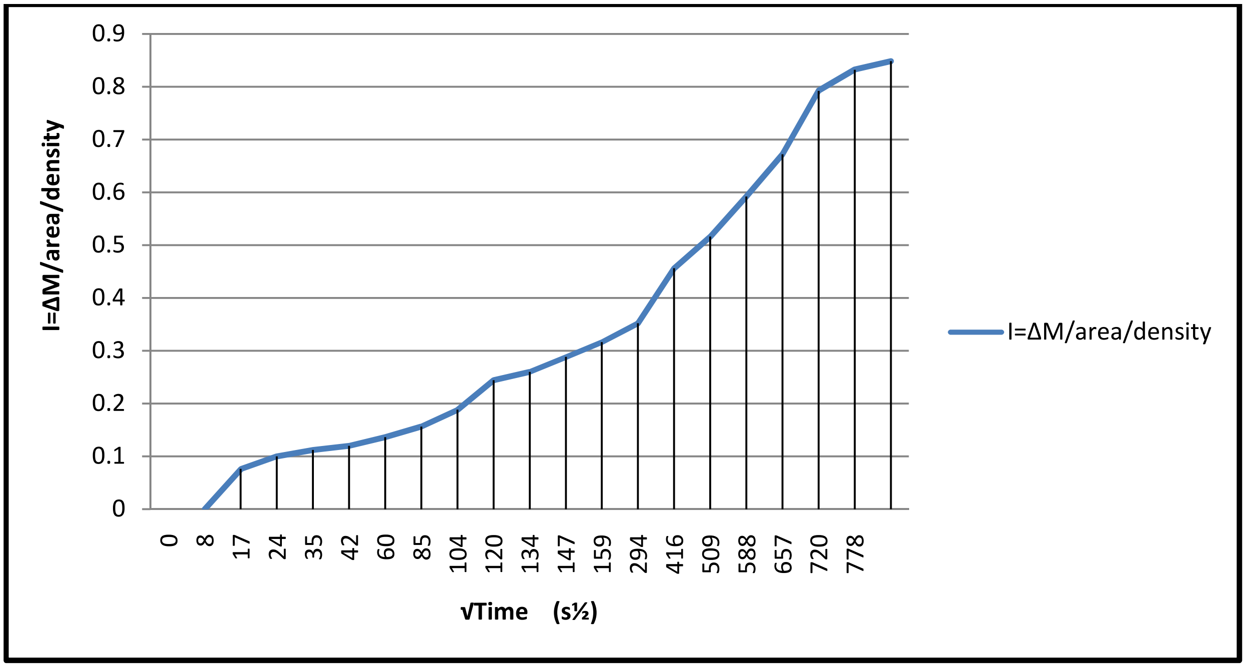


Fig.6.1.7 Graphical representation of sorptivity index of mortar OPC 50% +GGBFS 50%

Table 6.8: Sorptivity index of mortar for 100% PSC

Test Time (S)		√Time (s½)	Mass (g)	Change in mass, ΔM (g)	Area (mm^2)	Density (g/mm^3)	I=ΔM/area/density
Days	Seconds						
	0	0	245.09	0	2500	0.001	0.000
	60	8	245.72	0.63	2500	0.001	0.253
	300	17	246.56	1.47	2500	0.001	0.588
	600	24	247.01	1.92	2500	0.001	0.769
	1200	35	247.71	2.62	2500	0.001	1.048
	1800	42	248.18	3.09	2500	0.001	1.235
	3600	60	248.87	3.78	2500	0.001	1.511
	7200	85	249.86	4.77	2500	0.001	1.907
	10800	104	250.49	5.40	2500	0.001	2.159
	14400	120	250.85	5.76	2500	0.001	2.303
	18000	134	251.11	6.02	2500	0.001	2.408
	21600	147	251.48	6.39	2500	0.001	2.555
	25200	159	252.16	7.07	2500	0.001	2.829
1	86400	294	254.26	9.17	2500	0.001	3.667
2	172800	416	255.23	10.14	2500	0.001	4.057
3	259200	509	255.38	10.29	2500	0.001	4.115
4	345600	588	255.59	10.50	2500	0.001	4.201
5	432000	657	256.01	10.92	2500	0.001	4.369
6	518400	720	256.18	11.09	2500	0.001	4.436
7	604800	778	255.97	10.88	2500	0.001	4.352

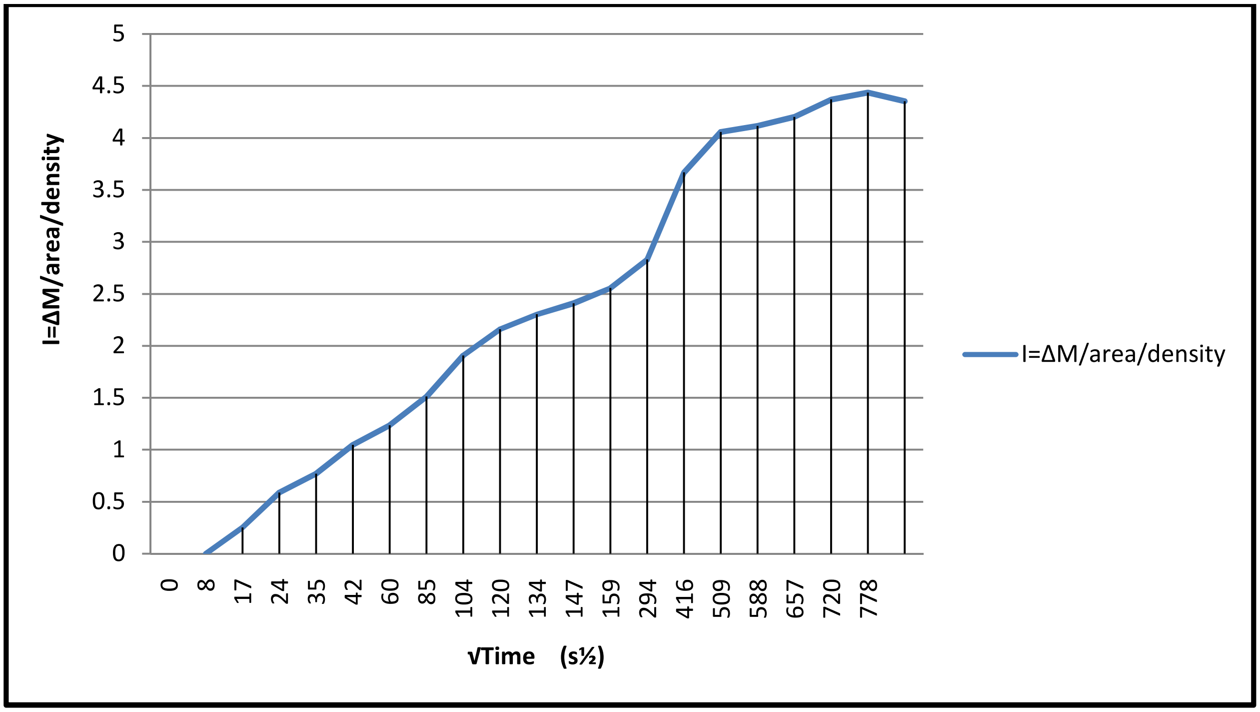


Fig.6.1.8 Graphical representation of Sorptivity of mortar 100% PSC

6.1.1 Observation of result:

Unexposed condition (Water curing for 28 Days)

1. In fig (6.1.1) it is observed that 28 days compressive strength of concrete after water curing is increased only for 30% replacement of GGBFS later for 40% and 50% replacement strength decreases when compared with 100% OPC. When GGBFS was not mixed 28 days strength was 51.26 N/mm^2 but with 30%, 40% and 50% GGBFS replacement the strengths are 53.93, 49.40 and 46.52 N/mm^2 respectively.

This is because the particles of GGBFS are very fine and spherical in shape. GGBFS is finer than Portland cement and it fit in between the cement particles. This phenomenon improves the strength of concrete initially. But afterward there is deficiency in calcium oxide as GGBFS contains very low CaO than OPC and thus strength decreases. So we can easily replace Ordinary Portland cement up to 30% GGBFS to make sustainable concrete of required target strength. Within the experiment performed, the Moreover we can get more compressive strength of concrete by using GGBFS with respect to using only OPC in concrete.

2. In case of determination of compressive strength 3cubes for 3days 3cubes for 7 days and 3 cubes for 28 days are casted for each type of mix. From the result shows that the initial strength gain of PSC is high but the replacement of 30% OPC by GGBFS gives the maximum 28days strength which is higher than100 % OPC and 100% PSC. In the light of the numbers in the figure 6.1.1, it is possible to judge about the selection of right percentages of GGBFS for making concrete. When the strength is compared with 100% PSC replacement up to 40 % GGBFS with OPC gives higher strength. PSC gives 47.40 N/mm^2 compressive strength which is lesser than the 30% and 40% replacement of GGBFS.

3.In case of determination of splitting tensile strength fig (6.1.2) 3 cylinder for 28 days are casted for each type of mix. From the result of splitting tensile strength it is extablished that higher replacement of ggbfs gives higher spilit tensile strength in experiment of literature review of (3) and (17) gives the similar kind of result this strength is dependent on the percentage of alkalies present in cementatious material (18). in fig 6.1.2 28 days splitting tensile strength for 100% OPC is 3.4 N/mm^2 and initially it decreases for 30% replacement later for 40% and 50% replacement it increases in a increasing manner.

For 100% PS splitting tensile strength is 3.49 N/mm^2 in this case only 50% replacement of GGBFS gives higher strength.

4. In case of determination of flexural strength 2 beams of size of 100mm width, 100mm depth, and span of 500 mm for 28 days are casted for each type of mix. From the fig 6.1.3 it is observed that !00% OPC has the good flexural strength compared to all the other mixes only the 50% replacement gives the similar value.

Though when we compared the flexural strength of 100% PSC i.e 6 N/mm^2 is the lowest for all the other type of mixes.

5. Observing the fig from 6.1.4 to 6.1.8 it is quite clear that permeability of PSC is higher than the all the rest mixes and it is also a reason for low flexural splitting tensile and compressive strength.

6. Comparing all the strength related data it can be concluded that 30% replacement of GGBFS can be possible without compromising strength of concrete.

6.2 Exposed condition (Water curing for 28 Days + 4% $MgSO_4$ solution for 60 days and 120day respectively)

Magnesium sulphate hydrate dissolved in water a content of 4% was used in the study as a salt. all the specimens that were subjected to sulphate attack were initially cured in water for 28days after remoulding. They were then immersed in the Magnesium sulphate solution for 60 days and 120 days respectively. Here the results expressed after the exposure.

Fig 6.1 specimen immersed in $MgSO_4$ solution

Table 6.9: Cube Compressive strength before and after immersion in $MgSO_4$

MIX	28 Days Curing in Water Bath	28 Days Curing in Water Bath + 60 Days in $MgSO_4$ Solution	28 Days Curing in Water Bath + 120 Days in $MgSO_4$ Solution
OPC 100%	51.26	52.30	59.85
OPC 70% + GGBFS 30%	53.93	53.85	59.85
OPC 60% + GGBFS 40%	49.40	51.26	60.00
OPC 50%+ GGBFS 50%	46.52	50.076	39.56
PSC 100%	47.40	52.59	47.70

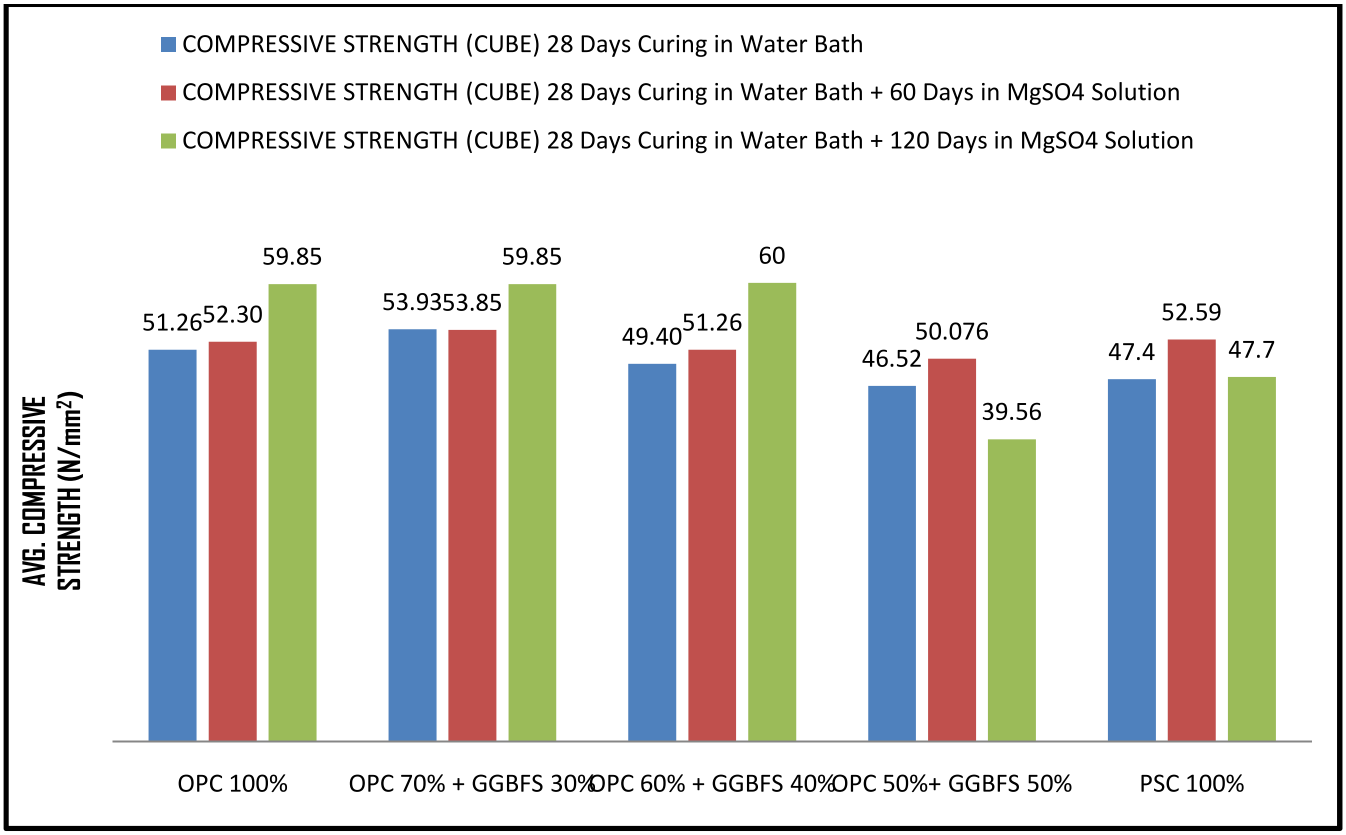


Fig.6.2.1 Graphical representation of cube Compressive strength before and after immersion in $MgSO_4$

Table 6.10: **Residual Cube Compressive strength after immersion in $MgSO_4$**

MIX	28 Days Curing in Water Bath + 60 Days in $MgSO_4$ Solution	28 Days Curing in Water Bath + 120 Days in $MgSO_4$ Solution
OPC 100%	1.04	8.59
OPC 70% + GGBFS 30%	-0.08	5.92
OPC 60% + GGBFS 40%	1.86	10.60
OPC 50%+ GGBFS 50%	3.56	-6.96
PSC 100%	5.19	0.30

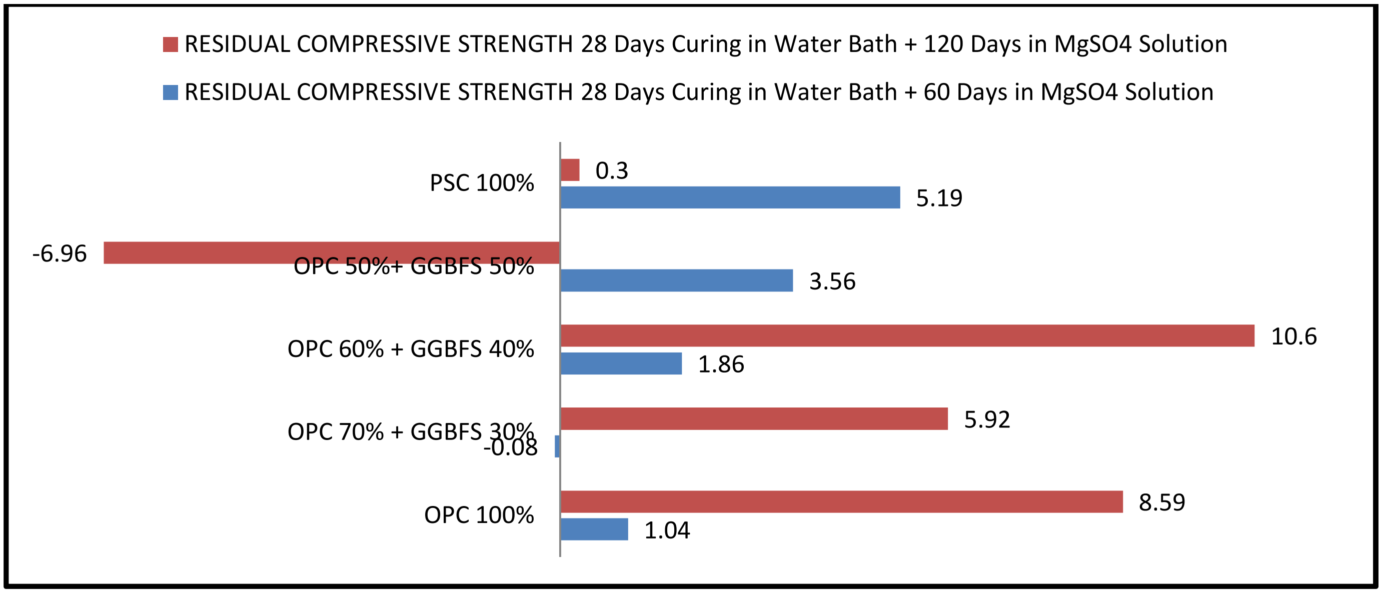


Fig.6.2.2 Graphical representation of residual cube Compressive strength after immersion in $MgSO_4$

Table 6.11 : UPV data before and after (60 days) immersion in $MgSO_4$

MIX	28 Days Curing in Water Bath	28 Days Curing in Water Bath + 60 Days in $MgSO_4$ Solution
OPC 100%	4.795	4.752
OPC 70% + GGBFS 30%	4.850	4.703
OPC 60% + GGBFS 40%	4.814	4.690
OPC 50%+ GGBFS 50%	4.835	4.226
PSC 100%	4.870	4.361

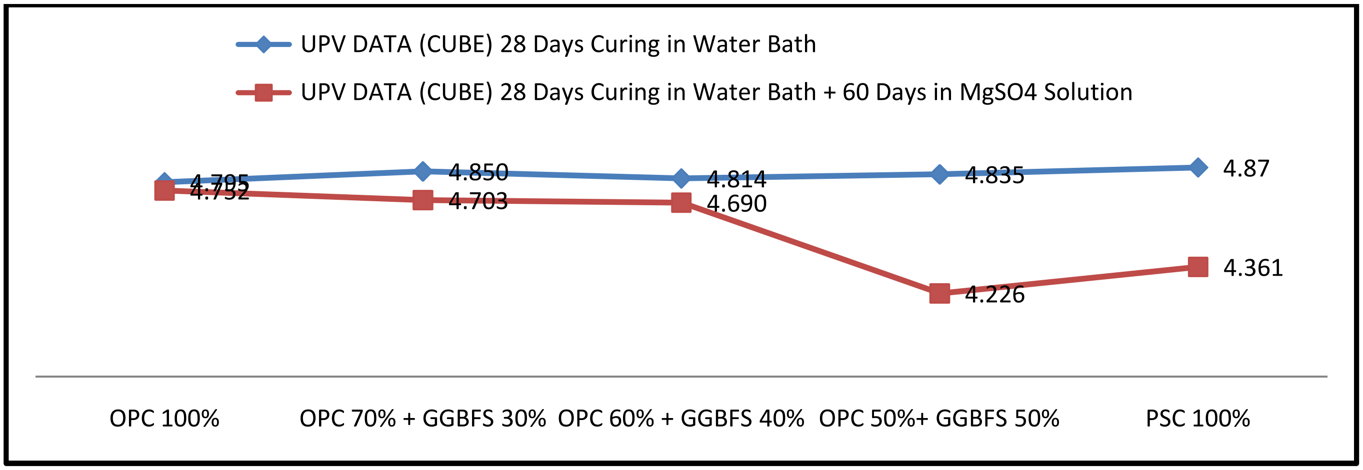


Fig. 6.2.3 Graphical representation of UPV data before and after (60 days) immersion in $MgSO_4$

Table 6.12: UPV data before and after (120 days) immersion in $MgSO_4$

MIX	28 Days Curing in Water Bath	28 Days Curing in Water Bath + 120 Days in $MgSO_4$ Solution
OPC 100%	4.864	4.996
OPC 70% + GGBFS 30%	4.777	4.554
OPC 60% + GGBFS 40%	4.886	4.753
OPC 50%+ GGBFS 50%	4.808	4.320
OPC 100%	5.029	4.239

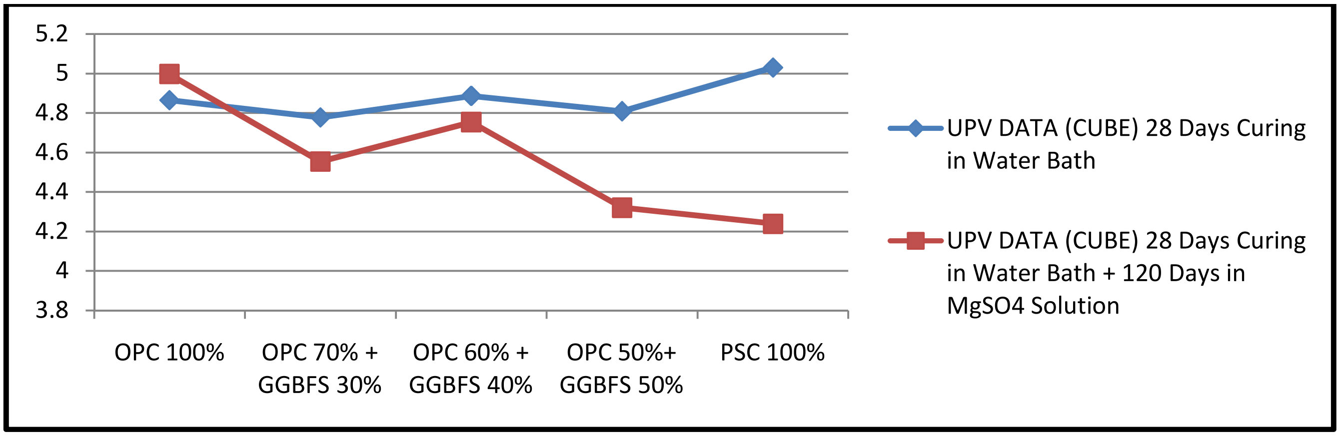


Fig. 6.2.4 Graphical representation of UPV data before and after (120 days) immersion in $MgSO_4$

Table 6.13: Splitting tensile strength of cylinder before and after immersion in $MgSO_4$

MIX	28 Days Curing in Water Bath	28 Days Curing in Water Bath + 60 Days in $MgSO_4$ Solution	28 Days Curing in Water Bath + 120 Days in $MgSO_4$ Solution
OPC 100%	3.40	4.671	4.253
OPC 70% + GGBFS 30%	3.08	3.259	3.885
OPC 60% + GGBFS 40%	3.45	3.471	3.662
OPC 50%+ GGBFS 50%	4.24	5.066	4.528
PSC 100%	3.49	4.700	3.756

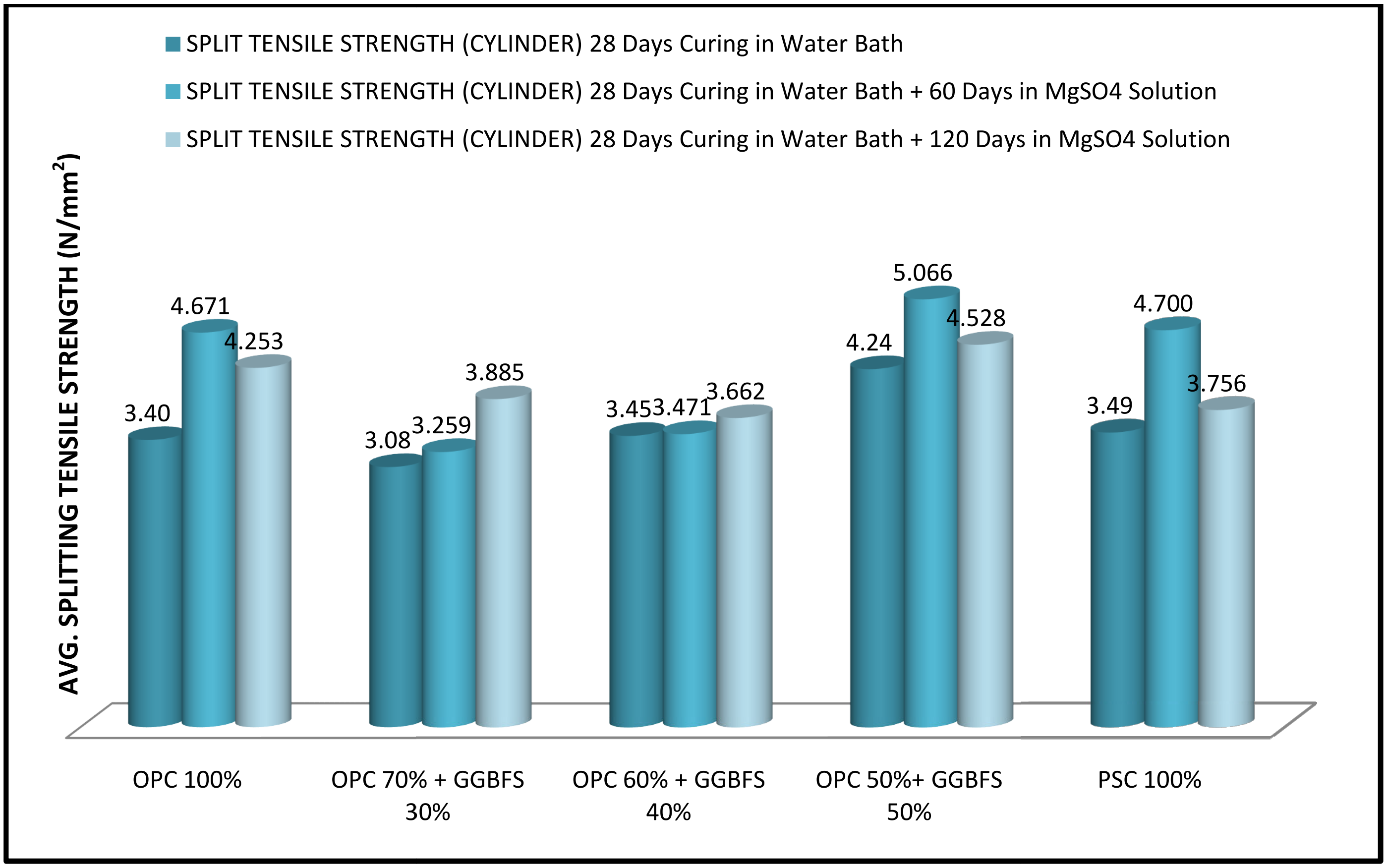


Fig. 6.2.5 Graphical representation of Splitting tensile strength before and after immersion in $MgSO_4$

Table 6.14: **Residual Splitting tensile strength of cylinder after immersion in $MgSO_4$**

MIX	28 Days Curing in Water Bath + 60 Days in $MgSO_4$ Solution	28 Days Curing in Water Bath + 120 Days in $MgSO_4$ Solution
OPC 100%	1.271	-0.418
OPC 70% + GGBFS 30%	0.179	0.626
OPC 60% + GGBFS 40%	0.021	0.191
OPC 50%+ GGBFS 50%	0.826	-0.538
PSC 100%	1.210	-0.944

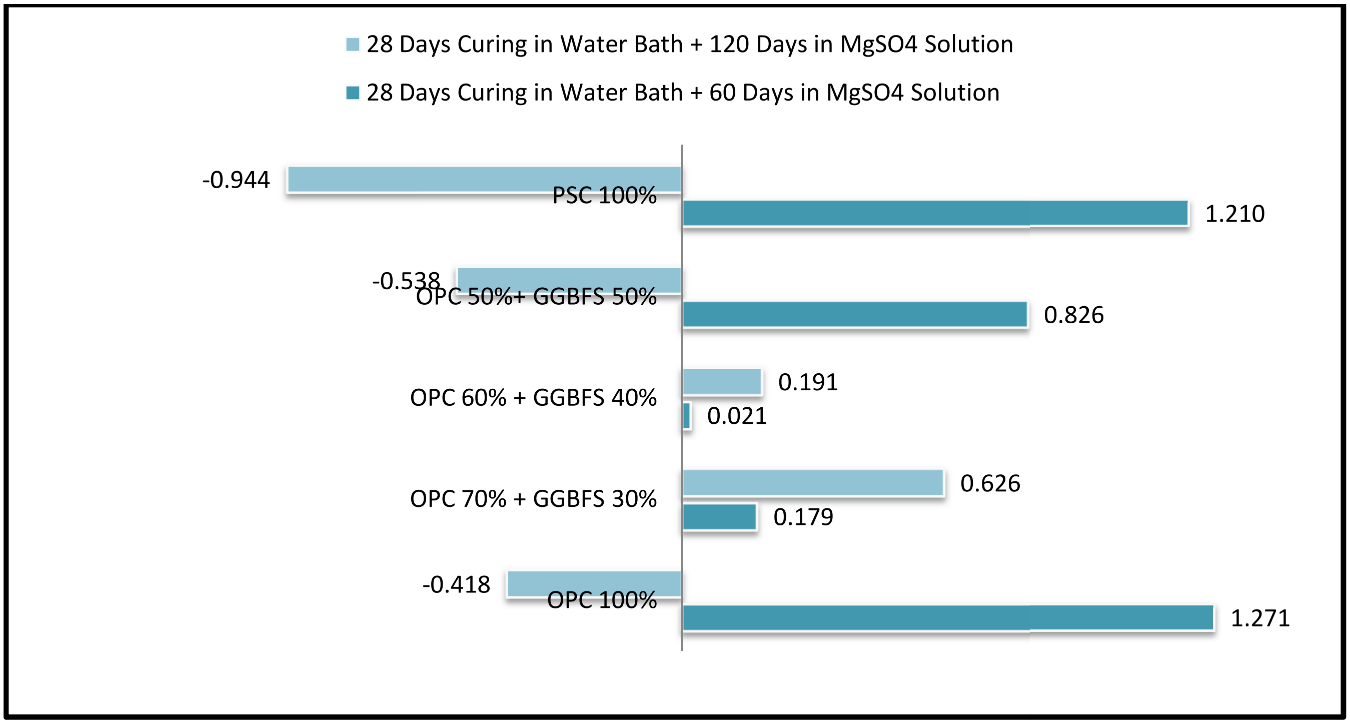


Fig. 6.2.6 Graphical representation of residual splitting tensile strength after immersion in $MgSO_4$

Table 6.15: Flexural strength of beam before and after immersion in $MgSO_4$

MIX	28 Days Curing in Water Bath	28 Days Curing in Water Bath + 60 Days in $MgSO_4$ Solution	28 Days Curing in Water Bath + 6120 Days in $MgSO_4$ Solution
OPC 100%	8.50	7.50	7.50
OPC 70% + GGBFS 30%	7.25	7.50	5.50
OPC 60% + GGBFS 40%	7.50	7.750	6.25
OPC 50%+ GGBFS 50%	8.50	8.50	7.00
PSC 100%	6.00	6.00	6.75

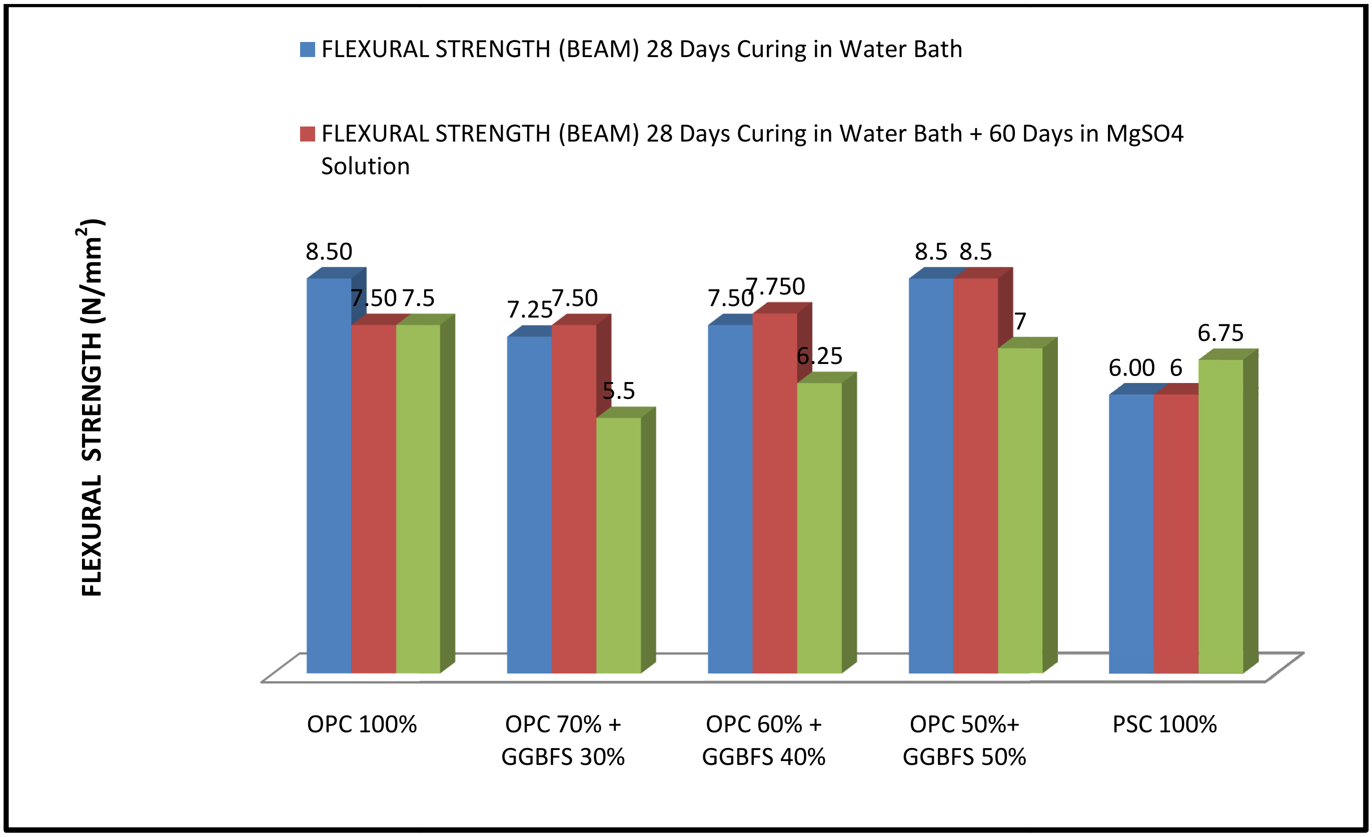


Fig. 6.2.7 Graphical representation of Flexural strength of beam before and after immersion in $MgSO_4$

Table 6.16 : Residual Flexural strength of beam after immersion in $MgSO_4$

MIX	28 Days Curing in Water Bath + 60 Days in $MgSO_4$ Solution	28 Days Curing in Water Bath + 120 Days in $MgSO_4$ Solution
OPC 100%	-1.00	-1.00
OPC 70% + GGBFS 30%	0.25	-1.75
OPC 60% + GGBFS 40%	0.25	-1.25
OPC 50%+ GGBFS 50%	0.00	-1.50
PSC 100%	0.00	0.75

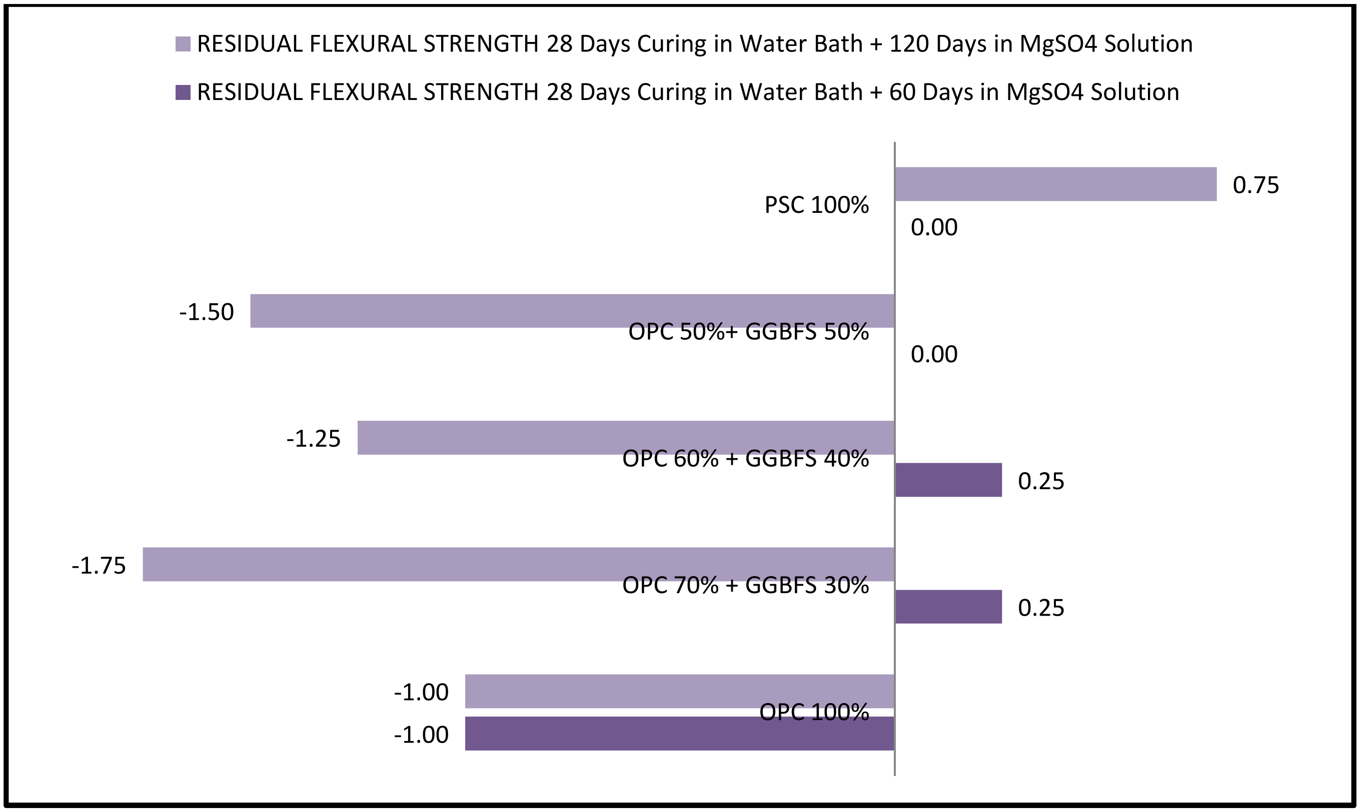


Fig. 6.2.8 Graphical representation of residual flexural strength of beam after immersion in $MgSO_4$

Table 6.17 : Change in % weight of cube after immersion in $MgSO_4$

MIX	Change in % weight after 60 days	Change in % weight after 120 days
OPC 100%	0.0014	0.0008
OPC 70% + GGBFS 30%	0.0019	0.0022
OPC 60% + GGBFS 40%	0.0015	0.0027
OPC 50%+ GGBFS 50%	0.0044	0.0414
PSC 100%	-0.0173	-0.0324

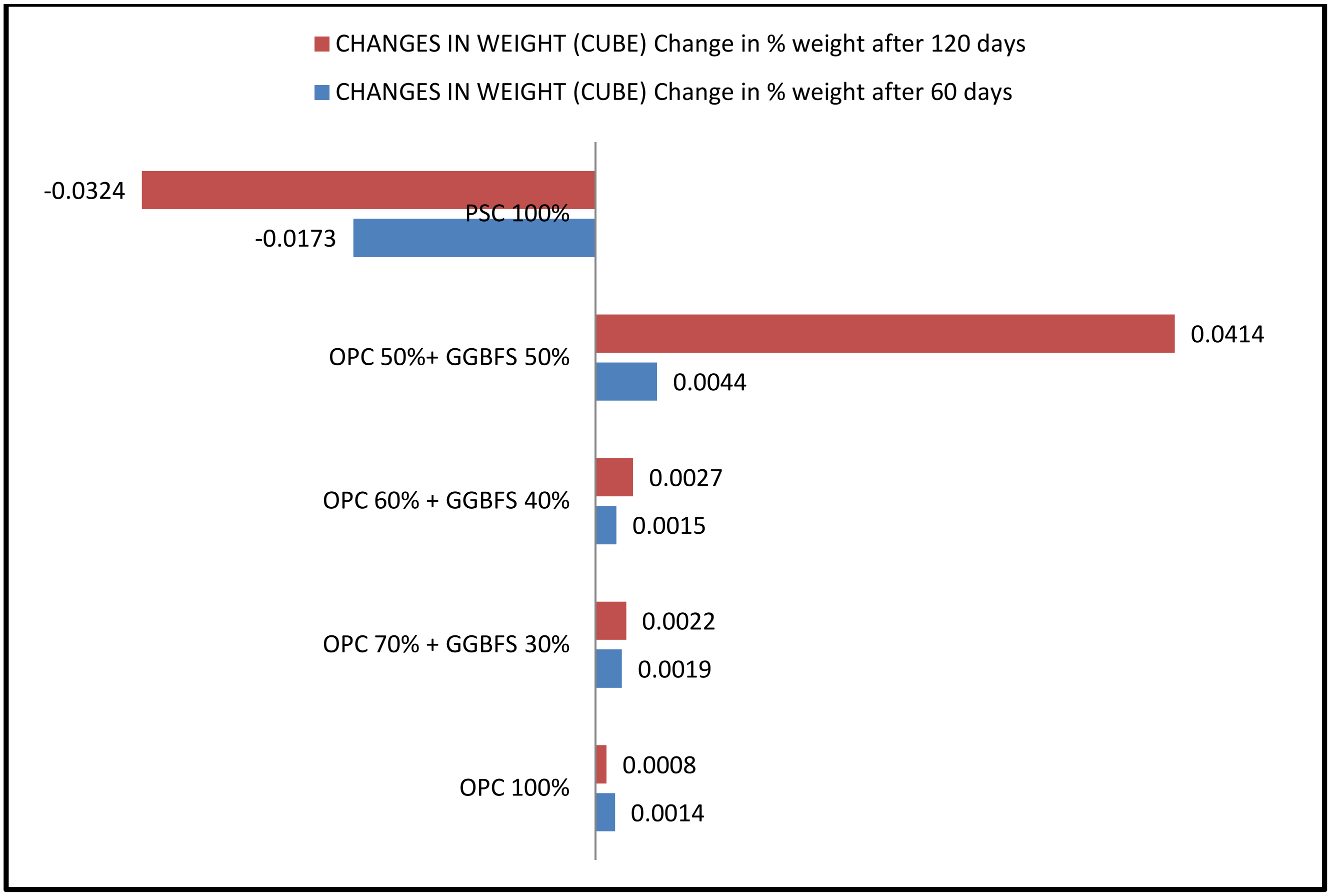


Fig. 6.2.9 Graphical representation of Change in % weight of cube after immersion in $MgSO_4$

Table 6.18 : Change in % weight of cylinder after immersion in $MgSO_4$

MIX	Change in % weight after 60 days	Change in % weight after 120 days
OPC 100%	0.0015	0.0015
OPC 70% + GGBFS 30%	0.0003	0.002
OPC 60% + GGBFS 40%	-0.0051	0.121
OPC 50%+ GGBFS 50%	0.0085	-0.0036
PSC 100%	0.0113	-0.0018

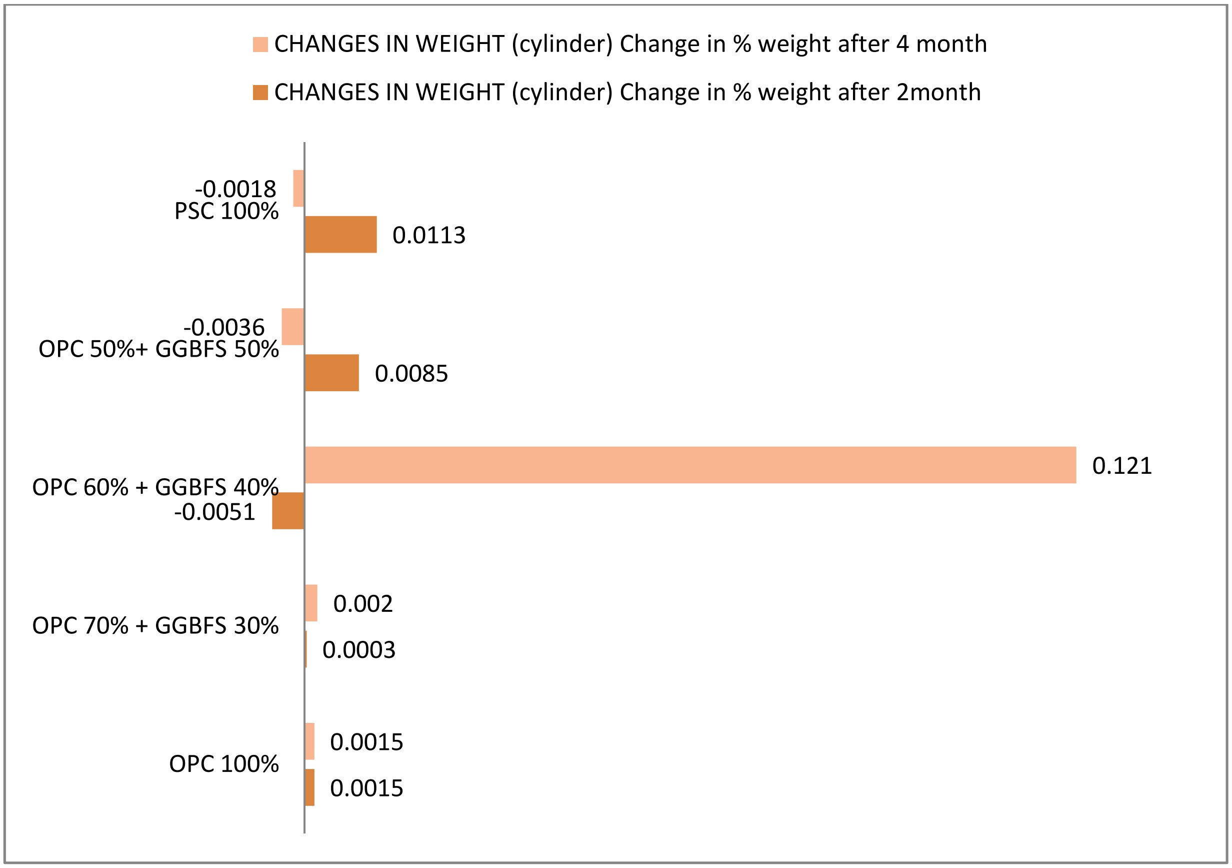


Fig. 6.2.10 Graphical representation of Change in % weight of cylinder after immersion in $MgSO_4$

Table 6.19 : **Change in % weight of beam after immersion in $MgSO_4$**

MIX	Change in % weight after 60 days	Change in % weight after 120 days
OPC 100%	0.002	0.0008
OPC 70% + GGBFS 30%	-0.002	0.0023
OPC 60% + GGBFS 40%	0.014	-0.0107
OPC 50%+ GGBFS 50%	0.030	0.0717
PSC 100%	0.008	0.0124

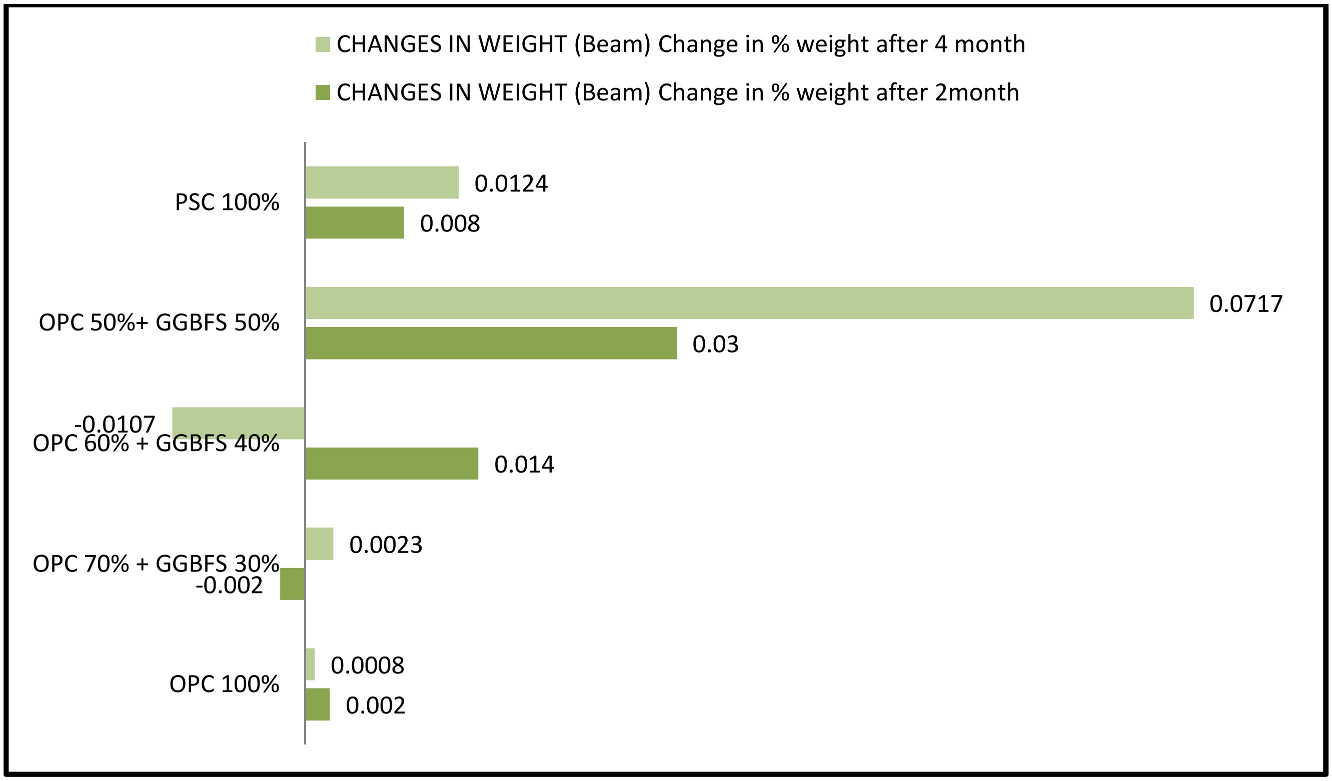


Fig. 6.2.11 Graphical representation of Change in % weight of beam after immersion in $MgSO_4$

Table 6.20 : Half cell potential value (-ve) before and after immersion in $MgSO_4$

MIX	28 Days Curing in Water Bath	28 Days Curing in Water Bath + 60 Days in $MgSO_4$ Solution	28 Days Curing in Water Bath + 120 Days in $MgSO_4$ Solution
OPC 100%	223.00	315.00	448.70
OPC 70% + GGBFS 30%	252.00	283.00	321.70
OPC 60% + GGBFS 40%	232.00	275.00	393.40
OPC 50%+ GGBFS 50%	177.50	198.11	500.33
PSC 100%	372.67	203.00	467.89

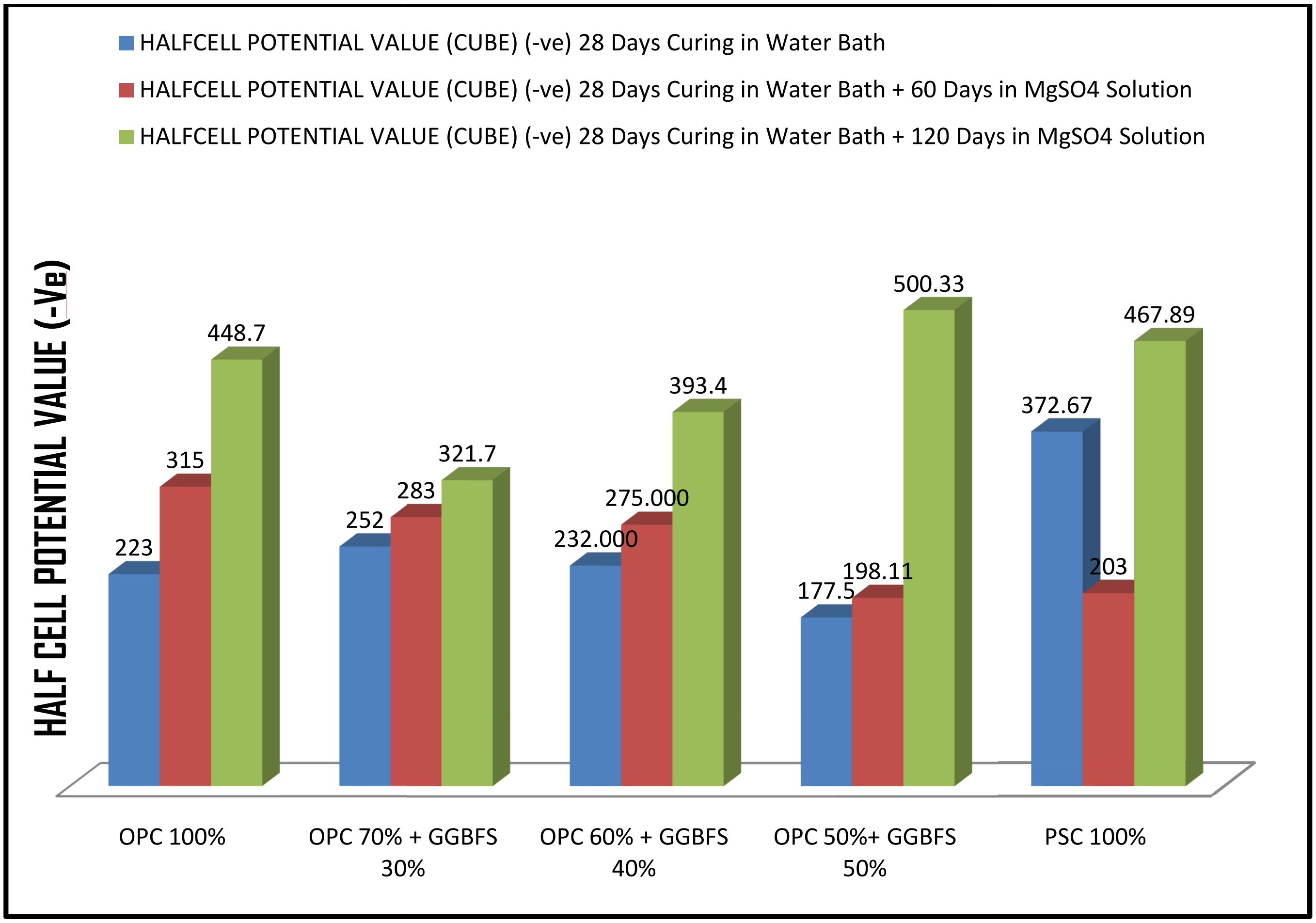


Fig. 6.2.12 Graphical representation of Half cell potential value (-Ve) before and after immersion in $MgSO_4$

6.2.1 Observation of result:

Exposed condition (Water curing for 28 Days + 4% $MgSO_4$ solution for 60 days and 120day respectively)

1. The result illustrated in Table 6.8 and figure 6.2.1 explain that compressive strength between the concrete immersed in $MgSO_4$ for 60days and 120days and standard curing of concrete. The figure show the improvement of strength immersed in $MgSO_4$ relative to the strength of curing with water on all concrete mixed except 30% replacement is higher in case of 60days curing and in case of 120 days curing strength is increased except 50% replacement when compared with 100% OPC mix. These type of result can be explain as the GGBFS attributed to the formation of the expansive ettringite in the presence of tricalcium aluminate inside the cement paste matrix and the infiltrated SO_4^- ion, which is resulted in the filling the voids thus increasing the concrete maturity.

2. The same figure 6.2.1 also gives a comparison between the 100% PSC and the other type of mixes. In these case 100% PSC shows an increase in strength after 60 days immersion but after 120 days the strength decreases similarly as in case of 50% GGBFS replacement as shown in the result of sorptivity PSC and 50% GGBFS replacement shows higher permeability which is can cause less strength. Moreover we can get more compressive strength of concrete by using GGBFS upto 40% replacement with respect to using only OPC and PSC in concrete.

3. Residual strength after $MgSO_4$ exposure is increasing with percentage increase in GGBFS up to 50% replacement after 60 days $MgSO_4$ curing fig 6.2.2. In these cases the strength are increase more than there respective 28 days compressive strength. But after 120 days curing 100% OPC 30% and 40% GGBFS replacement shows positive residual strength.50% GGBFS replacement and 100% PSC shows a decrease in residual strength due to its high permeability. Thus it can be concluded that for durability purpose of concrete in $MgSO_4$ a replacement up to 40% GGBFS can serve the intended purpose.

4. According to IS 13311(Part 1) UPV value more than 4.5 km/Sec signifies excellent quality concrete. Here in the table6.10 and 6.11 and fig 6.2.3 and 6.2.4 it is observed that only 50% GGBFS replacement and 100% PSC concrete have the UPV value less than 4.5 km/Sec. From the residual strength and compressive strength result it has been found these two mix also have a decreasing tendency of strength. So 30% and 40% mixes gained more strength and more density with respect to 100% PSC mix. Even after $MgSO_4$ exposure UPV values remain more than 4.5 Km/Sec in these particular two mixes.

5. The result illustrated in Table6.12 and figure 6.2.5 explain that splitting tensile strength between the concrete immersed in $MgSO_4$ for 60days and 120days and standard curing of concrete. The figure show the values of strength immersed in $MgSO_4$ relative to the strength of curing with water 100% OPC has more tensile strength value than 30% and 40% replacement by GGBFS. but 50% replacement has much higher values than the other all type of mixes in case of 60 days immersion .though after 120 days 100% OPC 100% PSC and 50% GGBFS replacement shows a decrease in tensile strength but 30% and 40% GGBFS replacement shows an increase in the strength. From the durability point of view it can be said that up to 40% replacement of GGBFS is more reliable that other type both the 100% OPC and 100% PSC concrete.

6. Residual tensile strength fig 6.2.6 after $MgSO_4$ exposure is only positive for 60 days as well as 120 days is the 30% and 40% GGBFS replacement.

7. The result illustrated in Table and figure 6.2.7 explains that flexural strength between the concrete immersed in $MgSO_4$ for 60days and 120days and standard curing of concrete. The figure show the effect of $MgSo_4$ solution on flexural strength is detrimental in all the mixes except 100% PSC.30 % and 40 % GGBFS replacement gives comparatively good result in case of flexural strength for 60days of exposure. For long time exposure 100% PSC shows an positive result other than any other type of mix.

8. In fig 6.2.8 Residual tensile strength after $MgSO_4$ exposure is only positive for 60 days for the replacement of 30 and 40% GGBFS as well as 120 days is the 30% and 40% GGBFS replacement, and 100% PSC shows a long term residual strength gain.

9. The percentage change in weight in case of cube cylinder and beam having very small value and mist of the mixes it is in the increasing tendency. It is due to the deposition of $MgSO_4$ salts outside the specimens.

10. Half-cell potential drops become more negative after the exposure for all the mixes. i.e. rebar corrosion has started in this exposure. From Fig 6.2.12 it can be said that addition of GGBFS does not influence in corrosion potential of rebar i.e. percentage potential drop of sustainable concretes are similar to traditional concrete in fact up to 50% replacement and 60 days of exposure the mixes gives good potential resistance but after 120 days Half-cell potential drops is high for 50% replacement . So sustainable concrete can be made by addition with same rebar corrosion potential in $MgSo_4$ exposure.

6.3 Exposed condition (Water curing for 28 Days + 4% H_2SO_4 solution for 60 days and 120days respectively)

Sulphuric acid dissolved in water a content of 4% was used in the study all the specimens that were subjected to sulphate attack were initially cured in water for 28days after remoulding. They were then immersed in the Sulphuric acid solution for 60 days and 120 days respectively. Here the results expressed after the exposure.

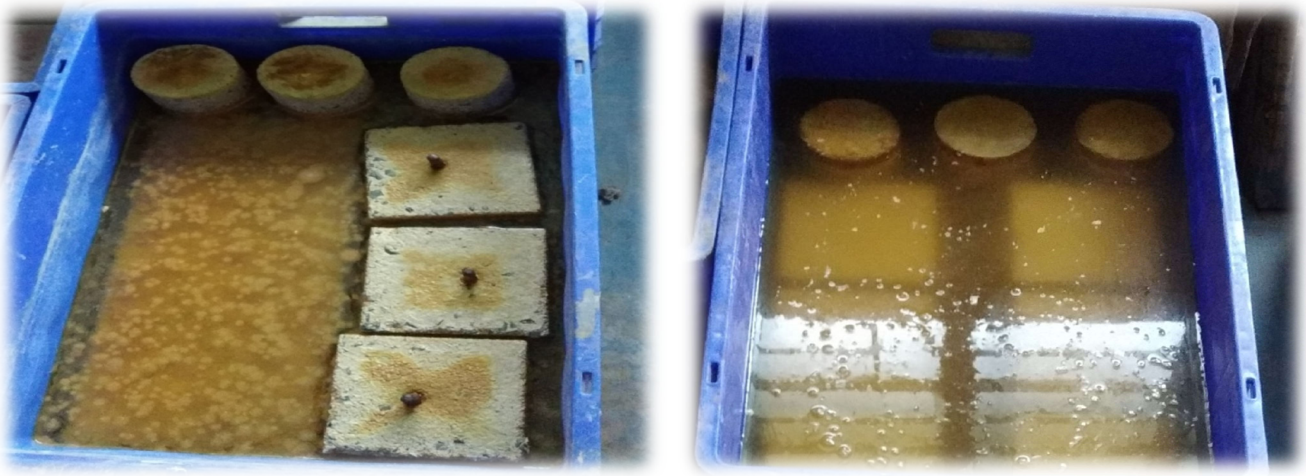


Fig 6.2 Specimens immersed in H_2SO_4 solution

Fig6.3 Specimens after removal from H_2SO_4 solution

Table 6.21: Cube Compressive strength before and after immersion in H_2SO_4

MIX	28 Days Curing in Water Bath	28 Days Curing in Water Bath + 60 Days in H_2SO_4Solution	28 Days Curing in Water Bath + 120 Days in H_2SO_4 Solution
OPC 10%	51.26	49.18	47.11
OPC 70% + GGBFS 30%	53.93	36.74	37.48
OPC 60% + GGBFS 40%	49.40	45.48	42.22
OPC 50%+ GGBFS 50%	46.52	41.33	39.70
PSC 100%	47.40	49.93	44.88

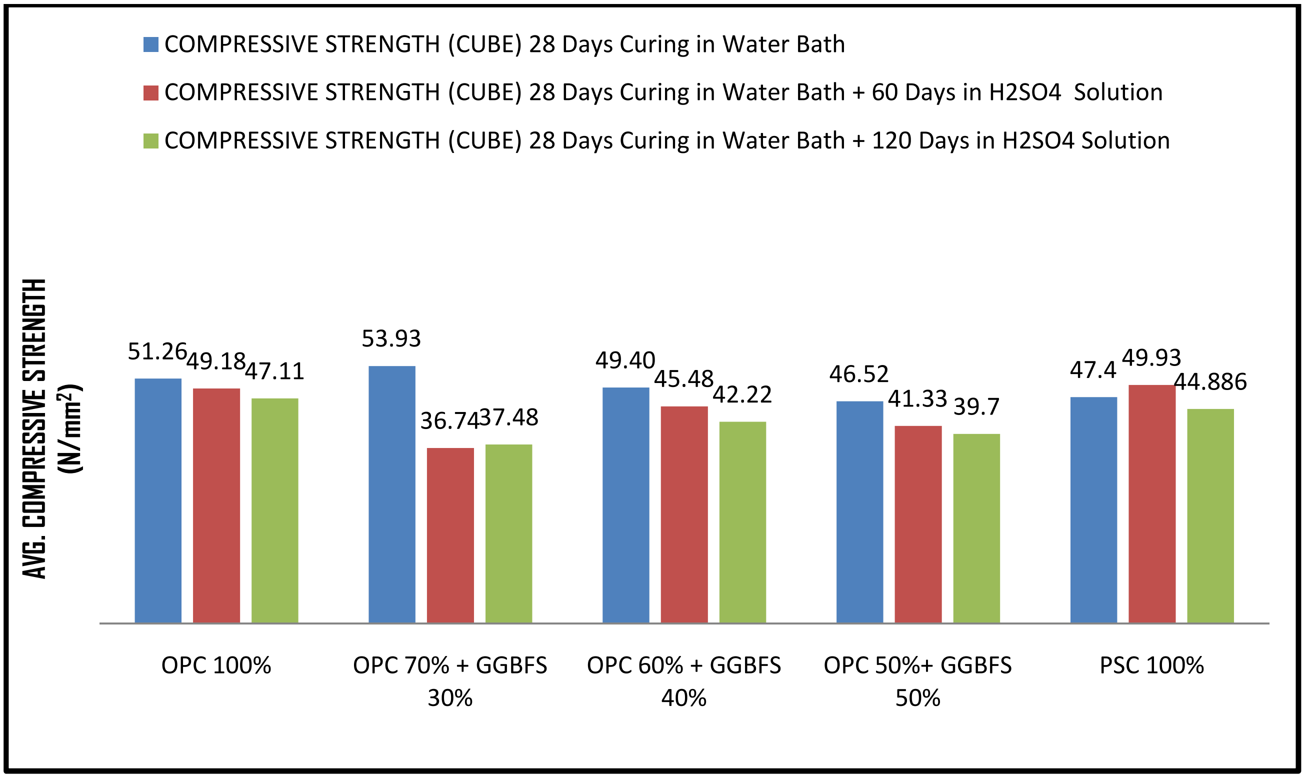


Fig.6.3.1 Graphical representation of cube Compressive strength before and after immersion in H_2SO_4

Table 6.22 : Residual Cube Compressive strength after immersion in H_2SO_4

MIX	28 Days Curing in Water Bath + 60 Days in H_2SO_4 Solution	28 Days Curing in Water Bath + 120 Days in H_2SO_4 Solution
OPC 100%	-2.08	-4.15
OPC 70% + GGBFS 30%	-17.19	-16.45
OPC 60% + GGBFS 40%	-3.92	-7.18
OPC 50%+ GGBFS 50%	-5.19	-6.82
PSC 100%	2.53	-2.51

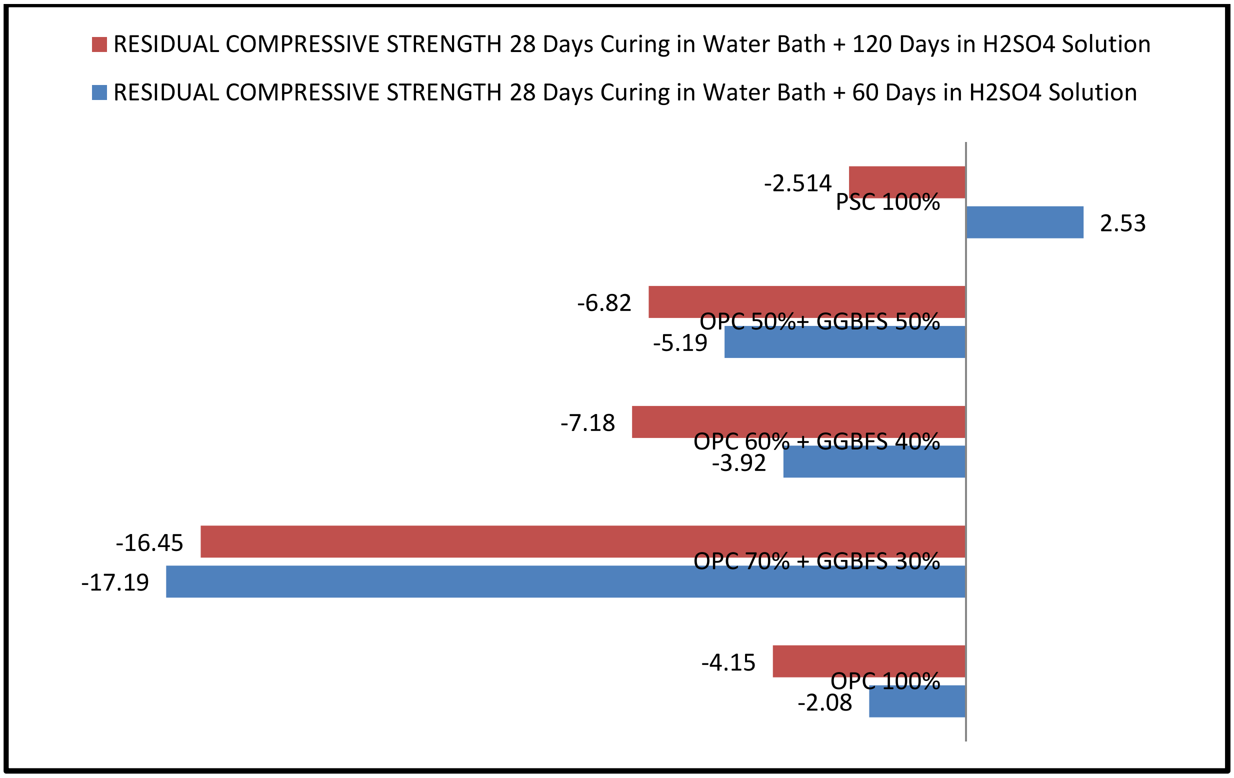


Fig.6.3.2 Graphical representation of residual cube Compressive strength after immersion in H_2SO_4

Table 6.23 : UPV data before and after (60 days) immersion in H_2SO_4

MIX	28 Days Curing in Water Bath	28 Days Curing in Water Bath + 60 Days in H_2SO_4 Solution
OPC 100%	5.067	4.881
OPC 70% + GGBFS 30%	4.844	4.609
OPC 60% + GGBFS 40%	4.699	4.220
OPC 50%+ GGBFS 50%	4.639	4.559
PSC 100%	5.035	4.121

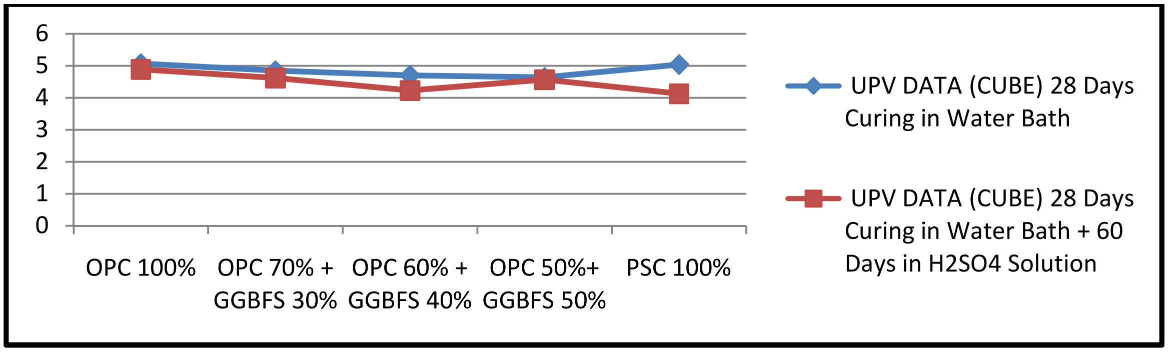


Fig. 6.3.3 Graphical representation of UPV data before and after (60 days) immersion in H_2SO_4

Table 6.24: UPV data before and after (60 days) immersion in H_2SO_4

MIX	28 Days Curing in Water Bath	28 Days Curing in Water Bath + 120 Days in H_2SO_4 Solution
OPC 100%	4.967	4.856
OPC 70% + GGBFS 30%	4.882	4.736
OPC 60% + GGBFS 40%	4.531	4.703
OPC 50%+ GGBFS 50%	4.889	3.86
PSC 100%	4.881	4.395

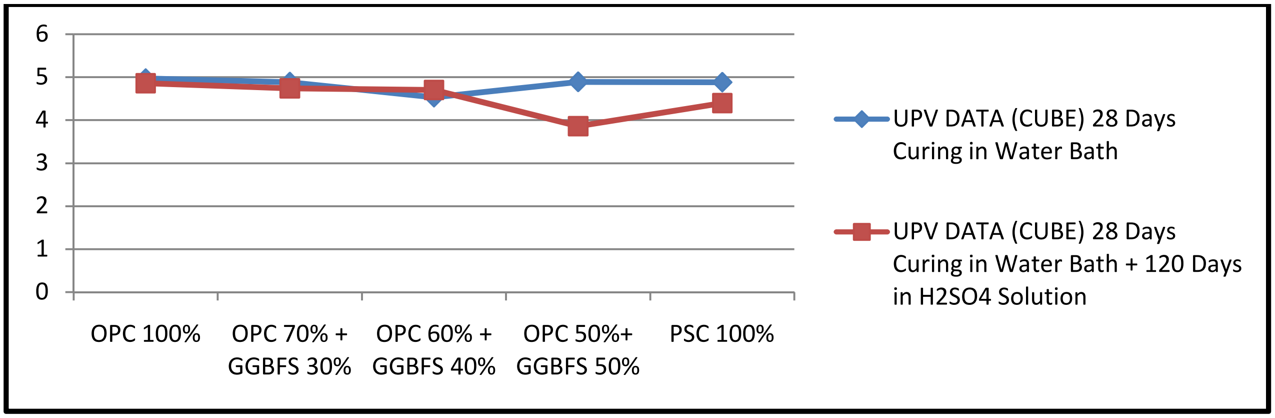


Fig. 6.3.4 Graphical representation of UPV data before and after (120 days) immersion in H_2SO_4

Table 6.25 : Splitting tensile strength of cylinder before and after immersion in H_2SO_4

MIX	28 Days Curing in Water Bath	28 Days Curing in Water Bath + 60 Days in H_2SO_4 Solution	28 Days Curing in Water Bath + 120 Days in H_2SO_4 Solution
OPC 100%	3.40	4.616	4.743
OPC 70% + GGBFS 30%	3.08	4.237	3.885
OPC 60% + GGBFS 40%	3.45	4.893	3.646
OPC 50%+ GGBFS 50%	4.24	4.991	3.974
PSC 100%	3.49	4.457	4.379

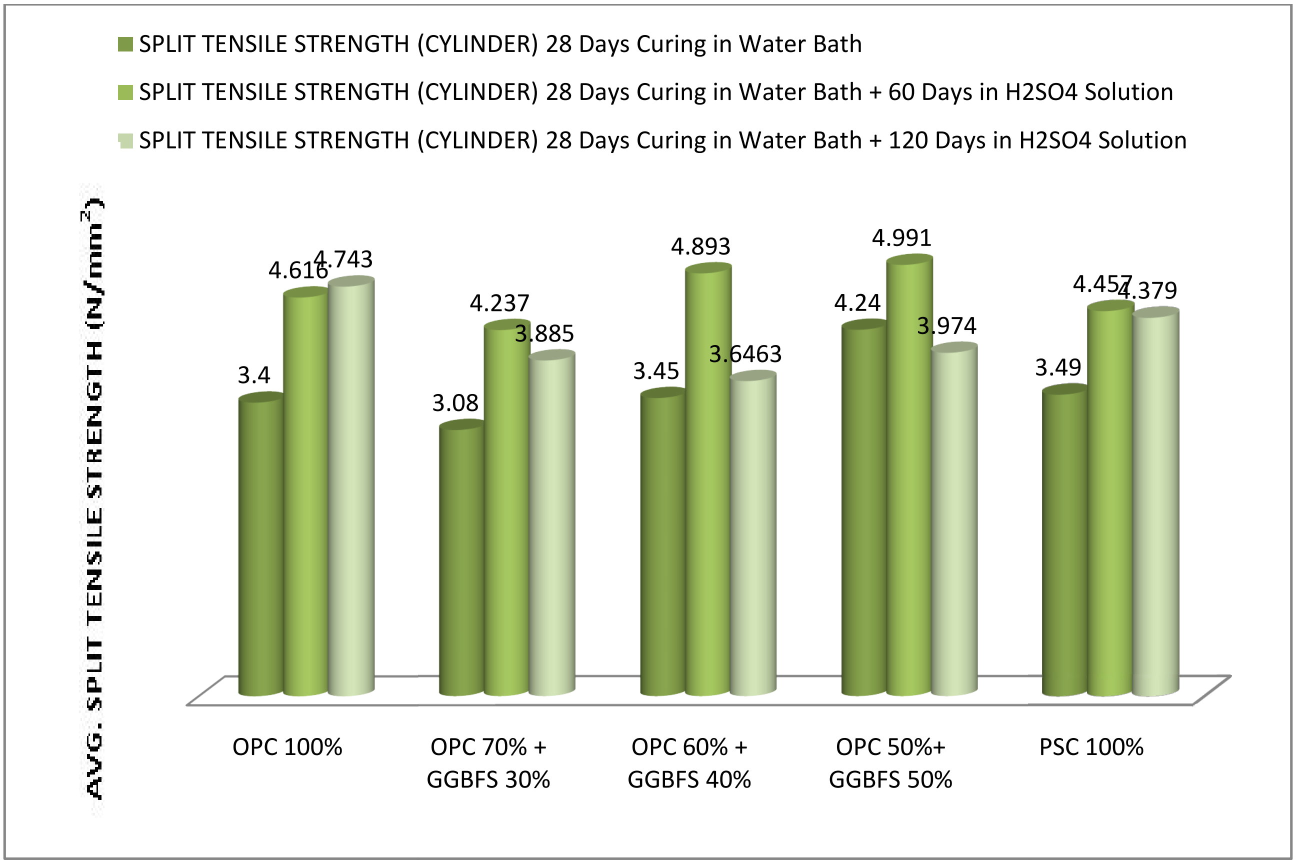


Fig. 6.3.5 Graphical representation of splitting tensile strength before and after immersion in H_2SO_4

Table 6.26 : Residual Splitting tensile strength of cylinder after immersion in H_2SO_4

MIX	28 Days Curing in Water Bath + 60 Days in H_2SO_4 Solution	28 Days Curing in Water Bath + 120 Days in H_2SO_4 Solution
OPC 100%	1.216	1.343
OPC 70% + GGBFS 30%	1.157	0.805
OPC 60% + GGBFS 40%	1.443	0.1963
OPC 50%+ GGBFS 50%	0.751	-0.266
PSC 100%	0.967	0.889

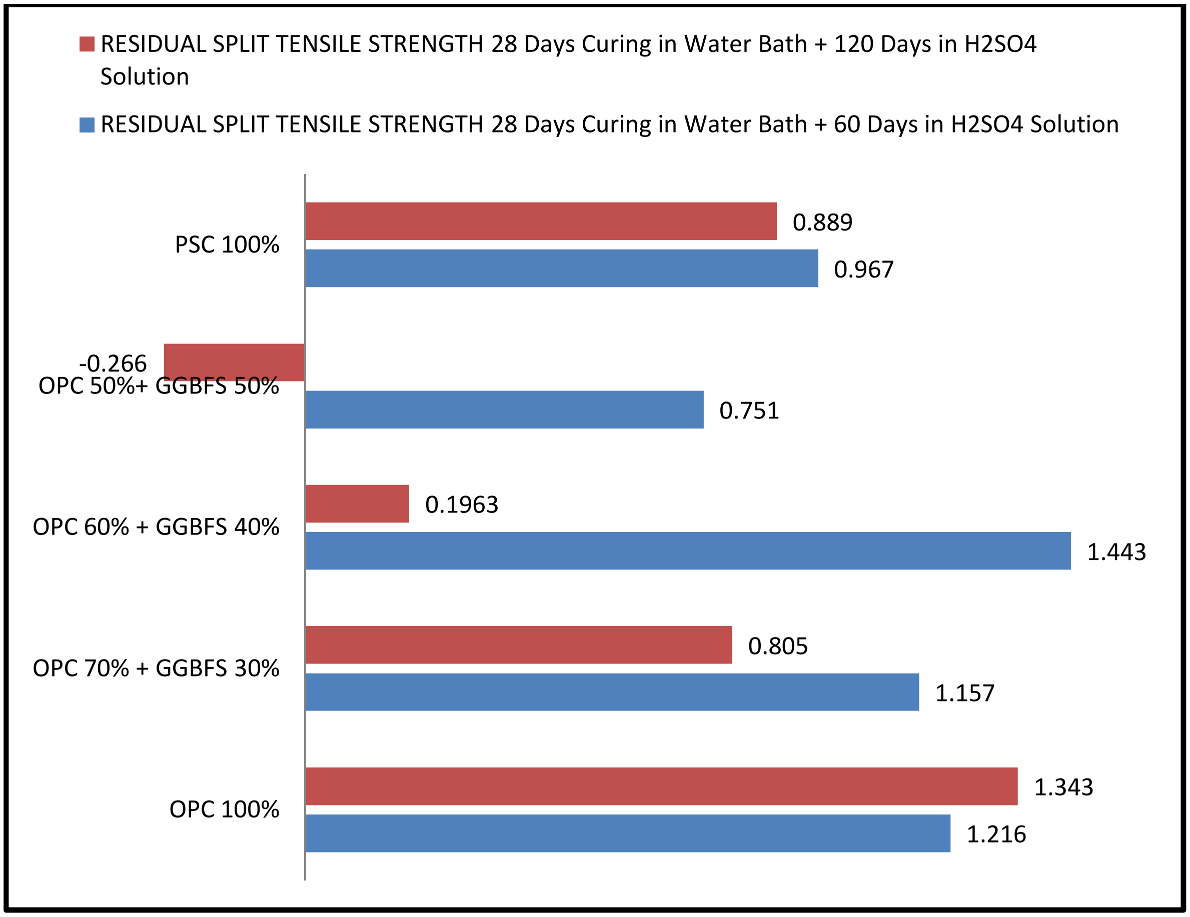


Fig. 6.3.6 Graphical representation of residual splitting tensile strength after immersion in H_2SO_4

Table 6.27 : Flexural strength of beam before and after immersion in H_2SO_4

MIX	28 Days Curing in Water Bath	28 Days Curing in Water Bath + 60 Days in H2SO4 Solution	28 Days Curing in Water Bath + 120 Days in H2SO4 Solution
OPC 100%	8.50	8.25	8.50
OPC 70% + GGBFS 30%	7.25	7.00	7.50
OPC 60% + GGBFS 40%	7.50	6.50	6.75
OPC 50%+ GGBFS 50%	8.50	7.00	6.75
PSC 100%	6.00	8.50	7.25

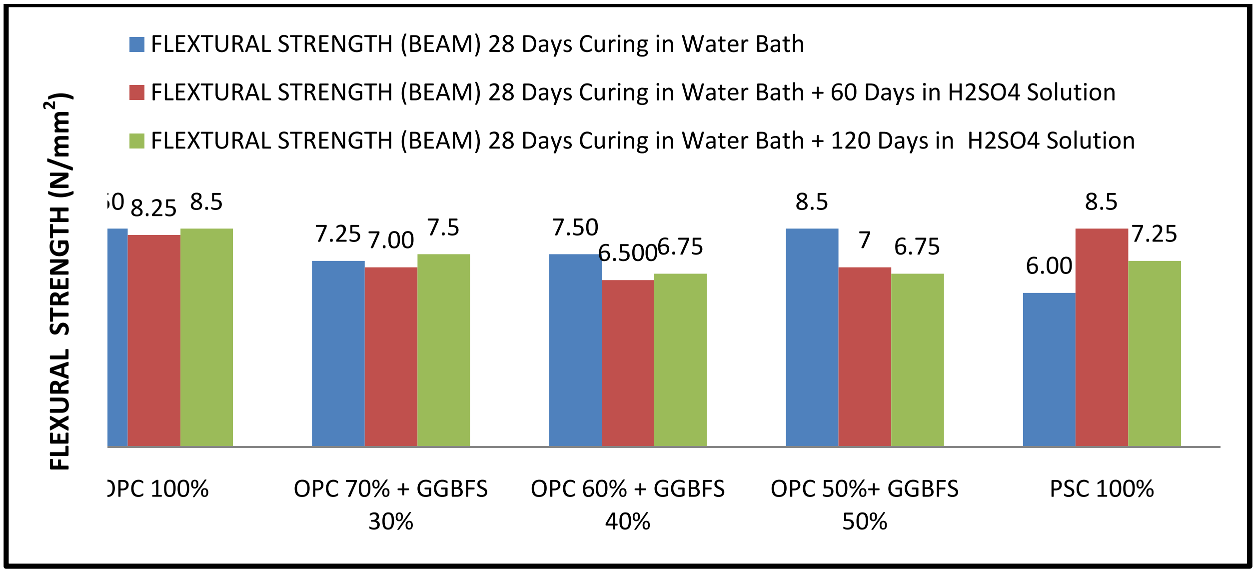


Fig. 6.3.7 Graphical representation of Flexural strength of beam before and after immersion in H_2SO_4

Table 6.28 : Residual Flexural strength of beam after immersion in H_2SO_4

MIX	28 Days Curing in Water Bath + 60 Days in H2SO4 Solution	28 Days Curing in Water Bath + 120 Days in H2SO4 Solution
OPC 100%	-0.25	0.00
OPC 70% + GGBFS 30%	-0.25	0.25
OPC 60% + GGBFS 40%	-1.00	-0.75
OPC 50%+ GGBFS 50%	-1.50	-1.75
PSC 100%	2.50	1.25

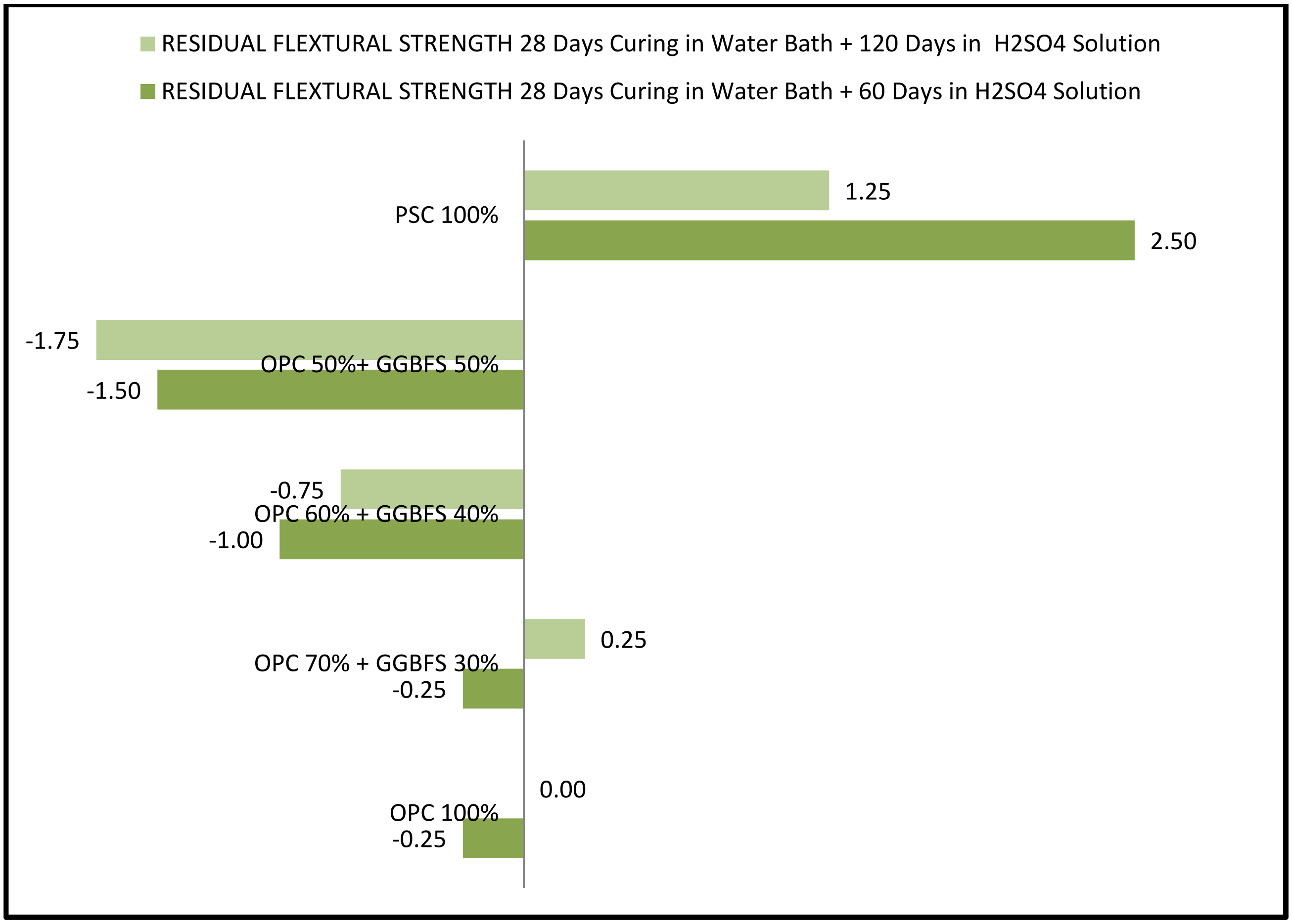


Fig. 6.3.8 Graphical representation of residual flexural strength of beam after immersion in H_2SO_4

Table 6.29: **Change in % weight of cube after immersion in H_2SO_4**

MIX	Change in % weight after 60 days	Change in % weight after 120 days
OPC 100%	-0.0150	-0.015
OPC 70% + GGBFS 30%	-0.0212	-0.023
OPC 60% + GGBFS 40%	0.0020	0.010
OPC 50%+ GGBFS 50%	0.0247	0.0173
PSC 100%	0.0036	0.0141

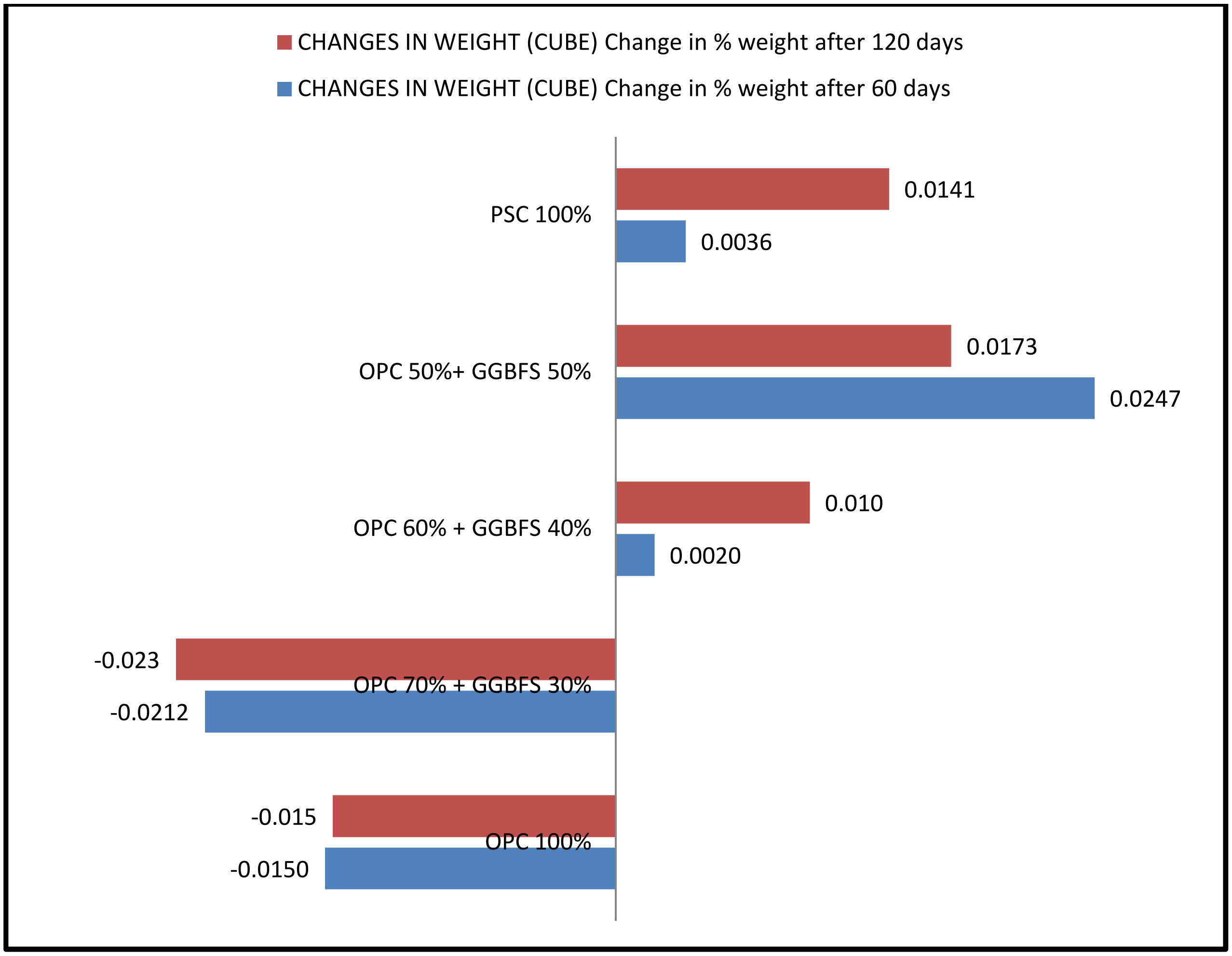


Fig. 6.3.9 Graphical representation of Change in % weight of cube after immersion in H_2SO_4

Table 6.30: Change in % weight of cylinder after immersion in H_2SO_4

MIX	Change in % weight after 60 days	Change in % weight after 120 days
OPC 100%	-0.025	-0.016
OPC 70% + GGBFS 30%	0.021	-0.017
OPC 60% + GGBFS 40%	0.006	-0.059
OPC 50%+ GGBFS 50%	0.011	0.027
PSC 100%	0.004	0.03

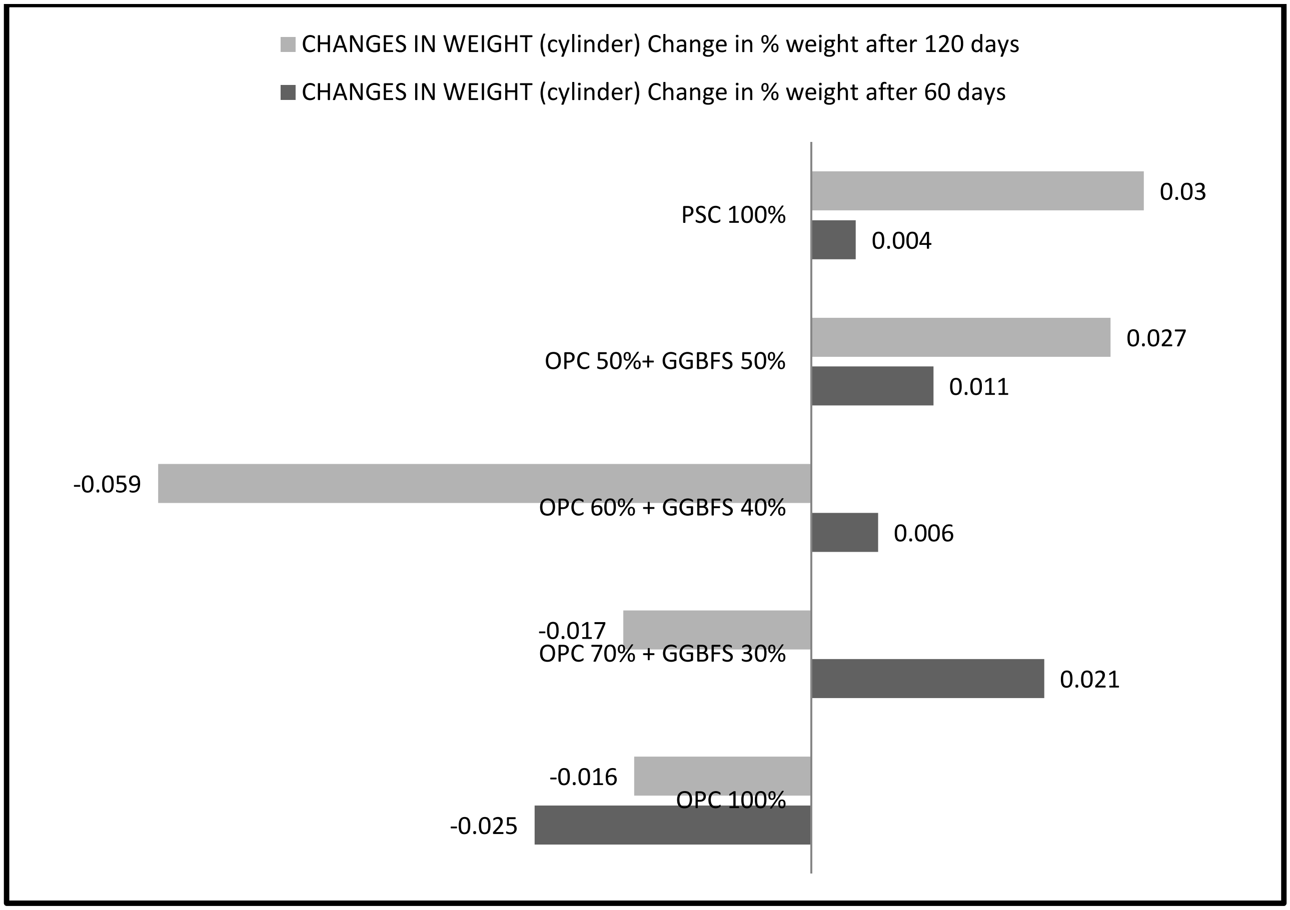


Fig. 6.3.10 Graphical representation of Change in % weight of cylinder after immersion in H_2SO_4

Table 6.31: Change in % weight of beam after immersion in H_2SO_4

MIX	Change in % weight after 60days	Change in % weight after 120days
OPC 100%	-0.015	-0.0183
OPC 70% + GGBFS 30%	0	0.0219
OPC 60% + GGBFS 40%	0.007	0.0815
OPC 50%+ GGBFS 50%	-0.001	0.0084
PSC 100%	0.011	0.0184

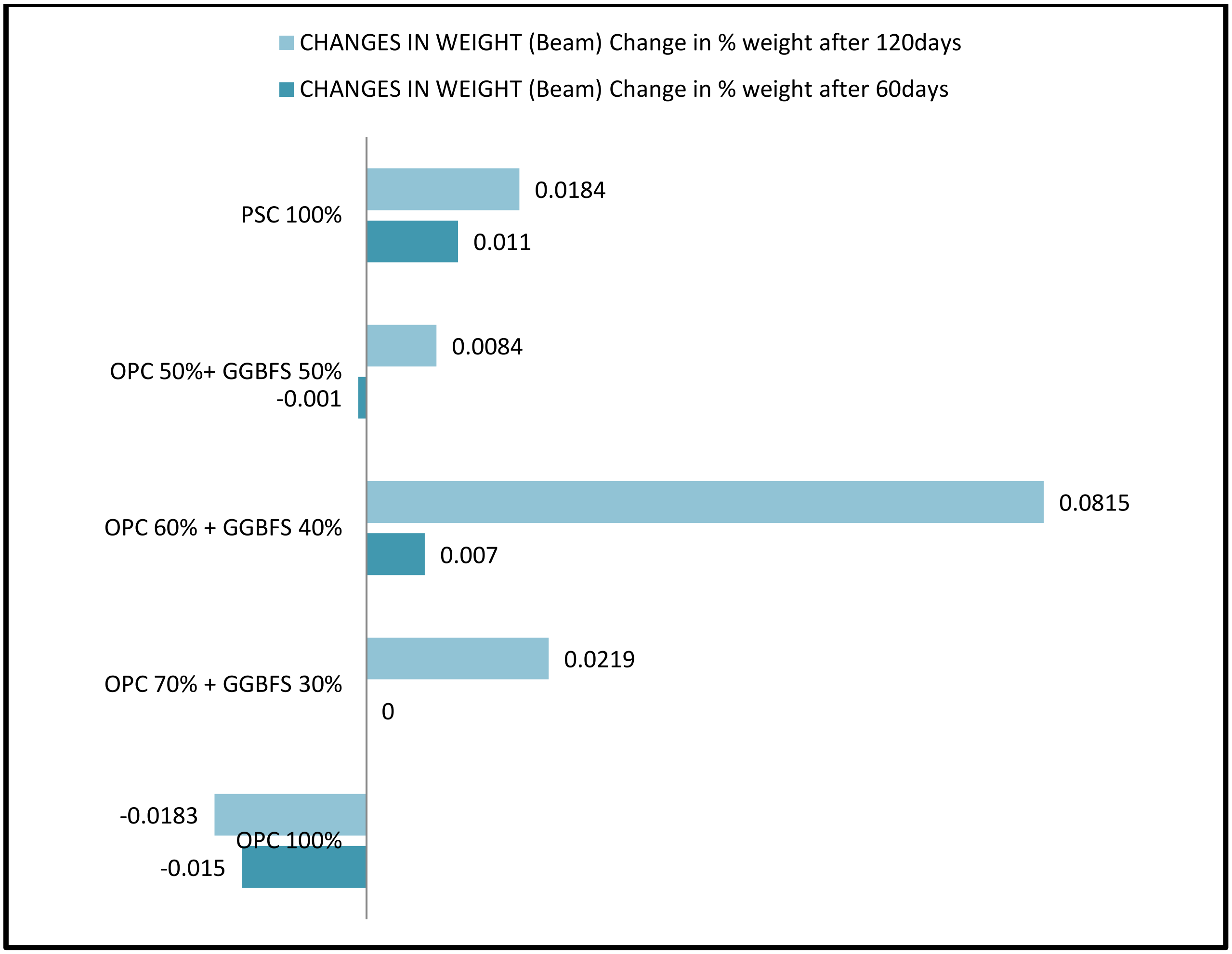


Fig. 6.3.11 Graphical representation of Change in % weight of beam after immersion in H_2SO_4

Table 6.32.: Half cell potential value (-ve) before and after immersion in H_2SO_4

MIX	28 Days Curing in Water Bath	28 Days Curing in Water Bath + 60 Days in H2SO4 Solution	28 Days Curing in Water Bath + 120 Days in H2SO4 Solution
OPC 100%	166.00	345.00	429.55
OPC 70% + GGBFS 30%	278.00	228.00	180.33
OPC 60% + GGBFS 40%	254.00	292.00	160.66
OPC 50%+ GGBFS 50%	147.60	226.89	257.89
PSC 100%	377.50	300.70	266.11

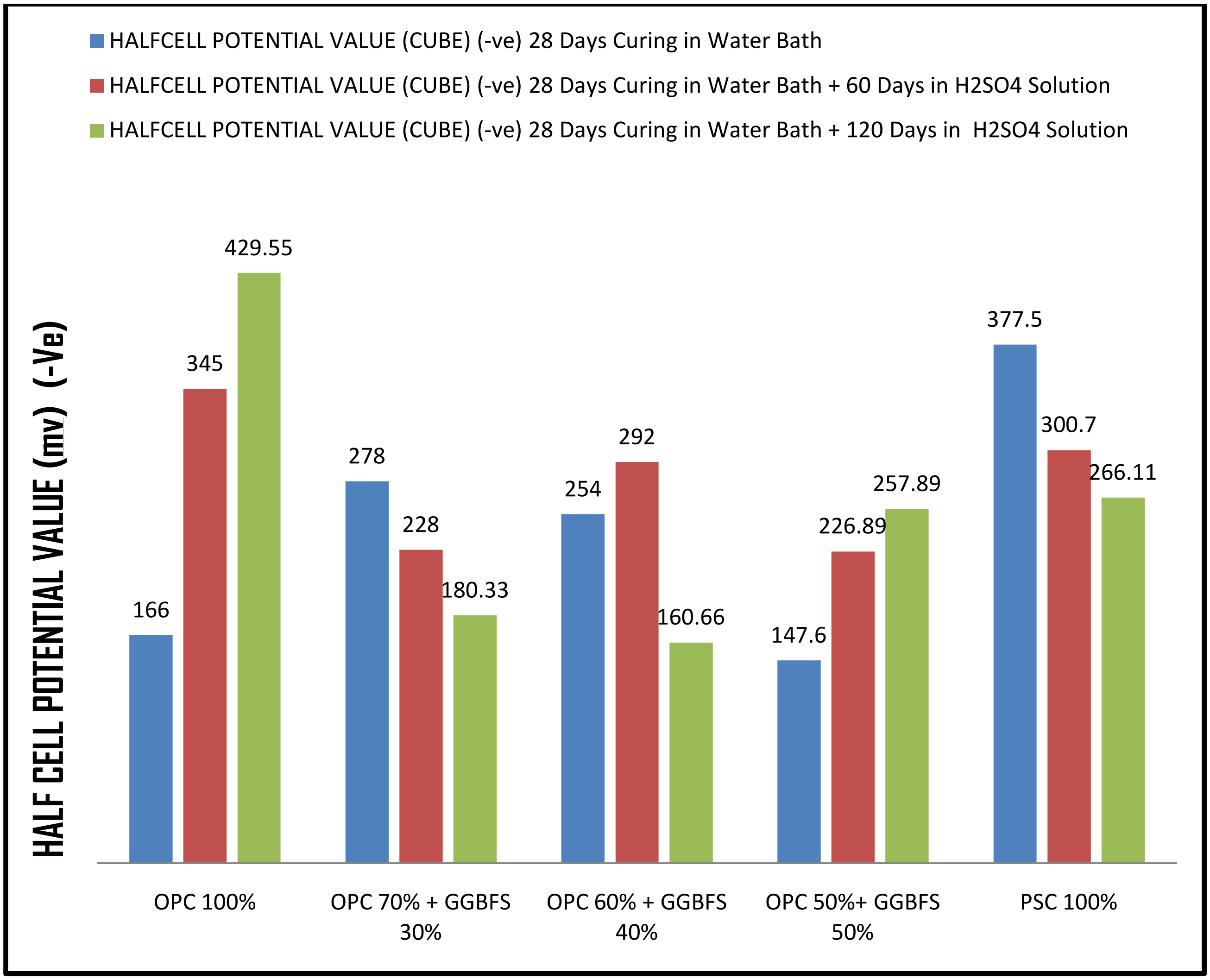


Fig. 6.3.12 Graphical representation of Half cell potential value (-ve) before and after immersion in H_2SO_4

6.3.1 Observation of result:

Exposed condition (Water curing for 28 Days + 4% H_2SO_4 solution for 60 days and 120day respectively)

1. The result illustrated in Table 6.20 and figure 6.3.1explain the compressive strength between the concrete immersed in H_2SO_4 for 60days and 120days and standard curing of concrete. The figure show the decrease of strength immersed in H_2SO_4 relative to the strength of curing with water on all concrete mix, except 100% PSC which shows higher strength after 60 days acid curing. it is also clear from the fig that replacement of 30% GGBFS shows an higher value of strength decrease when compared with the 28days water curing. The detrimental effect of H_2SO_4 in case of lower GGBFS content than other two replacements is high, and in case of 120 days curing strength is decreased in all the mixes. As sulphuric acid acts.

2. Residual strength figure 6.3.2 after H_2SO_4 exposure is decreasing in all type of mixes while comparing with 100% OPC mix with the other mixes 100%OPC gives better result. Also the 40% and 50% GGBFS replacement gives a low loss of strength than 30% GGBFS replacement. With percentage increase in GGBFS up to 50% replacement after 60 days $MgSO_4$ curing. Thus it can be concluded that for durability purpose of concrete in H_2SO_4 a replacement of40% GGBFS and 50% can serve the intended purpose.

3. According to IS 13311(Part 1) UPV value more than 4.5 km/Sec signifies excellent quality concrete. Here in the table 6.22 and 6.23 and fig 6.3.3 and 6.3.4 it is observed that only 40% GGBFS replacement and 100% PSC concrete have the UPV value less than 4.5 km/Sec after 60 days of acid curing. After 120 days acid exposure 50% GGBFS replacement show a lower value of UPV. So in the light of UPV data it can be said that 40% replacement of GGBFS is much durable than 50% replacement.

4. The result illustrated in Table and figure 6.3.5 explain that splitting tensile strength between the concrete immersed in H_2SO_4 for 60days and 120 days and standard curing of concrete. The figure show the values of strength immersed in H_2SO_4 relative to the strength of curing with water 100% OPC has more tensile strength value than 30% GGBFS replacement but less than the other two type of replacement. After 60 days of acid immersion the tensile strength increases in all the mix, but after 120 days immersion it decreases in all the mixes except 100% OPC but not below the initial splitting tensile strength i.e 28days strength except 50% GGBFS replacement.

5. In terms of tensile strength 100% OPC and 100% PSC is performing well in acid immersion than the supplementary cementitious material.

6. Residual tensile strength 6.3.6 after 60 days H_2SO_4 exposure is increasing for each of mixes also after 120 days exposure its decreases but not less that the initial strength only in case of 50 % replacement after 120 days it is less than the initial strength. So in context of durability in terms of tensile strength upto40% replacement can be choose, though 30% mixes is more reliable.

7. The result illustrated in Table and figure 6.3.7 explains that flexural strength between the concrete immersed in H_2SO_4 for 60days and 120days and standard curing of concrete. The figure show the effect of H_2SO_4 solution on flexural strength is detrimental in 50% GGBFS replacement. in case of 60 days immersion a decrease in flexural strength is taken place except for 100% PSC but after 120 days curing 30% replacement and also 100% PSC shows an increase in flexural strength than their initial flexural strength.. For long time exposure 30% replacement 100% OPC shows an positive result other than 50% and 100% PSC.
8. In fig 6.3.8 Residual tensile strength after H_2SO_4 exposure is only positive for PSC .for long term exposure 30% GGBFS shows an increase in residual strength.

9. The percentage change in weight in case of cube cylinder cylinder and beam having very small value and most of the mixes it is in the decreasing tendency. its is due to the aggressive nature of sulphuric acid solution.

10. Half-cell potential values table (6.31) were increasing in case of 100% OPC but for the other mixes the potential decreases after acid exposure. At 0%, 30%, 40% and 50% GGBFS replacements the half cell potentials are -166, -278, -254 and -147.6 mill Volts respectively. But after acid exposure, of 60 days potential values are -345, -228, -292 and -227 mV respectively and after 120 days potential values are -429, -180, -160 and -257 mV respectively.

11. When comparing the values of the half cell potentials with the 100% PSC mix the value is decreasing with the passage of time similar pattern of decrease is found in 30% GGBFS replacement.

CHAPTER - 7

CONCLUSION

7.1. Conclusion of this experimental work

1. By replacing Ordinary Portland cement with GGBFS up to 30% of cementitious material, sustainable concrete can be made with required strength as compared to using only OPC. So higher grade of sustainable concrete can be made by part replacement of cement with unprocessed fly ash having strength more or equal to traditional concrete.

2. If the splitting tensile strength and flexural strength requirement is high we can replace the 40% of cementitious material by GGBFS.
3. From the sorptivity result it is established that 100% PSC gives the maximum value of sorptivity index thus it is the most permeable mix. Replacement of OPC up to 40% GGBFS almost have the same value of permeability compared to 100% OPC.

3. When GGBFS is used and placed in $MgSO_4$ solution compressive strength, splitting tensile strength is increased for 40% replacement the flexural strength result is also satisfactory. So using GGBFS up to 40% in sea coast area can be beneficial than OPC and PSC in case of durability concern.

4. It is observed that when GGBFS is used as partial replacement of cement the residual strength increases that is strength loss minimizes. So using GGBFS we can reduce the deterioration of concrete with respect sulphate attack.

5. When GGBFS is used and placed in H_2SO_4 solution compressive strength, splitting tensile strength is increased for 40% replacement the flexural strength result is also satisfactory. So using GGBFS up to 40% in area prone to sulphuric acid exposure can be beneficial than OPC in case of durability concern and also in the point of economical mix.

6. PSC also shows good durability in case of sulphuric acid exposure compared to $MgSo_4$ exposure.

7. In Half-cell potential test non-corroded steels have displayed widespread range of potential values. Potential drops before and after acid exposure of same sample reveals that corrosion in steel not started in acid exposure. So corrosion susceptibility of sustainable concretes by replacement of GGBFS is possible up to 40%replacement in case of acidic exposure.

7.2 Limitation of study:

1. Due to limited period of time, percentage variations in replacements of sustainable materials were insufficient as compared to requirement. More variations were needed.

2. Exposure was done for 60 days and 120 days only which is insufficient to assess long term durability. In long period durability behavior of concrete may be changed.

3. For limited time of acid exposure, high acid concentration (pH =0.30) is used. If the experiment was done with 5 to 6 pH of acid then difference may not arise in short days. But in reality this concentration (pH =0.30) rarely arises with concrete surface.

4. Due to limited period of time, Studying Scanning Electron Microscope images of different concrete mixes can be done for observing the changes in surface topography at different exposure conditions can not be possible.

7.3 Future scope of work:

1. Experiments for replacement percentages up to 100% may be done to see how strength varies.

2. Long term durability (for minimum of 1 year) in acid exposure may be performed to analyze how much residual strength remains in comparison to traditional concrete in same exposure.

3. This experiment is done in for a fixed concentration of sulphuric acid and magnesium sulphate solution. But experiments in different concentrations of acid solution are needed.

5. This experiment was performed with fixed amount of (0.8%) water reducing admixture. But water demand varies with different percentage of replacements. Sometimes mix getting flow able. So to maintain required workability and thus strength of concrete percentage of water reducing admixture is also to be varied and optimized. This optimization is to be find out.

6. the strength of concrete increases with partial replacements of cement with GGBFS. For a fixed target strength redesign of mix is needed to find the specific amount cementitious material.

7. EDM and SEM study, Chloride attack, fire resistance, thermal properties and other different properties should be investigated in these concrete mixes.

ANNEXURE-1
MIX-DESIGN CALCULATION
(Based on IS 10262 : 2009)

Sample calculation of mix design for Mix Type-1
(When 100%OPC is used)

a) Maximum nominal size of aggregate : 20mm

b) Exposure condition : Extreme

c) Minimum cement content : 360 Kg (For extreme Exposure)

d) Maximum cement content : 450 kg (Clause 8.2.4.2 of IS 456)

e) Maximum water cement ratio : 0.4

f) Workability : high

g) Type of aggregate : Crushed angular

h) Chemical Admixture Type : Super plasticizer

i) Degree of supervision : Good

Grade designation = M 45

Type of cement = OPC 53 Grade

Target Mean strength = f_{ck} + (1.65) S
= 45+1.65 x 5 = 53.25 N/mm2

W/C ratio = 0.4

Maximum water content limit = 186.000 Kg

Based on trial using chemical admixture water content Adopted = 167.400 Kg

Cement content =167.4×0.4 = 418.500

Adopt cement content = 420Kg

Volume of cement = 420/3120=0.135 m^3

Volume of Water = 0.168 m^3

Weight of water = 168 Kg

Chemical admixture (Master Rheobuild 1125) @.8% by weight of cement = 0.008 x 420 =3.360 Kg

Chemical admixture by volume = 3.360/1240= 0.0027 m^3 = 2.710 litre

Volume of (CA+FA) = 1-Volume of (Cement+Water+Admixture)

= 1-(0.135+0.168+.0027) = 0.695 m^3

For W/C ratio of 0.40, Vol of CA = 0.660 m^3

Volume of CA = 0.695 × 0.660 =0.458 m^3

Weight of CA = (0.458/ 2820) =1292.93 Kg

Weight of 20mm down size CA @60% of CA = 775.76 kg

Weight of 10mm down size CA @40% of CA = 517.17 kg

Volume of FA = Vol of (CA+FA) - Vol of CA
= (0.695-0.458) =0.236 m^3

Weight of sand = 0.236/2660 =628.264 Kg

Mix Design Summary

OPC : 420 Kg

Water : 168 Kg

20mm down Stone chips : 776 kg

10mm down stone chips : 517 kg

Zone-III sand : 628 Kg

Admixture (Master Rheobuild 1125) : 2.710 liter

Sample calculation of mix design for Mix Type-2
(When 70% OPC and 30% GGBFS is used)

a) Maximum nominal size of aggregate : 20mm

b) Exposure condition : Extreme

c) Minimum cement content : 360 Kg (For extreme Exposure)

d) Maximum cement content : 450 kg (Clause 8.2.4.2 of IS 456)

e) Maximum water cement ratio : 0.4

f) Workability : high

g) Type of aggregate : Crushed angular

h) Chemical Admixture Type : Super plasticizer

i) Degree of supervision : Good

Grade designation = M 45

Type of cement = OPC 53 Grade

Type of supplementary cementitious material =GGBFS

Target Mean strength = f_{ck} + (1.65)S
= 45+1.65x5= 53.25 N/mm2

W/C ratio = 0.4

Maximum water content limit = 186.000 Kg

Based on trial using chemical admixture water content Adopted = 167.400 Kg

Cement content =167.4×0.4 = 418.500

Adopt cement content = 420Kg

OPC content =0.7× 420 = 294 Kg

GGBFS content = (420-294) = 126 Kg

Volume of cement = 294/3120=0.094 m^3

Volume of GGBFS = 126/2850 = 0.044 m^3

Volume of Water = 0.168 m^3

Weight of water = 168 Kg

Chemical admixture (Master Rheobuild 1125)
@.8% by weight of cement = 0.008 x 420 =3.360 Kg

Chemical admixture by volume = 3.360/1240= 0.0027 m^3 = 2.710 liter

Volume of (CA+FA) = 1-Volume of (Cement+ GGBFS + Water + Admixture)
= 1-(0.094+0.044+0.168+.0027) =0.691 m^3

For W/C ratio of 0.40, Vol of CA = 0.660 m^3

Volume of CA = 0.691 × 0.660 =0.456 m^3

Weight of CA = (0.456/ 2820) =1285.81 Kg

Weight of 20mm down size CA @60% of CA = 771.48 kg

Weight of 10mm down size CA @40% of CA = 514.32 kg

Volume of FA = Vol of (CA+FA)-Vol of CA
= (0.691-0.456) = 0.235 m^3

Weight of sand = 0.235/2660 =624.804 Kg

Mix Design Summary

OPC : 294 Kg

GGBFS : 126 Kg

Water : 168 Kg

20 mm down Stone chips : 771 kg

10 mm down stone chips : 514 kg

Zone-III sand : 625 Kg

Admixture(Master Rheobuild 1125) : 2.710 liter

Sample calculation of mix design for Mix Type-3
(When 60% OPC and 40% GGBFS is used)

a) Maximum nominal size of aggregate : 20mm

b) Exposure condition : Extreme

c) Minimum cement content : 360 Kg (For extreme Exposure)

d) Maximum cement content : 450 kg (Clause 8.2.4.2 of IS 456)

e) Maximum water cement ratio : 0.4

f) Workability : high

g) Type of aggregate : Crushed angular

h) Chemical Admixture Type : Super plasticizer

i) Degree of supervision : Good

Grade designation = M 45

Type of cement = OPC 53 Grade

Type of supplementary cementitious material =GGBFS

Target Mean strength = $f_{ck} + (1.65)S$
= 45+1.65x5= 53.25 N/mm2

W/C ratio = 0.4

Maximum water content limit = 186.000 Kg

Based on trial using chemical admixture water content Adopted = 167.400 Kg

Cement content =167.4×0.4 = 418.500

Adopt cement content = 420Kg

OPC content =0.6× 420 = 252 Kg

GGBFS content = (420-252) = 168 Kg

Volume of cement = 252/3120=0.081 m^3

Volume of GGBFS = 168/2850 = 0.059 m^3

Volume of Water = 0.168 m^3

Weight of water = 168 Kg

Chemical admixture (Master Rheobuild 1125)

@.8% by weight of cement = 0.008 x 420 =3.360 Kg

Chemical admixture by volume = 3.360/1240= 0.0027 m^3 = 2.710 litre

Volume of (CA+FA) = 1-Volume of (Cement+ GGBFS + Water + Admixture)
= 1- (0.081+0.059+0.168+.0027) =0.690 m^3

For W/C ratio of 0.40, Vol of CA = 0.660 m^3

Volume of CA = 0.690 × 0.660 =0.455 m^3

Weight of CA = (0.455/ 2820) =1283.43 Kg

Weight of 20mm down size CA @60% of CA = 770.06 kg

Weight of 10mm down size CA @40% of CA = 513.34 kg

Volume of FA = Vol of (CA+FA)-Vol of CA
= (0.690-0.455) = 0.235 m^3

Weight of sand = 0.235/2660 =624.804 Kg

Mix Design Summary

OPC : 252 Kg
GGBFS : 168 Kg
Water : 168 Kg
20mm down Stone chips : 770 kg
10mm down stone chips : 513 kg
Zone-III sand : 625 Kg
Admixture(Master Rheobuild 1125) : 2.710 liter

Sample calculation of mix design for Mix Type-4
(When 50% OPC and 50% GGBFS is used)

a) Maximum nominal size of aggregate : 20mm

b) Exposure condition : Extreme

c) Minimum cement content : 360 Kg (For extreme Exposure)

d) Maximum cement content : 450 kg (Clause 8.2.4.2 of IS 456)

e) Maximum water cement ratio : 0.4

f) Workability : high

g) Type of aggregate : Crushed angular

h) Chemical Admixture Type : Super plasticizer

i) Degree of supervision : Good

Grade designation = M 45

Type of cement = OPC 53 Grade

Type of supplementary cementitious material =GGBFS

Target Mean strength = f_{ck} + (1.65)S
= 45+1.65x5= 53.25 N/mm2

W/C ratio = 0.4

Maximum water content limit = 186.000 Kg

Based on trial using chemical admixture water content Adopted = 167.400 Kg

Cement content =167.4×0.4 = 418.500

Adopt cement content = 420 Kg

OPC content =0.5× 420 = 210 Kg

GGBFS content = (420-210) = 210 Kg

Volume of cement = 210/3120=0.067 m^3

Volume of GGBFS = 210/2850 = 0.074 m^3

Volume of Water = 0.168 m^3

Weight of water = 168 Kg

Chemical admixture (Master Rheobuild 1125)
@.8% by weight of cement = 0.008 x 420 =3.360 Kg

Chemical admixture by volume = 3.360/1240= 0.0027 m^3 = 2.710 litre

Volume of (CA+FA) = 1-Volume of (Cement + GGBFS
+Water + Admixture)
= 1-(0.067+0.074+0.168+.0027) =0.688 m^3

For W/C ratio of 0.40, Vol of CA = 0.660 m^3

Volume of CA = 0.688 × 0.660 =0.454 m^3

Weight of CA = (0.454/ 2820) =1281.06 Kg

Weight of 20mm down size CA @60% of CA = 768.64 kg

Weight of 10mm down size CA @40% of CA = 512.42 kg

Volume of FA = Vol of (CA+FA) - Vol of CA
= (0.688-0.454) = 0.234 m^3

Weight of sand = 0.235/2660 = 622.497 Kg

Mix Design Summary

OPC : 210 Kg

GGBFS : 210 Kg

Water : 168 Kg

20mm down Stone chips : 769 Kg

10mm down stone chips : 512 Kg

Zone-III sand : 622.5 Kg

Admixture(Master Rheobuild 1125) : 2.710 liter

Sample calculation of mix design for Mix Type-5
(When 100% PSC is used)

a) Maximum nominal size of aggregate : 20mm

b) Exposure condition : Extreme

c) Minimum cement content : 360 Kg (For extreme Exposure)

d) Maximum cement content : 450 kg (Clause 8.2.4.2 of IS 456)

e) Maximum water cement ratio : 0.4

f) Workability : high

g) Type of aggregate : Crushed angular

h) Chemical Admixture Type : Super plasticizer

i) Degree of supervision : Good

Grade designation = M 45

Type of cement = PSC 33 Grade

Target Mean strength = $f_{ck} + (1.65)S$
= 45+1.65x5= 53.25 N/mm2

W/C ratio = 0.4

Maximum water content limit = 186.000 Kg

Based on trial using chemical admixture water content Adopted = 167.400 Kg

Cement content =167.4×0.4 = 418.500

Adopt cement content = 420Kg

Volume of cement = 420/2900=0.145 m^3

Volume of Water = 0.168 m^3

Weight of water = 168 Kg

Chemical admixture (Master Rheobuild 1125) @.8% by weight of cement = 0.008 x 420 =3.360 Kg

Chemical admixture by volume = 3.360/1240= 0.0027 m^3 = 2.710 litre

Volume of (CA+FA) = 1-Volume of (Cement+Water+Admixture)
= 1-(0.145+0.168+.0027) =0.684 m^3

For W/C ratio of 0.40, Vol of CA = 0.660 m^3

Volume of CA = 0.684 × 0.660 =0.452 m^3

Weight of CA = (0.452/ 2820) =1273.92 Kg

Weight of 20mm down size CA @60% of CA = 764.35 Kg

Weight of 10mm down size CA @40% of CA = 509.57 Kg

Volume of FA = Vol of (CA+FA) -Vol of CA
= (0.695-0.458) =0.233 m^3

Weight of sand = 0.236/2660 =619.028 Kg

Mix Design Summary

OPC : 420 Kg
water : 168 Kg
20mm down Stone chips : 764 Kg
10mm down stone chips : 510 Kg
Zone-III sand : 619 Kg
Admixture(Master Rheobuild 1125) : 2.710 liter

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