STUDY OF ACID RESISTANCE OF SUSTAINABLE BLENDED CONCRETE

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 **"Study of acid resistance of sustainable blended concrete "** has been prepared by Sourav Dey (Examination Roll No: M6CNE19012 and Registration No: 105564 of 2008-09) 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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Declaration of Originality and Compliance of Academic Ethics

We hereby declare that the thesis entitled **"Study of acid resistance of sustainable blended concrete** "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.**

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ABSTRACT

Sustainable Development can be defined 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. So sustainable development cannot be achieved if the environment is not protected.

Cement is one of the most important civil engineering construction materials. Production of cement is a major cause of air pollution. Each ton of cement produce one ton of CO_2 which is a greenhouse gas, and is released into the atmosphere. Therefore any effort to reduce the use of cement is a sustainable development. So with partially replacing the cement by Fly ash, Natural prozzolonas, Silica fume, Rice husk ash, Blast furnace slag, Metakaoline, etc. we can make concrete a more environmental friendly material. 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. And reducing the production of cements will therefore be a contribution towards the sustainable development. Such durability increase can be achieved by choosing appropriate mix designs and selecting suitable aggregates and admixtures. In this experiment Ordinary Portland cement is partially replaced by Fly ash, to make sustainable concrete.

The main objective of this experimental study is to conduct a comparative Strength & Durability investigation related to acid (Nitric acid and Hydrochloric acid) resistivity on High volume(30%,40% &50%) site mixed sustainable Fly ash based blended(Flyash+OPC) cement concrete and commercially available OPC and PPC cement concrete of different grades and to find the optimal mix design of high volume site mixed Fly ash based concrete which can be used economically and commercially.

Compressive strength of cubes, Splitting tensile strength of cylinders, and Flexural strength of beams of different mixes have been compared to see how the concrete strength differs. In addition different types of non-destructive tests such as Ultrasonic pulse velocity(UPV) test, Half-cell potential tests etc have also been performed on the concrete samples for better analysis of their strength and durability characteristics.

These experiments may be treated as small initiatives towards better environment and sustainable development programme.

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Chapter-1

INTRODUCTION

1.1 General:

Construction industry is one of the most important industry in the world as numbers of different Civil engineering structures such as Buildings, Bridges, Dams, Barrages etc are being continuously constructed all around the world. Concrete is the main element for construction industry. But for a variety of reasons concrete is not sustainable as the principal binder in concrete is Portland cement, the production of which causes emission of green house gas which is the main causes of Global Warming and climate change, concrete consumes huge quantities of virgin or natural materials, and many concrete structures suffer from lack of durability which has an adverse effect on the resource productivity of the industry.

When concrete is exposed to different types of chemicals, the durability of concrete is quite influenced. There are a significant number of infrastructures in the world which are constantly under corrosion from different types of chemicals such as acid. The socioeconomic losses associated with infrastructure deterioration due to acid attack exceed billions of dollars all around the world in Petrochemical, Oil Refinery, Sewerage treatment plant, Steel plant, Chemical factory etc. due to reduction of strength and durability properties.

The main reason for that is Concrete is susceptible to acid attack because of its alkaline nature. The components of the cement paste break down during contact with acids.

Most pronounced is the dissolution of calcium hydroxide which occurs according to the following reaction:

$$2HX + Ca(OH)_2 \dashrightarrow CaX_2 + 2H_2O$$

(X is the negative ion of the acid)

1.2 Needs of additives and other building materials for making sustainable concrete:

Sustainable concrete can be made by using currently available resources in such a manner that it will not affect the required needs of our future generations. Thus sustainable concrete may be produced by

1. Minimising use of ordinary portland cement as production of OPC which emits enormous amount of greenhouse gases, consumes vast amounts of limestone, consumes large amount of energy and using supplementary cementitious materials or additives.
2. Using supplementary fine aggregates in place of sand because extraction of sand, gravel, crushed rock, which are natural products cause disturbance to ecological system and disrupt the natural equilibrium.
3. Using durable concrete to make structure maintenance free and thus reducing further cement consumption.
4. Using Industrial wastewaters and non-potable waters in place of potable municipal water for mixing concrete unless proven harmful by testing.

Fly Ash, Ground-granulated slag (GGBS), Silica fume, Rice Husk Ash are very good supplementary cementitious materials which are already used replacing OPC minimising the production of OPC. The use of these materials fulfil the sustainability issues as well as meets the requirement of reduction the quantity of such materials which are actually accumulates all around the world as solid waste if not used. These materials are used during the production of cement as well as used directly as additives in the concrete at site. Now a days the the quantity used of these materials are not very large. Our aim should be enhance the use of these materials in the cement and concrete industry.

1.3 Fly ash as additive:

The main objective of using fly ash in the concrete is to get durable concrete at reduced cost. fly Ash based concrete have a greater long duration strength than ordinary controlled cement concrete. flyash is produced in a large quantity at different thermal power plants and having no production cost. So, flyash which have only carriage cost can be used in manufacturing of concrete economically.

The use of flyash in concrete is very effective as flyash reduces heat of hydration and thermal cracking, increases workability and reduces the water requirement for a given slump of concrete due to its spherical shape, reduces permeability by reducing capillary voids in the micro structure due to its small size, reduces corrosion of steel in RCC by reducing carbonation and Chloride attack of concrete, reduces Carbonation and sulphate attack by reducing permeability and excess released lime content, reduce the deleterious effect of released lime through pozzolanic reaction, reduces harmful expansion of concrete due to alkali- aggregate reaction through the reaction between the siliceous glass in fly ash and the alkali hydroxide of Portland cement paste and uncreative portion of fly ash act as micro aggregates and fills up the matrix to render packing effect and results in increased strength.

1.3.1. Chemical Composition of Flyash:

The major constituents of most of the fly ashes are Silica (SiO_2), alumina (Al_2O_3), ferric oxide (Fe_2O_3) and calcium oxide (CaO). The other minor constituents of the fly ash are Mg_2O_3, Na_2O, K_2O, SO_2 , MnO_2, TiO_2 and unburnt carbon. There is wide range of variation in the principal constituents - Silica (25-60%), Alumina (10-30%) and Ferric Oxide (5-25%). When the sum of these three principal constituents is 70% or more and reactive calcium oxide is less than 10% - technically the fly ash is considered as **siliceous fly ash** or class F fly ash. Such type of fly ash is produced by burning of anthracite or bituminous coal and possess pozzolanic properties. If the sum of these three constituent is equal or more than 50% and reactive calcium oxide is not less than 10%, fly ash will be considered as **Calcareous fly ash** also called as class C fly ash.
This type of fly ash is commonly produced by burning of lignite or sub-bituminous coal and possess both pozzolanic and hydraulic properties.

Siliceous fly ash characteristically contains a large part of silicate glass of high silica content and crystalline phases of low reactivity mullite, magnetite and quartz. The active constituents of class F fly ash is siliceous or alumino-silicate glass.
In calcareous or class C fly ash, the active constituents are calcium alumino-silicate glass, free lime (CaO), anhydrate ($CaSO_4$), tricalcium aluminate and rarely, calcium silicate.
The glassy materials of fly ash are reactive with the calcium and alkali hydroxides released from cement fly ash system and forms cementitious gel, which provide additional strength.

1.3.2. Physical Properties of Flyash:

The fly ash particles are generally glassy, solid or hollow and spherical in shape. The hollow spherical particles are called as cenospheres. The fineness of individual fly ash particle rage from 1 micron to 1 mm size. The fineness of fly ash particles has a significant influence on its performance in cement concrete. The fineness of particles is measured by measuring specific surface area of fly ash by Blaine's specific area technique. Greater the surface area more will be the fineness of fly ash. The other method used for measuring fineness of fly ash is dry and wet sieving. The specific gravity of fly ash varies over a wide range of 1.9 to 2.55.

1.3.3 Pozzolanic Properties of fly ash:

Pozzolanic activity of fly ash is an indication of the lime fly ash reaction. It is mostly related to the reaction between reactive silica of the fly ash and calcium hydroxide which produce calcium silicate hydrate (C-S-H) gel which has binding properties. The alumina in the pozzolana may also react in the fly ash lime or fly ash cement system and produce calcium aluminate hydrate, ettringite, gehlenite and calcium monosulpho-aluminate hydrate. Thus the sum of reactive silica and alumina in the fly ash indicate the pozzolanic activity of the fly ash.

Reaction of Flyash with Cement in Concrete:

Ordinary Portland Cement (OPC) is a product of four principal mineralogical phases. These phases are Tricalcium Silicate-C_3S (3CaO.SiO), Dicalcium Silicate – C_2S (2CaO.SiO), Tricalcium Aluminate- C_3A (3CaO.Al O) and Tetracalcium alumino-ferrite – C_4 AF(4CaO. Al_2O_3,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 and water are shown as under:

$2\ C_3S$ +	6H --------------→	$C_3S_2H_3$	+	3CH
Tricalcium silicate	Water	C-S-H gel		Calcium hydroxide

$2C_2S$ +	4H---------------→	$C_3S_2H_3$	+	CH
Dicalcium silicate	Water	C-S-H gel		Calcium hydroxide

The hydration products from C_3S and C_2S are similar but quantity of calcium hydroxide (lime) released is higher in C_3S as compared to C_2S.

The reaction of C_3A with water takes place in presence of sulphate ions supplied by dissolution of gypsum present in OPC. This reaction is very fast and is shown as under:

C_3A	+	$3(CSH_2)$ +	26H -----------------------→	$C_3\ A(CS)_3\ H_{32}$
Tricalcium alluminate		Gypsum	water	Ettringite
C_3A	+	CSH_2 +	10H -----------------------→	C_3ACSH_{12}
				Monosulphoaluminate hydrate

Tetracalcium alumino-ferrite forms hydration product similar to those of C_3A, with iron substituting partially for alumina in the crystal structures of ettringite and monosulpho-aluminate hydrate.

Above reactions indicate that during the hydration process of cement, lime is released out and remains as surplus in the hydrated cement. This leached out surplus lime renders deleterious effect to concrete such as make the concrete porous, give chance to the development of micro- cracks, weakening the bond with aggregates and thus affect the durability of concrete.

If fly ash is available in the mix, this surplus lime becomes the source for pozzolanic reaction with fly ash and forms additional C-S-H gel having similar binding properties in the concrete as those produced by hydration of cement paste. The reaction of fly ash with surplus lime continues as long as lime is present in the pores of liquid cement paste.

Chapter-2

LITERATURE REVIEW

2.1 General:

There are so many studies and investigations on the developments of different types of sustainable concrete are going on since the last few years. Studies on the durability of Sustainable High volume Flyash concretes in terms of resistance to acid attacks have also been done. Brief reviews on some of those papers are discussed here.

2.2 Literature Review:

With increase in percentage replacement of flyash in High volume flyash concrete(HVFC) early age strength of concrete for 7 days & 14 days decrease and 28 days strength increases upto 50% replacement of fly ash. The mass variation of the specimens also been studied for the concretes when immersed in acids. Early age strength of concrete i.e for 7 days & 14 days decreases with increase in percentage replacement of fly ash whereas the 28 days strength of concrete increases with increase in percentage replacement of fly ash upto 50%, Flexural strength of concrete is decreasing with increase of percentage replacement of flyash, The surface of the specimens was badly damaged and cement mortar was completely eaten up and coarse aggregates were clearly visible in case of Sulfuric acid attack and the deterioration effect of sulfuric acid was found more severe than Hydrochloric acid. The mass loss is more in M30 grade HVFC when compared to that of M40 grade HVFC when immersed in acids due to higher content of pozzolanic material in M40 than in M30 grades HVFC, The decrease in the average compressive strength and rate of decrease is more in M40 grade HVFC than that of in M30 grade when immersed in acid solutions.
M. Vaishnavi & M. Kanta Rao (2014).

High volume fly ash with 50% replacement which results in reduction in water content and increase in workability condition. There is an initial decrease in strength by 20% and after 28 days it attains more strength in compare to concrete made with ordinary Portland cement. Deflection, load carrying capacity in beam made with high volume flyash concrete also increases.
Mini Soman.,Sobha.K.(2014)

The long term compressive strength of grades M30 and M60 concretes increases for 30% fly ash replacement compared to ordinary concrete up to 91days of age however there is decrease in strength for 40% and 50% of fly ash based concrete compared to OPC based concrete at all curing periods.
Venkateswara Rao A., SrinivasaRao K.(2017).

Experiments performed on concretes made of high volumes of class F fly ash by replacing cement with 40%, 45%, and 50% of flyash respectively for examine the fresh concrete properties, compressive strength, splitting tensile and flexural strength after 28 days of curing. From the tests, it is concluded that class-F fly ash can suitably be used up to 50% level of replacement in concrete for use of precast elements as well as RCC construction.
Gunaseelan A., Ramalingam K. M.(2016).

A study has been done to determine the effect of high volume fly ash on concrete mechanical properties by replacing class F fly ash of 40% to 70% by weight of cement which were compared with plain concrete and are evaluated for 7, 28 and 56 days. From the experimental tests carried out, it has been noticed that at each replacement level of cement with fly ash, an increase in strength is observed with an increase in age. Replacement of 50% fly ash to cement is chosen as the optimum percentage from this study by considering the strength.
Sri Harsha G., BinimolBabu (2016).

The Performance of High Volume Fly Ash Concrete replacing cement with 55%, 65%, 75%, and 85% fly ash ware examined and evaluated and the compressive strength of concretes determined. The results showed that the replacement of 55% Flyash gives the best value on compressive strength after 90 days of curing. On 55% and 65% replacement level Flexural Strength, Impact strength and Rapid chloride penetration test were carried out. The results revealed that the high volume fly ash shows better performance when compared with conventional concrete. Impact test shows good results. Flexure strength test gives higher values for specimens with 55% replacement of cement with fly ash concrete. Chloride ion penetration is lower for high volume fly ash concrete which shows that it has greater resistance to corrosion. The optimum replacement level of cement with fly ash is 55%.
Dr. Senhil Selvan (2015).

The behavior with various partial replacements of cements like 30%, 40%, 50%, 60% ware studied. In compare to conventional concrete, 50% replacement showed overall equal strength in 28 days. The results ware taken for 7 and 28 days. It was found that addition of fly ash improves the workability of concrete. Addition of 50% fly ash reduced 7day strength by about 20% when compared to control mix. But it was almost equal to that of control mix at 28 days and attained higher strength thereafter, all hardened properties are similar for OPCC and HVFAC at 28 days. The strength of concrete with 40%, 45%, and 50% fly ash content, even at 28 days ware sufficient enough for use in reinforced cement concrete construction. The concrete containing 50% fly ash developed high strength, while concrete containing 60% fly ash developed moderate strength .
Gaddam Dinesh, Nitesh kumar Sah (2017).

A experimental study was done on the M20 grade concrete with partial replacement of cement by fly ash by 0, 5, 10,15 and by 20% for Compressive strength, Split tensile strength at age of 7 and 28 day. Durability study on acid attack was also studied and percentage of weight loss was compared with normal concrete. Test results indicated that the use of fly ash in concrete had improved the performance of concrete in strength as well as in durability aspect. The optimum 7 and 28-day compressive strength, split tensile strength have been obtained in the range of 20 % fly ash replacement level.
Siddamreddy Anil Kumar Reddy, Dr. K. Chandrasekhar Reddy (2013).

For a particular curing age, both the strength and mass of M-20 Concrete decrease with an increase in the concentration of Nitric acid. Also, for a particular concentration of Nitric acid, the strength and weight of concrete decrease with curing age. A near linear relationship exists between weight loss and loss in compressive strength. It can therefore be concluded that deterioration of concrete cured in acidic medium increases with concentration of acid and curing age. The durability decreases faster as the concrete ages.
Taku Kumator Josiphiah, Amartey D Yusuf and Kassar T (2015).

An investigation was carried out to study the effect of hydrochloric acid in mixing and curing water for M30 and M25 grades of concrete. The concretes ware prepared in addition with Hydrochloric acid(HCl) in various concentrations. In addition to this a controlled specimen without HCl were prepared for comparison. The compressive strength was evaluated for 14, 28 and 90 days. The results show that the samples with different concentration of HCL achieves a little higher compressive strength on 28 days strength but the 14 days and 90 days strength remains lower as per comparison with the normal water design mix of same grade.
Himanshu Sharma, Dr. Hemant Sood (2015).

An attempt was made to study the influence of superplasticizer dose of 0.25, 0.30 and 0.35 percentage on performance of Self-Compacting Concrete containing 10% fly ash of cement content. The experimental tests for fresh and hardened properties of Self-Compacting Concrete for three mixes of M20 grade are studied and the results are compared with normal vibrated concrete. The tests considered for study ware, slump test, compaction factor test, unit weight and compressive strength test The results showed that for the constant water cement ratio, increase of superplasticizer dose in Self-Compacting Concrete leads to gain of good self compaction ability in addition to marginal reduction in unit weight. Moreover, there was also slightly increase in compressive strength than that of normal concrete mix.
S. M. Dumne (2014).

The effect of Hydrochloric acid (HCl) on Blended Cement (Fly ash based(BC)) and Silica Fume Blended Cement(SFBC) and their concretes was examined. The BC and SFBC and their concretes BCC and SFBCC produced with HCl dosage of 100, 150, 300, 500 and 900 mg/l added in deionised water. In addition to this control specimens were prepared with deionised water (without HCl) for comparison. The setting times and compressive strength were evaluated for 28 and 90 days apart from studying Rapid chloride ion permeability. The results show that, as HCl concentration increases, there is retardation in initial and final setting of cements (BC and SFBC). The compressive strength of both BCC and SFBCC has come down with an increase in the concentration of HCl at both 28 and 90 days. Compressive strengths of BCC and SFBCC have decreased in the range of 2 to 19%, at 28 and 90 day age respectively, with an increase in HCl concentration, when compared with the control specimens. It was also observed that Chloride ion permeability has increased with an increase in the concentration of the acid. X-ray diffraction analysis has been carried out for both BCC and SFBCC specimens at HCl concentration of 500 mg/l in deionised water.
B. Madhusudhana Reddy, H Sudarsana Rao & M.P George (2012).

Superabundant super plasticizer dose has an adverse relationship with the wear resistance property of HVFA concrete and with the increase in fly ash there is a reduction in wear resistance. With the superabundant dose of superplasticizer, the superplasticizing action per volume decreases as more dose is added and the Superabundant superplasticizer dose had no observable relationship, beneficial or adverse, with the compressive strength, flexural strength and splitting tensile strength of HVFA concrete. The Superabundant super plasticizer dose can help to achieve exceptionally low water/binder ratios with good fresh concrete properties in terms of flow and slump for HVFA concrete which is helpful to have good early and long term compressive strength of the concrete mix. With increase the fly ash content in HVFA concrete mixes, the overall compressive strength increases but the overall flexural strength, splitting tensile strength and abrasion resistance decreases.

Hafiz A. Alaka, Lukumon O. Oyedele (2016).

Among all the replacements of fly ash of 50-80% and silica fume of 0-15% for 50% of fly ash along with 10% of silica fume achieved higher strength than plain concrete due to reduction in porosity. Addition of silica fume to the cement gave more workability than fly ash replacement.

SrilaDey (2016).

An experiment was done on the durability studies on chemically activated high volume fly ash concrete (AHVFAC) with crusher sand as fine aggregate. OPC concrete and high volume fly ash concrete (HVFAC) were made for comparison. A small amount of Sodium Hydroxide(NaOH) was used as chemical activator to enhance the early age compressive strength of HVFAC. Studies such as compressive strength, weathering resistance, RCPT test, Sorptivity and carbonation test were determined. The test results indicate that performance of AHVFAC is reasonably higher to OPC concrete and shows better improvement over HVFAC in terms of strength and durability.

The compressive strength of AHVFAC was 1.1 to 1.2 times higher than HVFAC/control mixes. This was mainly due to the rapid fracture of silica-alumina in fly ash and its conversion into hydration products by the chemical activator. AHVFAC exhibited excellent resistance against weathering upto 30 cycles of alternate wetting and drying than both control mixes and HVFAC mixes. All the mixes including AHVFAC, HVFAC and control mixes showed low level of chloride penetration. Further, Sorptivity and carbonation characteristics of AHVFAC are even better than HVFAC/control mixes. The quite interesting performance of AHFAC is probably by the improvement in microstructure and due to the faster conversion of porous calcium hydroxide into less permeable calcium silicate hydrates. Moreover the slow pozzolanic reaction effect of fly ash at early ages is surpassed by chemical activator in HVFAC. Therefore chemical activation of HVFAC by NaOH with crusher sand is feasible with respect to its early strength .

D.Bhuvaneswari, V.Revathi (2016).

2.3 Object of study:

The main objective of this experimental study is to conduct a comparative durability investigation related to acid (Nitric acid and Hydrochloric acid) resistivity on high volume(30%,40% &50%) site mixed sustainable fly ash based blended(Fly ash+OPC) cement concrete and commercially available PPC cement concrete of different grades and to find the optimal mix design of high volume site mixed Fly ash based concrete.

2.4 Scope of work:

- To make sustainable concrete with different percentage of flyash replacing OPC Cement.
- To compare strength of flyash based concretes with respect to traditional concretes made with OPC and PPC cement.
- To assess durability of both traditional and flyash based sustainable concrete.
- To compare durability of flyash based sustainable concrete with the durability of traditional concretes.
- To investigate strength and different durability properties of traditional and sustainable Concrete including corrosion potential of rebar before and after acid exposure.

Chapter-3

EXPERIMENTAL PROGRAMME

3.1 General:

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

Mix Design Type-1 : where design was done for M30 concrete using Ordinary Portland Cement(OPC) only.

Mix Design Type-2 : where design was done for M30 concrete using 70% Ordinary Portland Cement(OPC) and 30% flyash of total cementitious materials.

Mix Design Type-3 : where design was done for M30 concrete using 60% Ordinary Portland Cement(OPC) and 40% flyash of total cementitious materials.

Mix Design Type-4 : where design was done for M30 concrete using 50% Ordinary Portland Cement(OPC) and 50% flyash of total cementitious materials.

Mix Design Type-5 : where design was done for M30 concrete using Portland Pozzolana Cement(PPC).

All the samples have been tested in 7 days, 28 days (after water curing) and then after 2 month & 4 month of acid exposure condition. Acids used is 4% Hydrochloric acid (HCl) and Nitric acid (HNO_3) and samples are fully immersed within acid solution for 2 month & 4 month. strength and durability properties of mixes have been compared before and after acid exposure Comparison has also been done for various types of mixes.

The aim of this research is mainly to identify and validate an optimum concrete mix design using fly ash which has enough strength and is durable in nature.

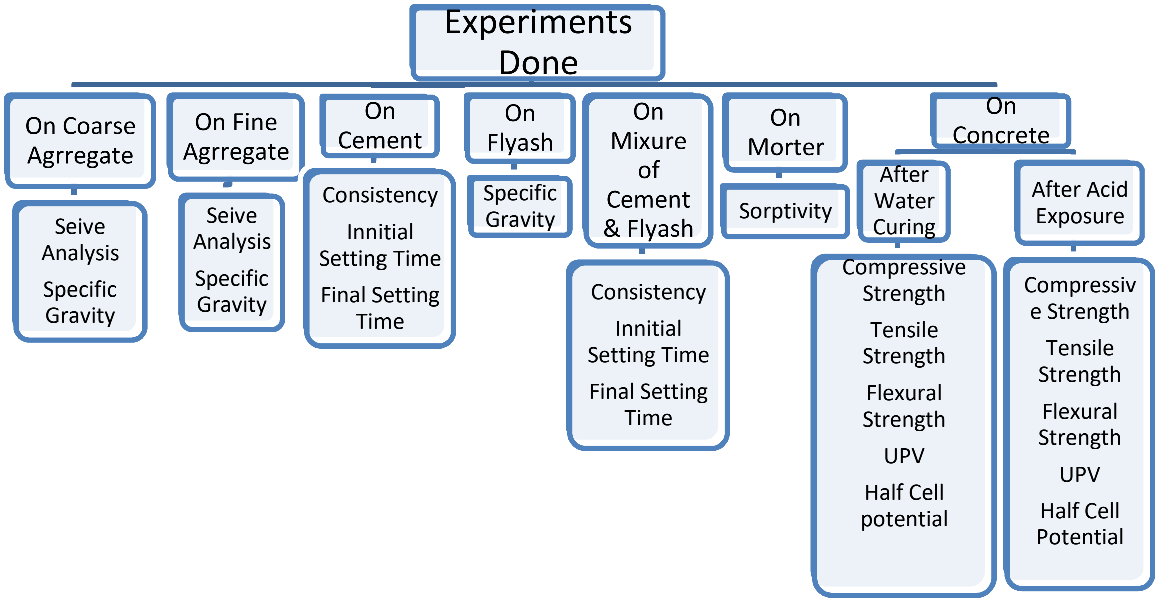


Fig.3.1 Experimental Programme

3.2 Materials used:

3.2.1 Cement:

Two types of cements have been used in this experimental programme:
i) Ordinary Portland Cement (53 Grade) [Conforming to IS 12269:2013] and
ii) Portland pozzolana cement (Fly Ash Based)[Conforming to IS 1489 (Part 1) : 1991]
The advantage of use of Ordinary Portland Cement (OPC) is this cement gains strength faster than other pozzolana based cement. So to achieve same compressive strength at 28 days, quantity of OPC required is less than Portland-Pozzolana cement.
On the other hand PPC produces less heat of hydration and offers greater resistance to the attack of aggressive environment than normal Portland cement. Moreover, it reduces the PPC (Fly ash based) is produced by grinding together Portland cement clinker and flyash. According to clause 5 of IS 1489 (Part 1) fly ash constituent shall not be less than 10% and not more than 25%.

Fig.3.2 Cement

3.2.2 Fly ash:

In India large quantity of fly ash gets produced and becomes available as a byproduct of coal-based power stations. It is a fine powder resulting from the combustion of powdered coal.

Fig.3.3 Fly ash

3.2.3 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 sul phates and should not absorb more than 10 % water of their own mass. The fine aggregates are used in this experimental programme- River sand (yellow) conforming to Zone-III has been used in the experiment work.

Fig.3.4 River sand (yellow) conforming to Zone-III

3.2.4 Coarse Aggregate:

Aggregate most of which is retained on 4.75-mm IS Sieve and containing only so much finer material as is permitted in IS 383 are Coarse Aggregate. Here 20 mm and 12.50 mm nominal size crushed stone angular in shape was used as Coarse Aggregate (C.A.).

- **Fig.3.5 10 mm Coarse Aggregate**

Fig.3.6 20 mm Coarse Aggregate

3.2.5 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.

Fig.3.7 Admixture

Durability of concrete has been experimented by submerging cube samples into **Hydrochloric Acid and Nitric Acid** solution for 28 days under normal room temperature.

3.2.6 Hydrochloric Acid: [conforming to IS 265 : 1993]

To achieve accelerated corrosion effect in short time, 4% diluted Nitric acid solution(having pH value 0.30) was chosen for the experiments. Niric acid of 35% was mixed with potable water. Each of the containers was filled with 15L of potable water and then 600gm concentrated acid added. The surface level was constantly maintained to compensate absorption or evaporation loss so that the samples remain submerged for 4 Month.

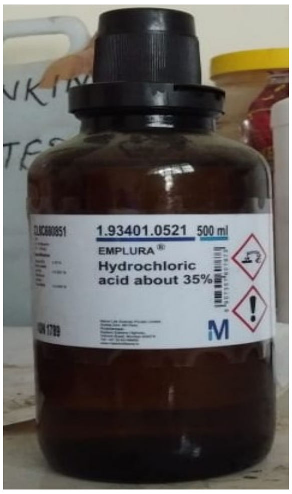


Fig.3.8 Hydrochloric Acid

3.2.7 Nitric Acid: [conforming to IS 264: 2005]

To achieve accelerated corrosion effect in short time, 4% diluted Nitric acid solution(having pH value 0.60) was chosen for the experiments. Nitric acid of 69% was mixed with potable water. Each of the containers was filled with 15L of potable water and then 600gm concentrated acid added. The surface level was constantly maintained to compensate absorption or evaporation loss so that the samples remain submerged for 4 Month.

Fig.3.9 Nitric Acid

Fig.3.10 Mixing of Acid with water for curing of the samples

Fig.3.11 Acid curing of the samples

3.2.8 Water

Potable water having pH value 7.0-7.5 was used for concrete mix. And other purpose during the test.

3.3 Test Procedures:

3.3.1 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 W_1 (say).The bottle was filled with water and weight of bottle with water = W_2.Then the bottle was dried and filled with kerosene. This weight was W_3. Again bottle was dried and cement was poured into the bottle. This weight was taken as W_4.Kerosene was added to cement in bottle till it flash with graduated mark. Weight was taken as W_5.

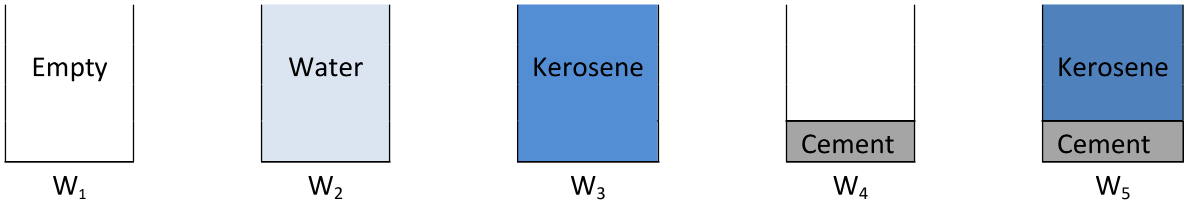
Weight of the empty bottle= W_1

Weight of bottle + Water= W_2

Weight of bottle + kerosene=W_3

Weight of bottle+Cement= W_4

Weight of bottle+Cement + kerosene = W_5



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

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

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

$$= \frac{W4-W1}{(W3-W1)-(W5-W4)} \times \frac{W3-W1}{W2-W1}$$

3.3.2 Standard consistency and setting time test of cement:

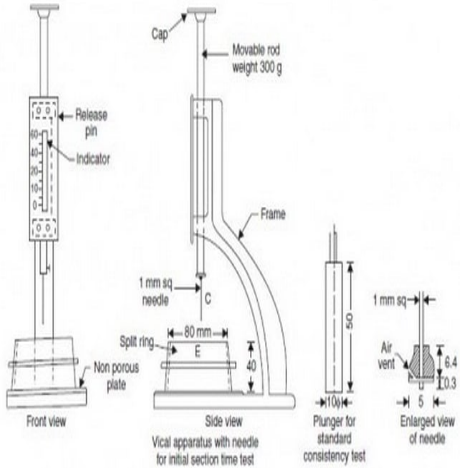


Fig.3.12 Vicat apparatus

Fig.3.13 Vicat apparatus in Lab

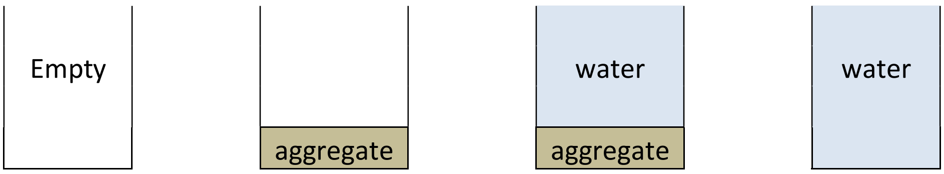
Standard consistency, initial setting time and final setting time of cement was done with The vicat apparatus. 10mm dia Plunger was used for determining the standard consistency, 1.13mm dia needle (Needle C) was used to determine initial setting time and Needle F was used to determine final setting time.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

3.3.3 Specific gravity test of aggregates:

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

Fig.3.14 Pycnometer

Weight of empty Pycnometer =W_1
Weight of pycnometer +weight of Aggregates= W_2
Weight of pycnometer +weight of Aggregates +Remaining quantity of water= W_3
Weight of pycnometer +weight of water full of pycnometer= W_4



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

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

3.3.4 Particle size distribution of aggregates:

To determine particle size distribution of sand 10 mm, 4.75 mm, 2.36 mm, 1.18 mm 600 micron 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.

Fig.3.15 IS Sieves

3.3.5 Workability Test of fresh concrete:

Workability of fresh concrete is determined following the IS code IS 1199-1959.
It has been done by two methods.

1. **Slump test:**
   It has been done for the concrete mixes.

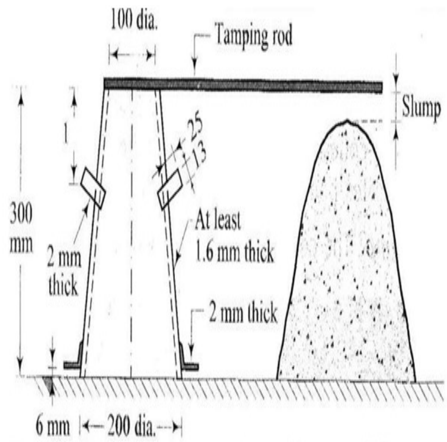


Fig.3.16 Slump Cone

Fig 3.17 Slump Cone in Lab

2. **Flow table test:**
   It has been done for the mortar mixes used for Sorptivity test.

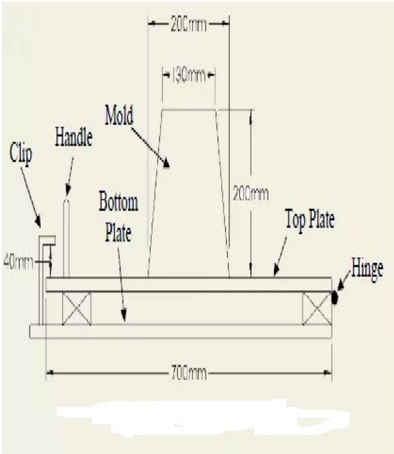


Fig.5.18 Flow table

Fig.5.19 Flow table in Lab

Fig.5.20 Flow table test in Lab

3.3.6 Acidity test of water and acid 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

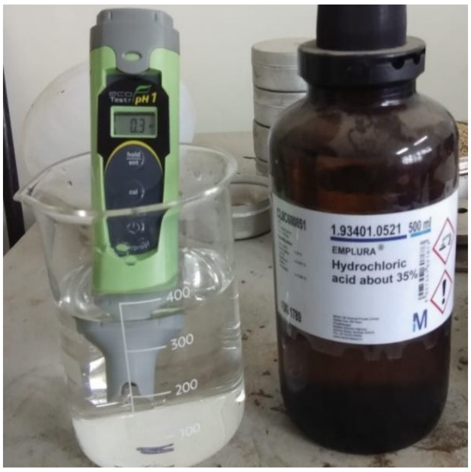


Fig.3.21 Determination of pH of HCl acid solution

Fig.3.22 Determination of pH of HNO_3 acid solution

3.3.7 Compressive Strength Test:

Compressive test has been conducted as per IS 516-1959 on 150x150x150mm size cubes. For each mix type, 3 cubes after 7 days, 3 cubes after 28 days , 3 cubes after 2 months and 4 months of acid(for Both HCl & HNO_3)exposure have been tested. Cubes have tested in compression testing machine .

Fig.3.23 Compression testing machine

Fig.3.24 Compressive strength test of cube

Fig.3.25 Failure of cube in compression

3.3.8 Split Tensile Strength Test:

Due to numbers of difficulties related to holding the test specimen properly in the testing machine without introducing stress concentration and for the application of uniaxial tensile load which is free from eccentricity to the specimen a numbers of indirect methods have been developed to determine the tensile strength. Split Tensile Strength test is such a indirect method where a compressive force is applied to the specimen in such a way that the specimen fails due to tensile stresses induced in the specimen. The tensile stress at which failure occurs is the tensile strength of concrete.

The test consists of applying compressive line loads along the opposite generators of a concrete cylinder placed with its axis horizontal between the platens of the compression testing machine.

Due to the applied line loading a fairly uniform tensile stress is induced over nearly two-third of the loaded diameter as obtained from elastic analysis. The magnitude of this tensile stress (acting in a direction perpendicular to the line of action of applied compression) is given by 2P/3.14DL, where P is applied load, D is the diameter and L is the length of the cylinder. Due to this tensile stress ,the specimen fails finally by splitting along the loaded diameter and knowing P at failure, the tensile strength can be determined.

200x100 mm size cylinders have been tested. For each mix type, 3 cylinders for 28 days , 3 cylinders after 2 months and 4 months of acid(for Both HCl & HNO_3)exposure have been tested.

Fig.3.26 Failure of Cylinder

3.27 Outer and Inner surface of a Cylinder after 4 months acid exposure

3.3.9 Flexural Strength Test:

Compressive tests has been conducted as per IS 516-1959 on 100x100x500mm size concrete beams. For each mix type, 1 beam after 28 days , 1 beam after 2 months and 4 months of acid(for Both HCl & HNO_3)exposure have been tested. Beams have been tested in Flexural strength testing machine .

Fig.3.28 Flexural strength testing machine

Fig.3.29 Failure of Beam

Fig.3.30 Failure of Beam

3.3.10 Ultrasonic pulse velocity test :

This test has been done to assess the quality of concrete by ultrasonic pulse velocity method as per IS: 13311 (Part 1) – 1992.

The ultrasonic pulse velocity method could be used to establish:-

a. The homogeneity of the concrete,
b. The presence of cracks, voids and other imperfections,
c. Changes in the structure of the concrete which may occur with time
d. The quality of the concrete in relation to standard requirements,
e. The quality of one element of concrete in relation to another, and
f. The values of dynamic elastic modulus of the concrete.

The underlying principle of this test is -

- The method consists of measuring the time of travel of an ultrasonic pulse passing through the concrete being tested. Comparatively higher velocity is obtained when concrete quality is good in terms of density, uniformity, homogeneity etc.

- The ultrasonic pulse is generated by an electro-acoustical transducer .When the pulse is induced into the concrete from a transducer, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves is developed which includes longitudinal , shear(transverse) and surface(Rayleigh) waves. The receiving transducer detects the onset of the longitudinal waves, which is the fastest.

- Because the velocity of the pulses is almost independent of the geometry of the material through which they pass and depends only on its elastic properties, pulse velocity method is a convenient technique for investigating structural concrete.

- The underlying principle of assessing the quality of concrete is that comparatively higher velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. In case of poorer quality, lower velocities are obtained. If there is a crack, void or flaw inside the concrete which comes in the way of transmission of the pulses, the pulse strength is attenuated and it passes around the discontinuity, thereby making the path length longer. Consequently, lower velocities are obtained. The actual pulse velocity obtained depends primarily upon the materials and mix proportions of concrete. Density and modulus of elasticity of aggregate also significantly affect the poise velocity.

The experiment done on Cube samples after 28 days and 2 month and 4 month acid (HCl and HNO_3) exposure.

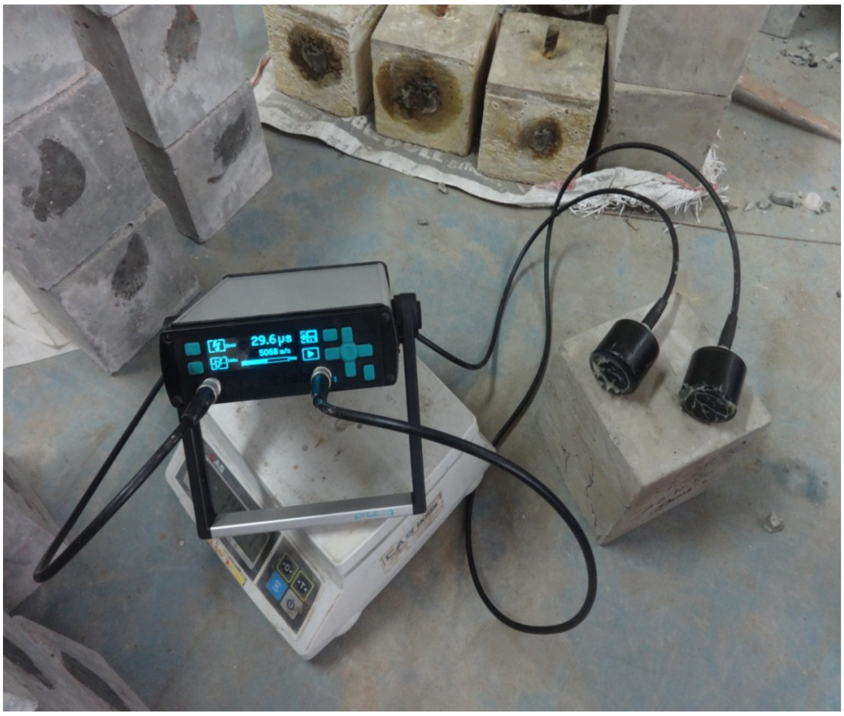


Fig.3.31 Ultrasonic pulse velocity test (Instrument)

Fig.3.32 Ultrasonic pulse velocity test in laboratory

3.3.11 Half-cell potential test:

Half-Cell Potentiometer survey has been carried out to check the chance of the corrosion of steel in a cube sample having a reinforcement. The corrosion of steel in concrete is an electrochemical process. It represents a galvanic element, similar to a battery producing an electric current and measurable as an electric field on the surface of the concrete. This potential field can measured with an electrode known as a Half-Cell (Copper/Copper Sulphate). By making measurements over the whole surface, a distinction can be made between corroding and non-corroding locations. A high impendence digital voltmeter is used to collect the data. An electrical correction is made to the steel either by exposing it or using already exposed steel. The foam rubber plugs saturated with water are pressed on the concrete surface at the pre-selected grid points. The readings in term of **milivolt** (mV) are noted.

The ASTM(ASTM C876-91) criteria for corrosion of steel in concrete for Copper/Copper Sulphate Half-Cell are as follows.

The experiment done on Cube samples after 28 days and 2 month and 4 month acid (HCl and HNO_3) exposure.

Table 1: 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

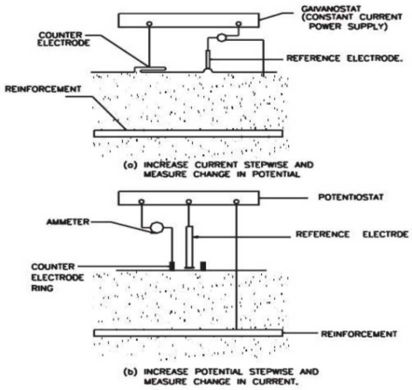


Fig.3.33 Schematic diagram of Half-cell potential test

Fig.3.34 Half-cell potential testing instrument

Fig.3.35 Half-cell potential testing in lab

Fig.3.36 Outer surface of Cubes for Half Cell Potentiometer after 4 months acid exposure

3.3.12 Sorptivity Test:

This test has been done as per ASTM C1585-2007. This test method is used to determine the rate of absorption (sorptivity) of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. The exposed surface of the specimen is immersed in water and water ingress of unsaturated concrete dominated by capillary suction during initial contact with water.

The absorption, *I*, is the change in mass divided by the product of the cross-sectional area of the test specimen and the density of water. For the purpose of this test, the temperature dependence of the density of water is neglected and a value of 0.001 g/mm3 is used. The units of *I* are mm.

$I = m_t / a*d$

where:

I = the absorption,

m_t = the change in specimen mass in grams, at the time *t*,

a = the exposed area of the specimen, in mm^2, and

d = the density of the water in g/mm^3.

The initial rate of water absorption ($mm/s^{1/2}$) is defined as the slope of the line that is the best fit to *I* plotted against the square root of time ($s^{1/2}$). This slope is ed by using least squares, linear regression analysis of the plot of *I* versus time^$^{1/2}$. For the regression analysis, all the points are used from 1 min to 6 h, excluding points for times after the plot shows a clear change of slope. If the data between 1 min and 6 h do not follow a linear relationship (a correlation coefficient of less than 0.98) and show a systematic curvature, the initial rate of absorption cannot be determined.

The secondary rate of water absorption ($mm/s^{1/2}$) is defined as the slope of the line that is the best fit to *I* plotted against the square root of time ($s^{1/2}$) using all the points from 1 *d* to 7 *d*. Least-square linear regression is used to determine the slope. If the data between 1 *d* and 7 *d* do not follow a linear relationship (a correlation coefficient of less than 0.98) and show a systematic curvature, the secondary rate of water absorption cannot be determined.

The experiments for Sorptivity done on 50x50x50 mm morter cubes. Mortars have been prepared mixing sand with cementitious materials. Cementetious materials have used same as used in preparation of concrete samples.

Fig.3.37 Mortar cubes(50x50x50 mm) for Sorptivity Test

Chapter-4

RESULT AND DISCUSSION

4.1 Material test results:

4.1.1 Specific gravity of different materials:

Table-2: Specific gravity of different materials

Materials	Sp. Gr.
OPC	3.120
PPC	2.900
Flyash	2.267
Sand	2.660
Stone Chips	2.820

4.1.2 Consistency and Setting Times of Cementitious materials:

Table-3: Consistency and Setting Times of Cementitious materials

Type of Cementitious materials	consistency	Initial setting tme	Final setting time
OPC	33%	2 hrs 20 minutes	3 hrs 20 minutes
OPC + 30% Flyash	37%	2 hrs 30 minutes	5 hrs 00 minutes
OPC + 40% Flyash	40%	2 hrs 25 minutes	5 hrs 05 minutes
OPC + 50% Flyash	43%	4 hrs 25 minutes	5 hrs 20 minutes
PPC	35%	2 hrs 35 minutes	4 hrs 00 minutes

Fly ash is having greater fineness than cement so the consistency increases when fly ash percentage increases.

Initial and final setting time increases when fly ash percentage increases.

4.1.3 Particle size distribution of Coarse aggregates:

20 mm size aggregate

Weight of sample taken=5000gm

Table-4: Particle size distribution of Coarse aggregates:

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%

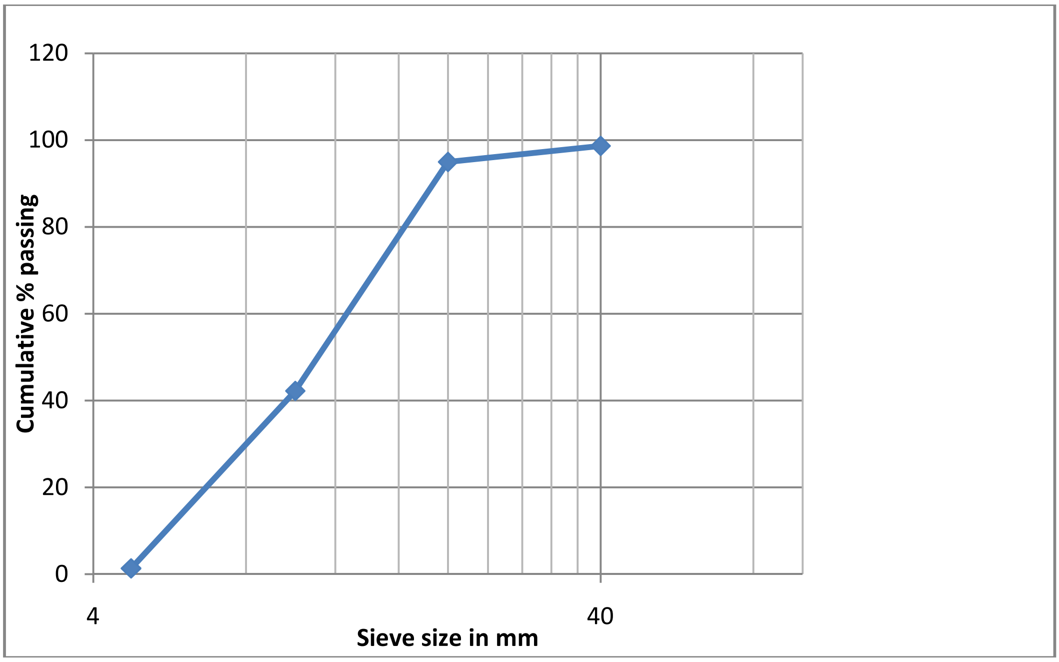


Fig.4.1 Particle size distribution of 20 mm down coarse aggregates

12.5 mm size aggregate

Weight of sample taken=5000gm

Table-5: Particle size distribution of Coarse aggregates:

Sieve Size	Weight retained(gm)	Cumulative Weight retained(gm)	Cumulative percentage retained	Cumulative percentage passing	Range as per IS 383
20	0	0	0	100	100%
12.5	335	335	6.79	91.87	90-100%
10	2498	2833	57.43	41.23	40-85%
4.75	2100	4933	98.66	1.34	0-10%
Pan	67	5000	100	0	0-10%

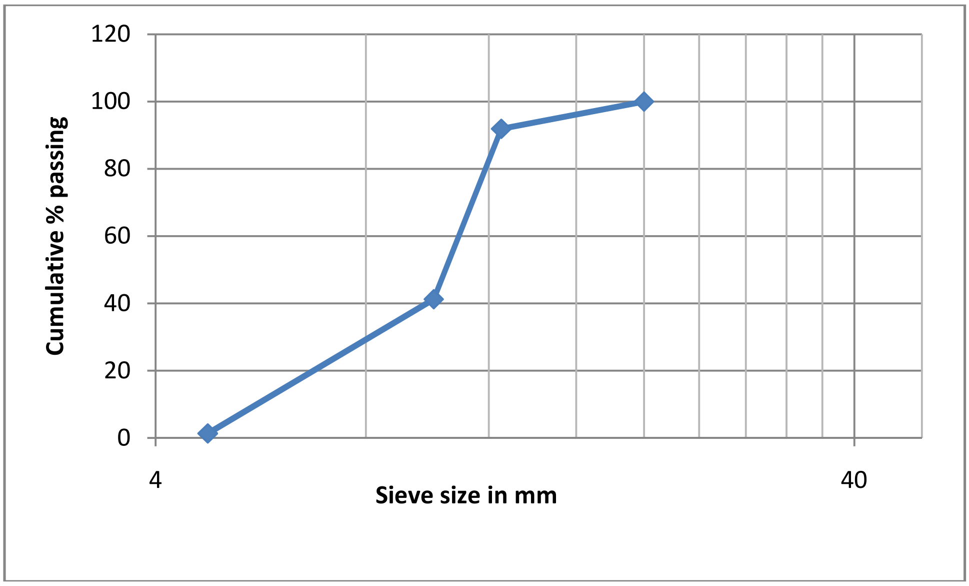


Fig.4.2 Particle size distribution of 12.5 mm down coarse aggregates

4.1.4 Particle size distribution of Fine aggregates:

Sand

Weight of sample taken=200gm

Table-6: Particle size distribution of sand

Sieve Size	Weight retained(gm)	Cumulative Weight retained(gm)	Cumulative percentage retained	Cumulative percentage passing	Range as per IS 383
10 mm	0	0	0.00	100.00	100%
4.75 mm	0.261	0.261	0.13	99.87	90-100%
2.36 mm	1.48	1.741	0.87	99.13	85-100%
1.18 mm	5.598	7.339	3.67	96.33	75-100%
600 Micron	45.816	53.155	26.58	73.42	60-79%
300 Micron	78.254	131.409	65.70	34.30	12-40%
150 Micron	64.721	196.13	98.07	1.94	0-10%
Pan	3.87	200	100.00	0.00	

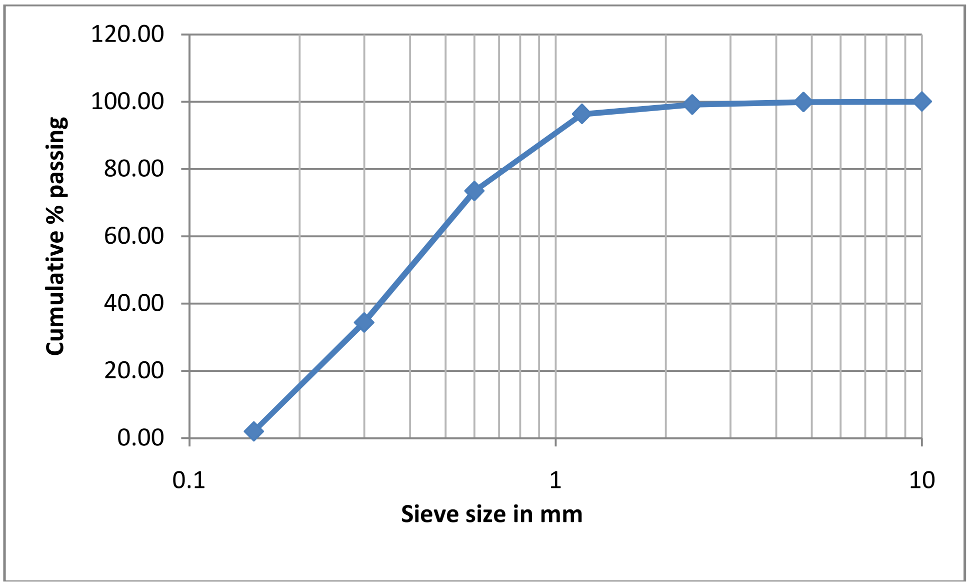


Fig.4.3 Particle size distribution of sand

4.1.5 Slump test of fresh concrete:

Table:7 Results of Slump Test:

Type of Mix	Slump in mm
OPC	110
OPC +30%	85
OPC+40%	25
OPC +50%	100
PPC	130

* The concrete mix having 50% flyash with 0.40 water cementitious material ratio and 0.70% admixture of cementitious materials was not workable and having 0(Zero) slump. So this mix could not be used for experimental works. For this reason to make the mix workable an increased water cement ratio of 0.45 and 1.00% admixture of cementitious materials has been used.

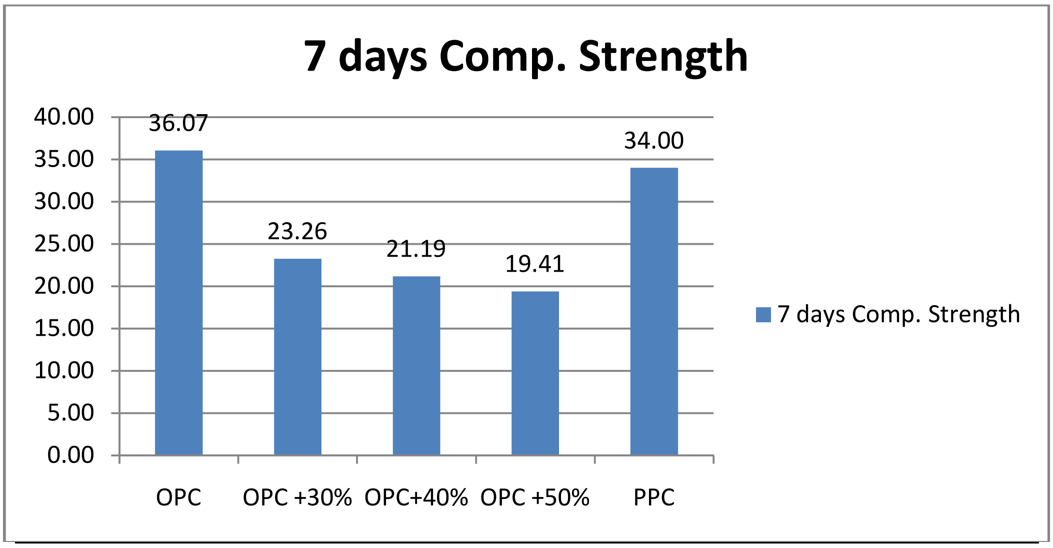
**It has also been noticed that the slump decreases rather than increasing with the increase of flyash content which may happen due to absorption of water by the high volume of very fine flyash particle having very large surface area during mixing .

4.2 Test results for Concrete sample:

4.2.1 Results of Compressive Strength:

Table:8 Results compressive strengths in MPa of 150x150x150 mm cube after 7 day water curing

Type of Mix	7 days Comp. Strength
OPC	36.07
OPC +30%	23.26
OPC+40%	21.19
OPC +50%	19.41
PPC	34.00



4.4 Graphical representation compressive strengths in MPa of 150x150x150 mm cube after 7 days water curing

Discussion on result:

7 Days average compressive strength are satisfactory & nearly similar for OPC(36.00MPa,i.e 83% of target strength) & PPC (34.07MPa,i.e 79% of target strength).

7 Days average compressive strengths are very low with respect to standard 7 Days average compressive strengths(i.e 75% of 28 days target strength and decrease with the increase in Flyash content. For 30% Flyash(23.26MPa,i.e 54% of target strength), 40% Flyash(21.19MPa,i.e 49% of target strength),and 50% Flyash(19.41MPa,i.e 45% of target strength).

The setting and hardening of the OPC takes place as a result of Hydration i.e. due to formation of C-S-H Gel through a reaction between the principal compound of cement (C_2S,C_2A,C_3A etc.) and water. During the hydration process of cement, lime is released out and remains as surplus in the hydrated cement. This surplus lime becomes the source for pozzolanic reaction with fly ash and forms additional C-S-H gel having similar binding properties in the concrete as those produced by hydration of cement paste. But this reaction started only after adequate free life is generated and for this reason the initial strength(7 days strength) decreases when flyash percentage increase.

Table:9 Results compressive strengths in MPa of 150x150x150 mm cube after water and HCl acid curing

Percentage of Flyash	Strength after 28 days water curing	Strength after 2 months acid curing	Strength after 4 months acid curing
OPC+0%	58.67	55.7	55.54
OPC+30%	45.19	53.33	55.78
OPC+40%	48.15	55.78	58.37
OPC+50%	42.52	43.93	45.44
PPC	53.33	54.26	55.04

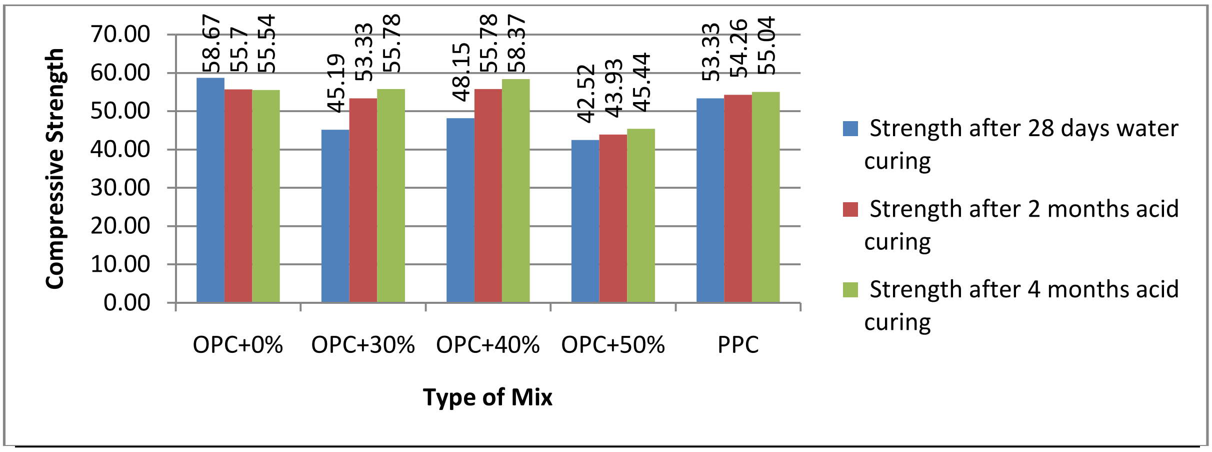


Fig.4.5 Graphical representation of compressive strengths in MPa of 150x150x150 mm cube after water and HCl acid curing

Discussion on result:

28 days Compressive strength:

28 Days Comp Strength is highest for concrete having OPC Cement and lowest for concrete sample having 50% flyash.

28 Days Comp Strength of sample having 40% flyash is greater than sample having 30% and 50% Flyash. 28 days comp strength of sample having PPC is less than the sample having OPC but greater than the samples having flyash mixed at site due to better mixing of flyash directly with cement clinker during the manufacturing of PPC.

28 days Compressive strengths of flyash based concretes is less with respect to Concrete made with OPC only as the flyash based concretes samples have small quantity of C-S-H gel in the initial stage than the concrete sample made with OPC.

Table:10 Percentage of Residual compressive strength with respect to 28 days compressive strength of 150x150x150 mm cube after HCl acid curing

Percentage of Flyash	% Residual strength after 2 months acid curing	% Residual strength after 4 months acid curing
0%	94.94	94.67
30%	118.01	123.43
40%	115.85	121.23
50%	103.32	106.87

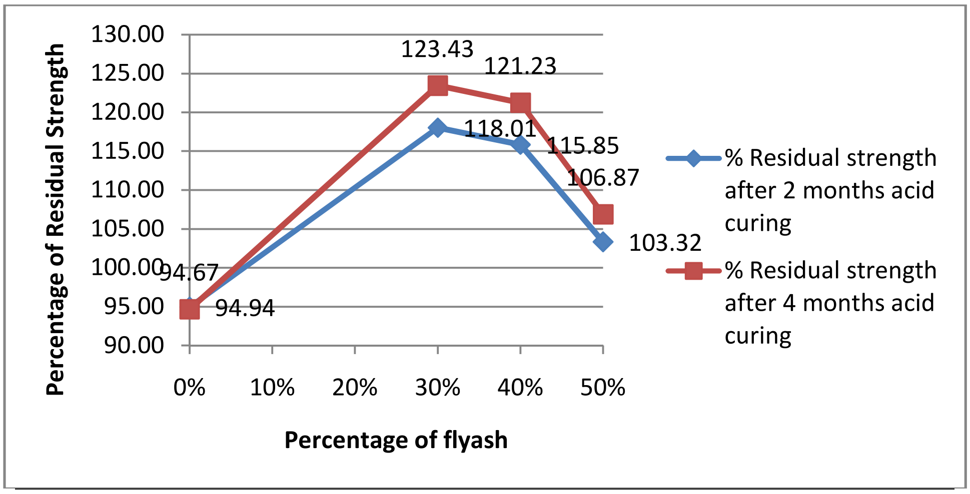


Fig.4.6 Graphical representation of percentage of residual compressive strength with respect to 28 days compressive strength of 150x150x150 mm cube after HCl acid curing

Discussion on result:

In case of HCl acid curing:

2 month and 4 month Compressive Strength maximum for the concrete sample having 40% Flyash

With respect to 28 days compressive strength 2 month and 4 month Compressive Strength is more for all samples except the concrete samples having OPC which is due to formation of $CaCl_2$ in case of OPC cement by the reaction with unreacted free lime and HCl acid in OPC cement .By the help of water, this soluble salts may easily be transported to the outer parts of mortars.
In this situation, continuous reactions increase the porosity of cement paste and increased pore volume speed up the rate of reaction.
With respect to 2 month compressive strength 4 month Compressive Strength is more for all samples except the concrete sample having OPC due to the same reason stated above.
The samples having flyash show better compressive strength due to pozzolanic action of flyash.
The unreactive portion of fly ash act as micro aggregates and fills up the matrix to render packing effect and results in increased strength.
There is no adverse effect of acid to decrease the compressive strength of the flyash based concrete due to presence of flyash.
The maximum residual value after 2 and 4 months acid curing has been noticed for the concrete Sample having 30% fly ash.

Table:11 Results of compressive strengths in MPa of 150x150x150 mm cube after water and HNO_3 acid curing

Percentage of Flyash	Strength after 28 days water curing	Strength after 2 months acid curing	Strength after 4 months acid curing
OPC+0%	58.67	55.37	55.12
OPC+30%	45.19	53.63	55.3
OPC+40%	48.15	55.7	57.81
OPC+50%	42.52	42.78	45.52
PPC	53.33	55.37	57.74

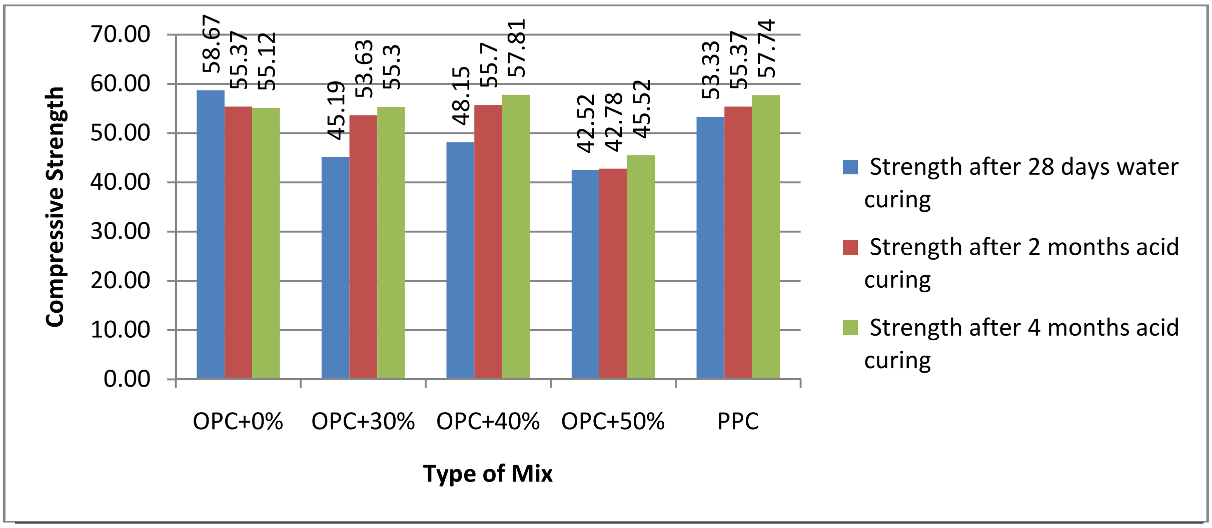


Fig.4.7 Graphical representation of compressive strengths in MPa of 150x150x150 mm cube after water and HNO_3 acid curing

Table :12 Percentage of Residual compressive strength with respect to 28 days compressive strength of 150x150x150 mm cube after HNO_3 acid curing

Percentage of Flyash	% Residual strength after 2 months acid curing	% Residual strength after 4 months acid curing
0%	94.38	93.95
30%	118.68	122.37
40%	115.68	120.06
50%	100.61	107.06

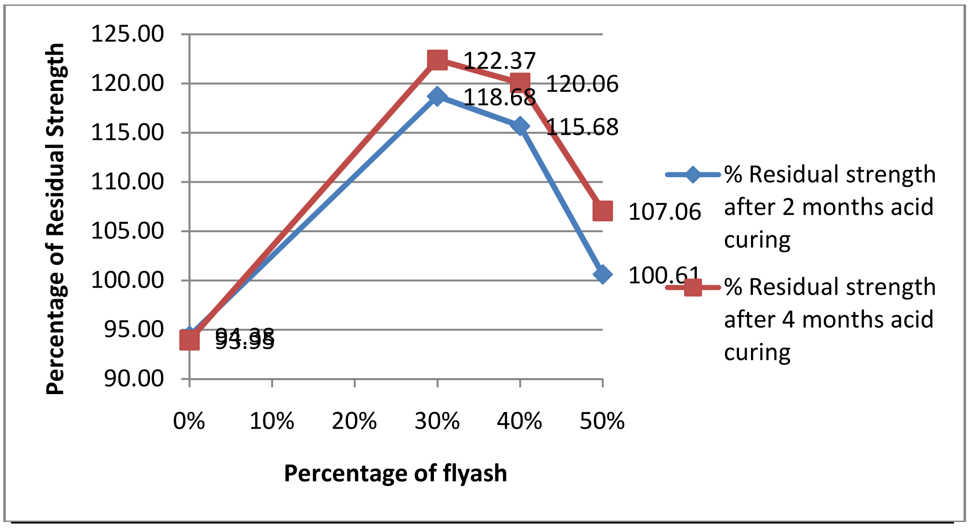


Fig.4.8 Graphical representation of percentage of Residual compressive strength with respect to 28 days compressive strength of 150x150x150 mm cube after HNO_3 acid curing

Discussion on result:

In case of HNO_3 acid curing:

In case of HNO_3 acid curing the concrete samples show same trend of results as in case of HCl acid curing. Only difference here it is due to formation of $Ca(NO_3)_2$ salts which generated by the reaction with unreacted free lime of OPC cement and HNO_3 acid.

The maximum residual value after 2 and 4 months acid curing has been noticed for the concrete Sample having 30% fly ash

4.2.2 Results of Split Tensile Strength:

Table :13 Results of split tensile strengths in MPa of 200x100 mm cylinder after water and HCl acid curing

Percentage of Flyash	Strength after 28 days water curing	Strength after 2 months acid curing	Strength after 4 months acid curing
OPC+0%	4.23	3.83	3.47
OPC+30%	3.50	3.8	3.96
OPC+40%	3.98	4.15	4.32
OPC+50%	3.10	3.32	3.43
PPC	3.75	3.95	4.12

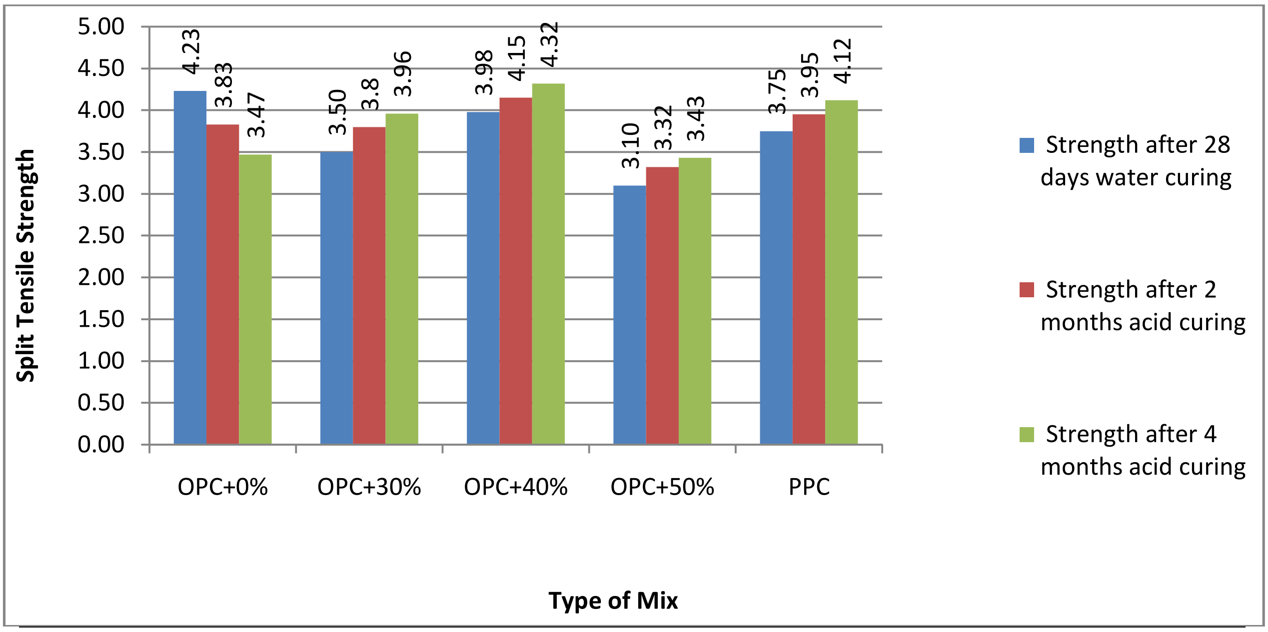


Fig.4.9 Graphical representation of split tensile strengths in MPa of 200x100 mm cylinder after water and HCl acid curing

Discussion on result:

28 days Split tensile strength:

The trend of results of 28 days Split tensile strength are same and due to the same reasons as the 28 days Compressive strength for all the concrete samples.

Table :14 Percentage of Residual split tensile strength with respect to 28 days tensile strength of 200x100 mm Cylinder after HCl acid curing

Percentage of Flyash	% Residual strength after 2 months acid curing	% Residual strength after 4 months acid curing
0%	96.45	94.81
30%	120.00	129.43
40%	124.62	128.64
50%	112.12	126.97

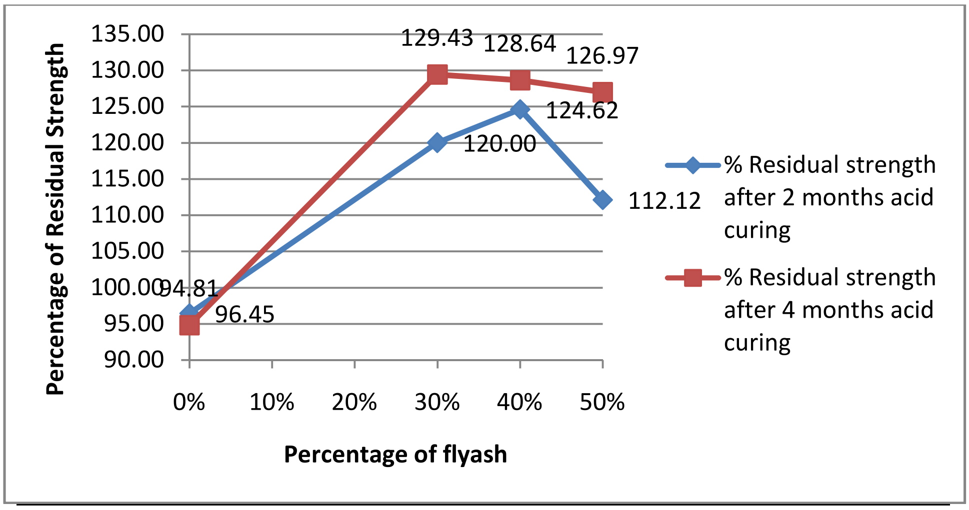


Fig.4.10 Graphical representation of Residual split tensile strength with respect to 28 days tensile strength of 200x100 mm Cylinder after HCl acid curing

Discussion on result:

In case of HCl acid curing:

2 month and 4 month Split Tensile Strength maximum for the concrete sample having 40% flyash and lowest for concrete sample having 50% flyash.

With respect to 28 days Split Tensile Strength 2 month and 4 month Split Tensile Strength is more for all samples except the concrete sample having OPC due to same reasons as compressive strength.

With respect to 2 month Split Tensile Strength, 4 month Split Tensile Strength is more for all samples except the concrete sample having OPC.

The samples having flyash show better Split Tensile Strength due to pozzolanic action of flyash. unreactive portion of fly ash act as micro aggregates and fills up the matrix to render packing effect and results in increased strength

There is no adverse effect of acid to decrease the Split Tensile Strength of the flyash based concrete due to presence of flyash.

The maximum residual value after 2 months acid curing has been noticed in case of concrete sample having 40% fly ash and maximum residual value after 4 months acid curing has been noticed for the concrete sample having 30% fly ash.

Table :15 Results of split tensile strengths in MPa of 200x100 mm cylinder after water and HNO_3 acid curing

Percentage of Flyash	Strength after 28 days water curing	Strength after 2 months acid curing	Strength after 4 months acid curing
OPC+0%	4.23	3.83	3.47
OPC+30%	3.50	3.8	3.96
OPC+40%	3.98	4.15	4.32
OPC+50%	3.10	3.32	3.43
PPC	3.75	3.95	4.12

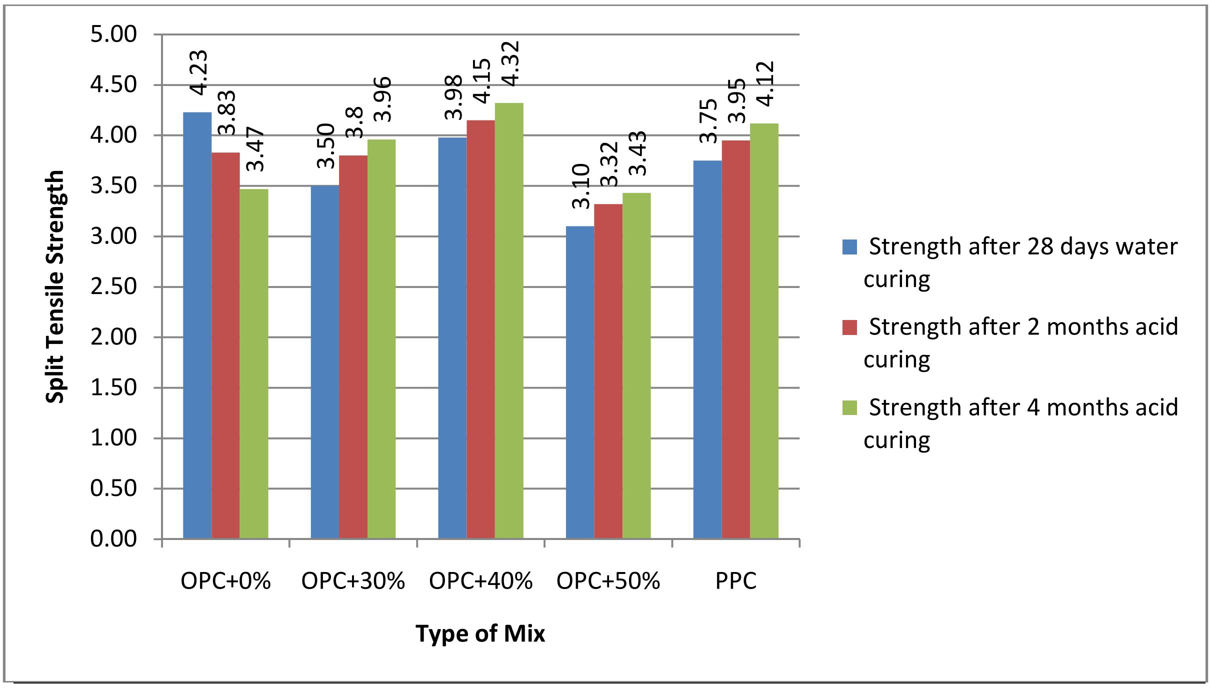


Fig.4.11 Graphical representation of split tensile strengths in MPa of 200x100 mm cylinder after water and HNO_3 acid curing

Table :16 Percentage of Residual split tensile strength with respect to 28 days tensile strength of 200x100 mm cylinder after HNO_3 acid curing

Percentage of Flyash	% Residual strength after 2 months acid curing	% Residual strength after 4 months acid curing
0%	98.91	96.45
30%	114.00	120.29
40%	114.57	116.08
50%	108.79	111.21

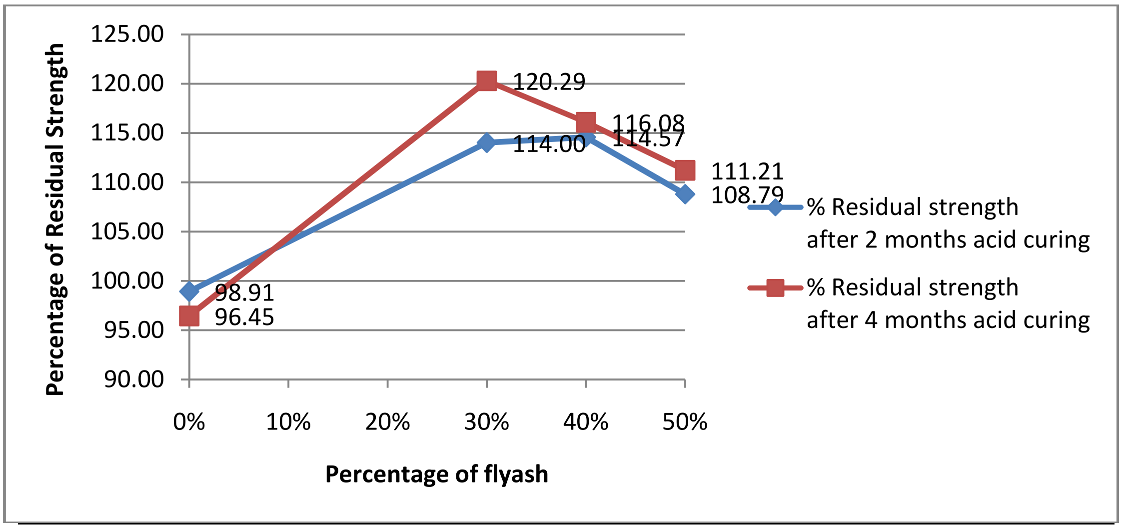


Fig.4.12 Graphical representation of percentage of Residual split tensile strength with respect to 28 days tensile strength of 200x100 mm cylinder after HNO_3 acid curing

Discussion on result:

In case of HNO_3 acid curing:

In case of HNO_3 acid curing the concrete samples show same trend of results as in case of HCl acid curing.

The maximum residual value after 2 months acid curing has been noticed in case of concrete Sample having 40% fly ash and maximum residual value after 4 months acid curing has been noticed for the concrete sample having 30% fly ash.

4.2.3 Results of Flexural Strength:

Table :17 Results of flexural strengths in MPa of 100x100 x500 mm Beam after water and HCl acid curing

Percentage of Flyash	Strength after 28 days water curing	Strength after 2 months acid curing	Strength after 4 months acid curing
OPC+0%	8.50	8.00	8.00
OPC+30%	7.00	7.50	8.00
OPC+40%	7.50	8.00	8.50
OPC+50%	6.00	6.50	6.50
PPC	7.50	7.50	8.00

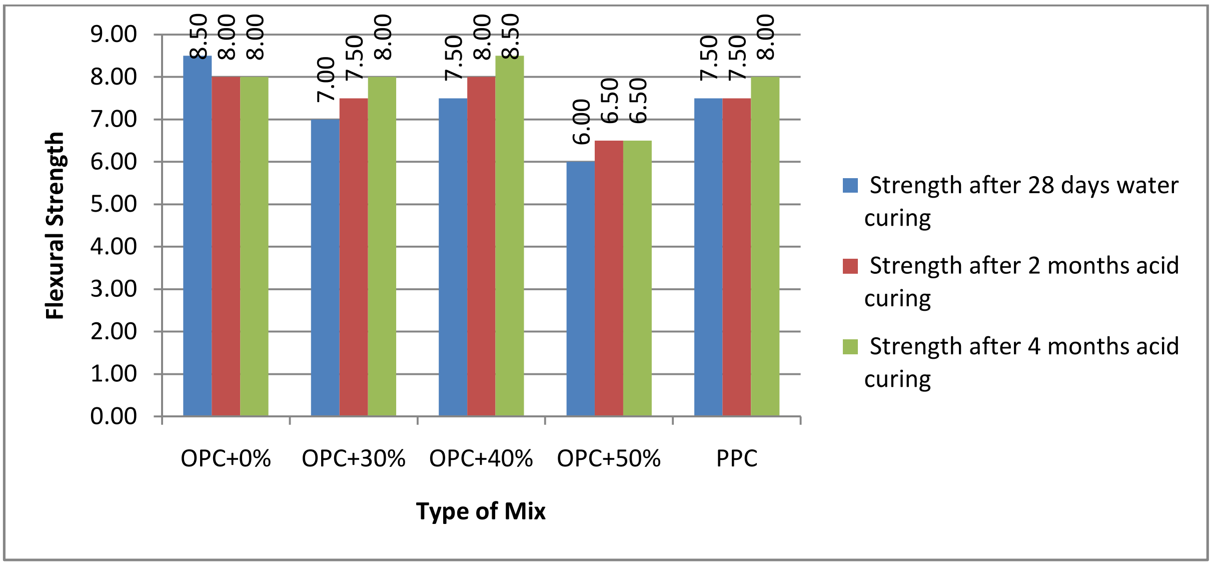


Fig.4.13 Graphical of flexural strengths in MPa of 100x100 x500 mm Beam after water and HCl acid curing

Discussion on result:

28 days Flexural strength:

The trend of result of 28 days Flexural strength are same and due to the same reasons as the 28 days compressive strength for all the concrete samples.

Table :18 Percentage of Residual flexural strength with respect to 28 days flexural strength in MPa of 100x100 x500 mm Beam after HCl acid curing

Percentage of Flyash	% Residual strength after 2 months acid curing	% Residual strength after 4 months acid curing
0%	94.12	94.12
30%	107.14	114.29
40%	106.67	113.33
50%	108.33	108.33

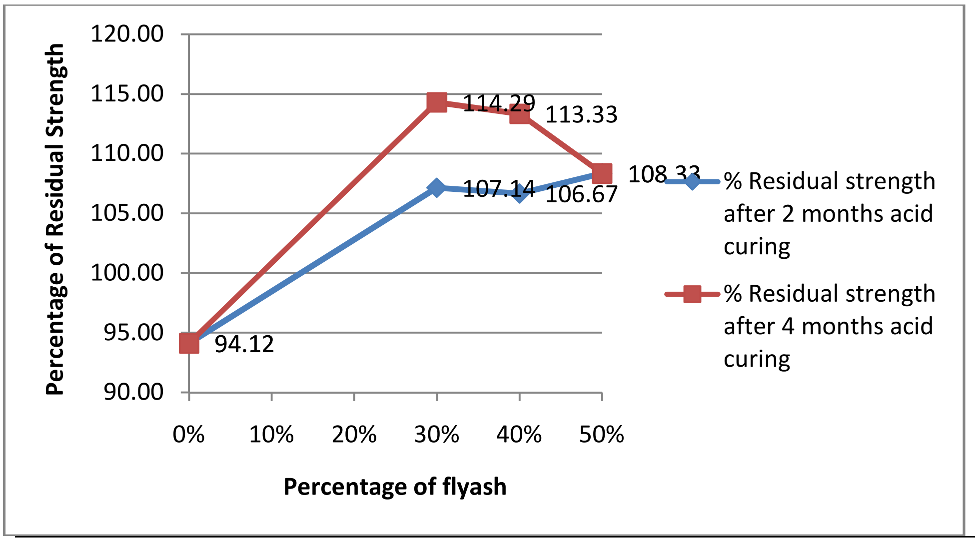


Fig.4.14 Graphical representation of percentage of Residual flexural strength with respect to 28 days flexural strength in MPa of 100x100 x500 mm Beam after HCl acid curing

Discussion on result:

In case of HCl acid curing:

2 month and 4 month Flexural Strength maximum for the concrete sample having 40% flyash and lowest for concrete sample having 50% flyash.

With respect to 28 days Flexural Strength 2 month and 4 month Flexural Strength is more for all samples except the concrete sample having OPC.

With respect to 2 month Flexural Strength, 4 month Flexural Strength is more for all samples except the concrete sample having OPC.

The samples having flyash show better Flexural Strength due to pozzolanic action of flyash. unreactive portion of fly ash act as micro aggregates and fills up the matrix to render packing effect and results in increased strength

There is no adverse effect of acid to decrease the Flexural Strength of the flyash based concrete due to presence of flyash.

The maximum residual value after 2 and 4 months acid curing has been noticed for the concrete Sample having 30% fly ash.

Table :19 Results of flexural strengths in MPa of 100x100 x500 mm Beam after water and HNO_3 acid curing

Percentage of Flyash	Strength after 28 days water curing	Strength after 2 months acid curing	Strength after 4 months acid curing
OPC+0%	8.50	8.00	7.50
OPC+30%	7.00	7.50	8.00
OPC+40%	7.50	8.00	8.50
OPC+50%	6.00	6.50	7.00
PPC	7.50	8.00	8.00

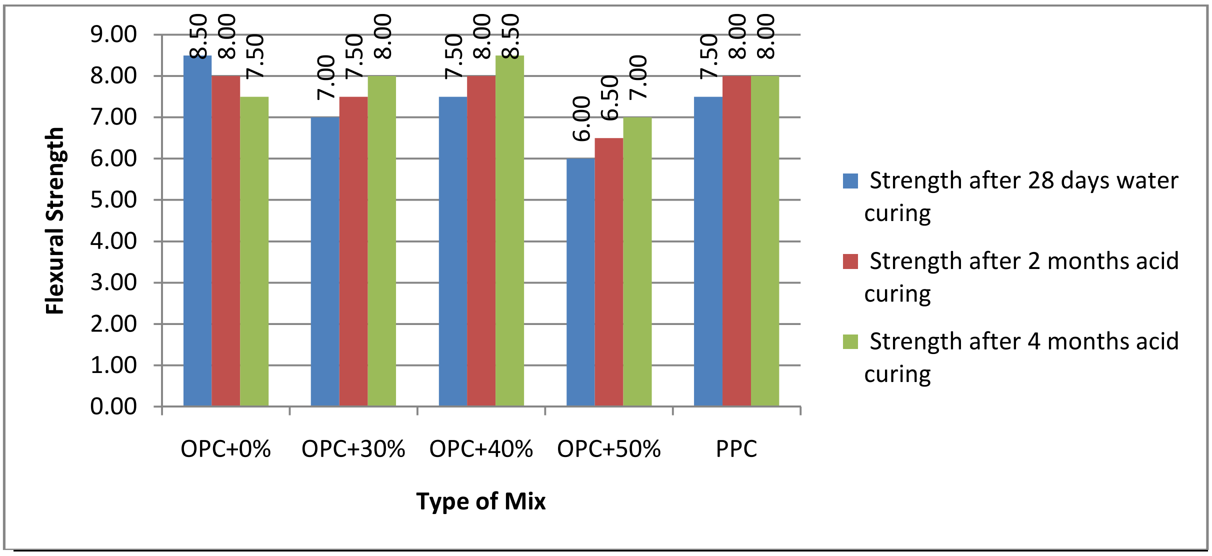


Fig.4.15 Graphical representation of of flexural strengths in MPa of 100x100 x500 mm Beam after water and HNO_3 acid curing

Table :20 Percentage of Residual flexural strength with respect to 28 days flexural strength in MPa of 100x100 x500 mm Beam after HNO_3 acid curing

Percentage of Flyash	% Residual strength after 2 months acid curing	% Residual strength after 4 months acid curing
0%	94.12	88.24
30%	107.14	114.29
40%	106.67	113.33
50%	108.33	116.67

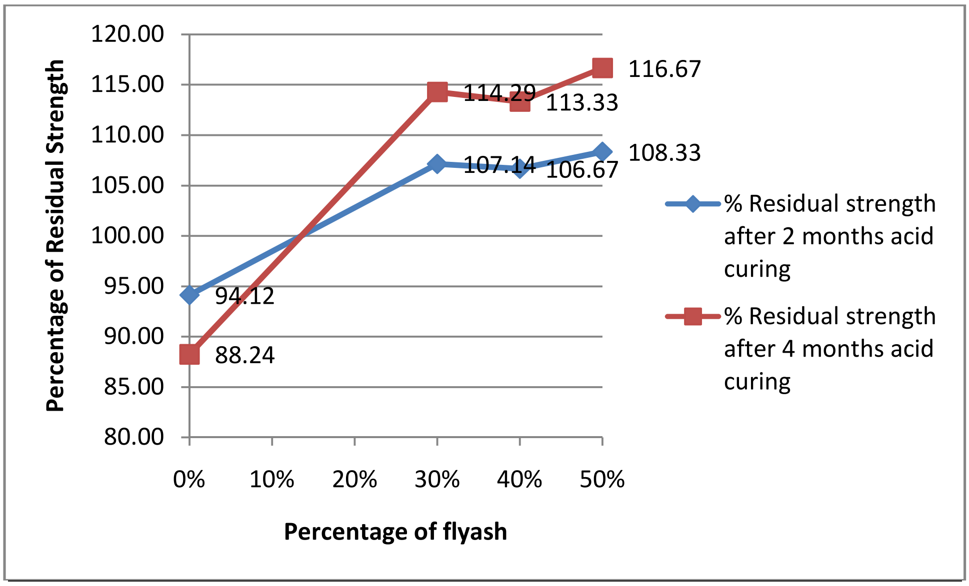


Fig.4.16 Graphical representation of Residual flexural strength with respect to 28 days flexural strength in MPa of 100x100 x500 mm Beam after HNO_3 acid curing

Discussion on result:

In case of HNO_3 acid curing:

In case of HNO_3 acid curing the concrete samples show same trend of results as in case of HCl acid curing.

The maximum residual value after 2 and 4 months acid curing has been noticed for the concrete Sample having 30% fly ash.

4.2.4 Results of UPV Test:

Table :21 Results of UPV test of 150x150x150 mm cube after water and HCl acid curing

Percentage of Flyash	value after 28 days water curing	Value after 2 months acid curing	Value after 4 months acid curing
OPC+0%	4.791	4.599	4.552
OPC+30%	4.515	4.605	4.643
OPC+40%	4.529	4.624	4.773
OPC+50%	4.373	4.479	4.538
PPC	4.516	4.860	4.870

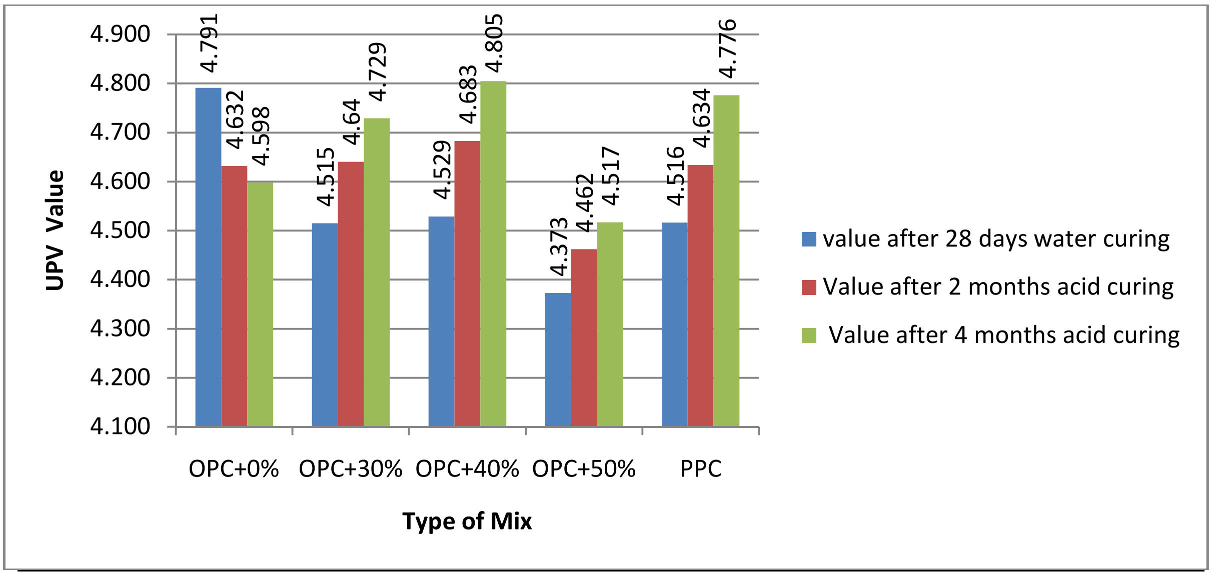


Fig.4.17Graphical representation of of UPV value of 150x150x150 mm cube after water and HCl acid curing

Discussion on result:

28 days UPV:

The trend of result of 28 days UPV values are same and due to the same reasons as the 28 days Compressive strength for all the concrete samples.

Table :22 Percentage of Residual UPV value with respect to 28 days UPV value of 150x150x150 mm cube after HCl acid curing

Percentage of Flyash	% Residual value after 2 months acid curing	% Residual value after 4 months acid curing
0%	95.99	95.01
30%	101.99	102.83
40%	102.10	105.39
50%	102.42	103.77

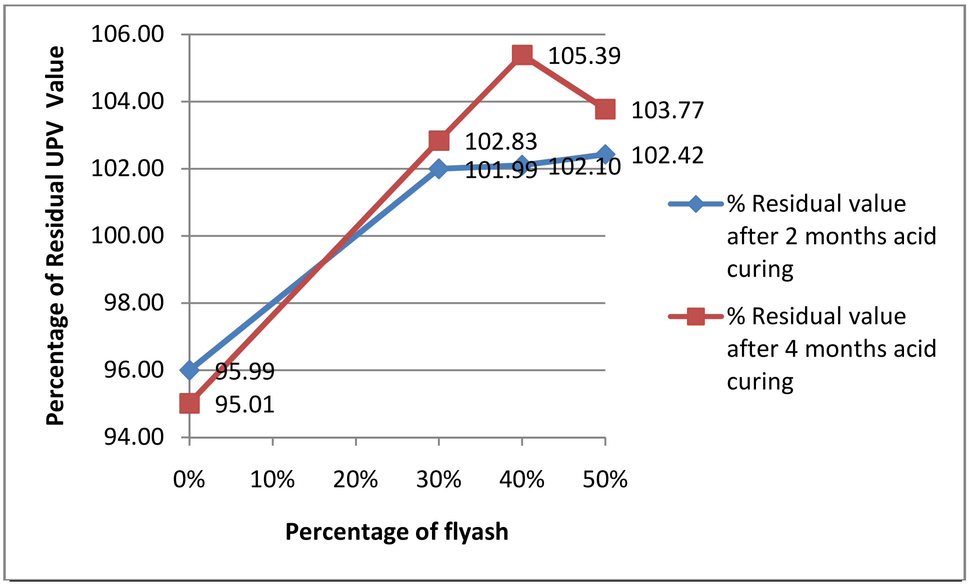


Fig.4.18 Graphical representation of Residual UPV value with respect to 28 days UPV value of 150x150x150 mm cube

Observation of result:

In case of HCl acid curing:

2 month and 4 month UPV value is maximum for the concrete sample having 40% flyash and lowest for concrete sample having 50% flyash.

With respect to 28 days UPV value 2 month and 4 month UPV value is more for all samples except the concrete sample having OPC.

With respect to 2 month UPV value, 4 month UPV value is more for all samples except the concrete sample having OPC.

The samples having flyash show better UPV value due to pozzolanic action of flyash.

There is no adverse effect of acid to decrease the UPV value of the flyash based concrete due to presence of flyash.

The maximum residual value after 2 and 4 months acid curing has been noticed for the concrete Sample having 40% fly ash

Table :23 Results of UPV test of 150x150x150 mm cube after water and HNO_3 acid curing

Percentage of Flyash	value after 28 days water curing	Value after 2 months acid curing	Value after 4 months acid curing
OPC+0%	4.791	4.632	4.598
OPC+30%	4.515	4.64	4.729
OPC+40%	4.529	4.683	4.805
OPC+50%	4.373	4.462	4.517
PPC	4.516	4.634	4.776

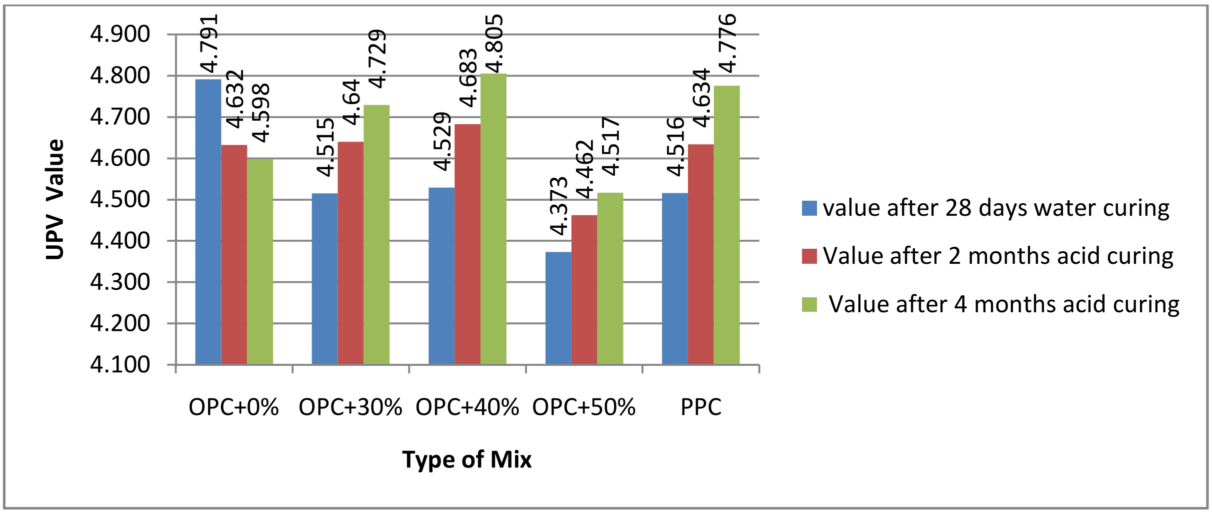


Fig.4.19 Graphical representation of of UPV test of 150x150x150 mm cube after water and HNO_3 acid curing

Table :24 Percentage of Residual UPV value with respect to 28 days UPV value of 150x150x150 mm cube after HNO_3 acid curing

Percentage of Flyash	% Residual value after 2 months acid curing	% Residual value after 4 months acid curing
0%	96.68	95.97
30%	102.77	104.74
40%	103.40	106.09
50%	102.04	103.29

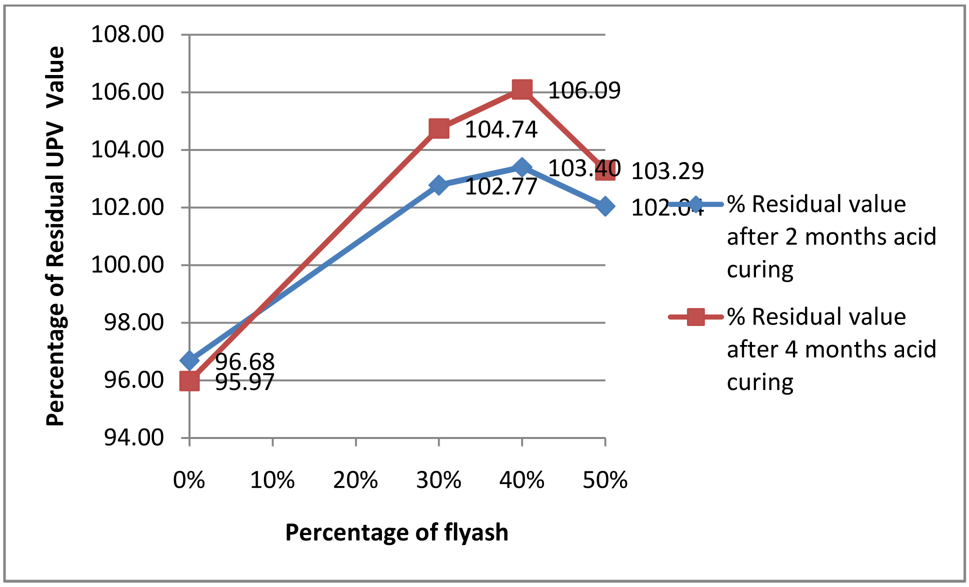


Fig.4.20 Graphical representation of Percentage of Residual UPV value with respect to 28 days UPV value of 150x150x150 mm cube after HNO_3 acid curing

Discussion on result:

In case of HNO_3 acid curing:

In case of HNO_3 acid curing the concrete samples show same trend of results as in case of HCl acid curing.

The maximum residual value after 2 and 4 months acid curing has been noticed for the concrete Sample having 30% fly ash

4.2.5 Results of Half Cell Potentiometer Test:

Table :25 Results of Half Cell potentiometer value(mV) of 150x150x150 mm cube after water and HCl acid curing

Percentage of Flyash	value after 28 days water curing	Value after 2 months acid curing	Value after 4 months acid curing
OPC+0%	-166	-484	-520
OPC+30%	-206	-463	-479
OPC+40%	-149	-469	-474
OPC+50%	-166	-482	-519
PPC	-124	-463	-520

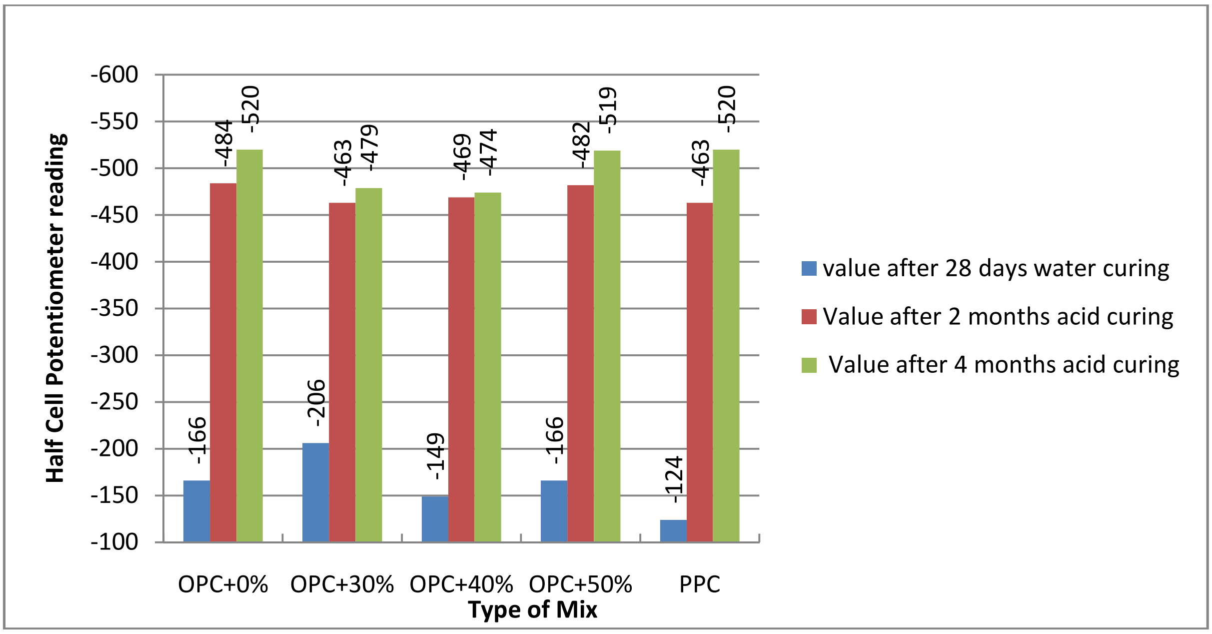


Fig.4.21 Graphical representation of Half Cell potentiometer value(mV) of 150x150x150 mm cube after water and HCl acid curing

Table :26 Percentage of Residual Half Cell potentiometer value with respect to 28 days Half Cell potentiometer value of 150x150x150 mm cube after HCl acid curing

Percentage of Flyash	% Residual value after 2 months acid curing	% Residual value after 4 months acid curing
0%	291.57	313.25
30%	224.76	232.52
40%	314.77	318.12
50%	290.36	312.65

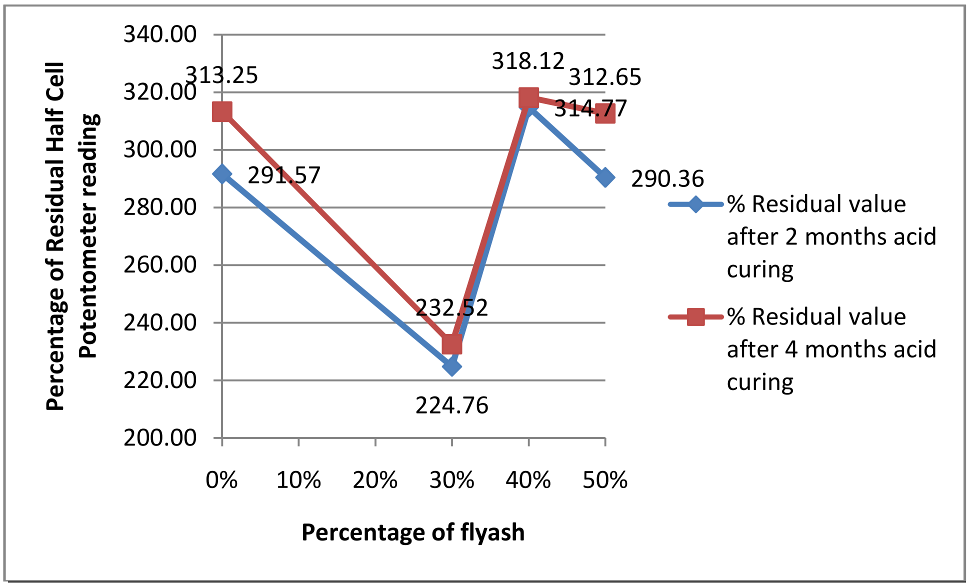


Fig.4.22 Graphical representation Percentage of Residual Half Cell potentiometer value with respect to 28 days Half Cell potentiometer value of 150x150x150 mm cube after HCl acid curing

Discussion on result:

In case of HCl acid curing:

It is found that the concrete samples give Half Cell potentiometer value greater than -200 mV after 28 days water curing which is a indication of low chances of corrosion activity. But after acid curing the values for all the concrete samples increase to near about -500 mV or even less than that which is a indication of high or severe chance of corrosion activity.

The chance of corrosion activity of steel increases due to carbonation attack and chloride attack. In the carbonation attack, due to carbonation of free lime, alkaline environment in the concrete comes down which disturbs the passive iron oxide film on the reinforcement. As the concrete is permeable, during the acid curing the ingress of water and acid infuse to the surface of steel which initiates the electrochemical process and as a result chance of corrosion activity increases.

In the Chloride attack, Chloride ions which produce due to the disruption of Chloride ion from HCl acid, which ingress into the concrete and increases the chance of corrosion.

Table :27 Results of Half Cell potentiometer value(mV) of 150x150x150 mm cube after water and HNO_3 acid curing

Percentage of Flyash	value after 28 days water curing	Value after 2 months acid curing	Value after 4 months acid curing
OPC+0%	-166	-226	-334
OPC+30%	-206	-270	-378
OPC+40%	-149	-276	-383
OPC+50%	-166	-348	-483
PPC	-124	-266	-380

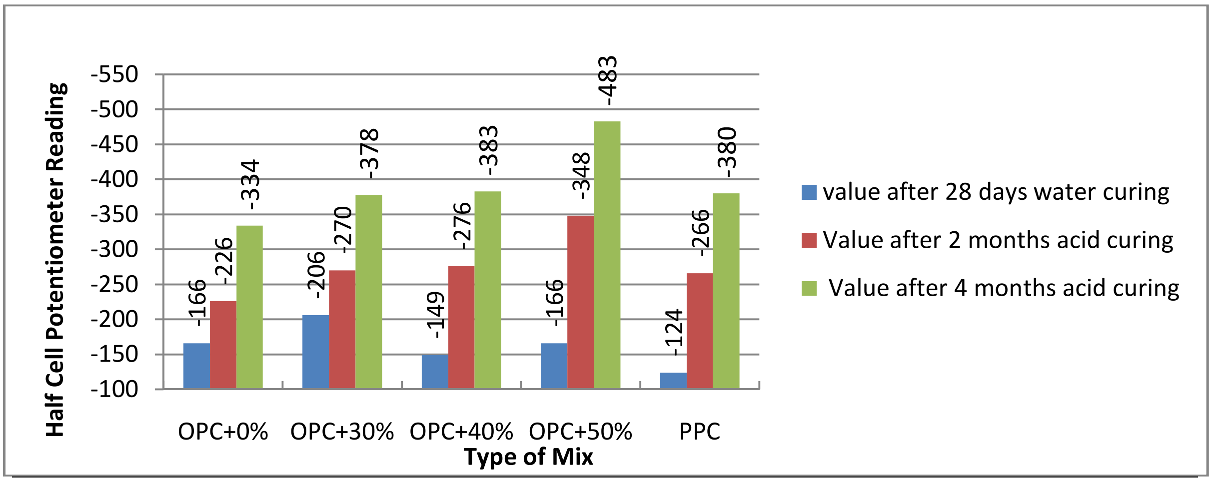


Fig.4.23 Graphical representation of Half Cell potentiometer value(mV) of 150x150x150 mm cube after water and HNO_3 acid curing

Table :28 Percentage of Residual Half Cell potentiometer value with respect to 28 days Half Cell potentiometer value of 150x150x150 mm cube after HNO_3 acid curing

Percentage of Flyash	% Residual value after 2 months acid curing	% Residual value after 4 months acid curing
0%	136.14	201.20
30%	131.07	183.50
40%	185.23	257.05
50%	209.64	306.45

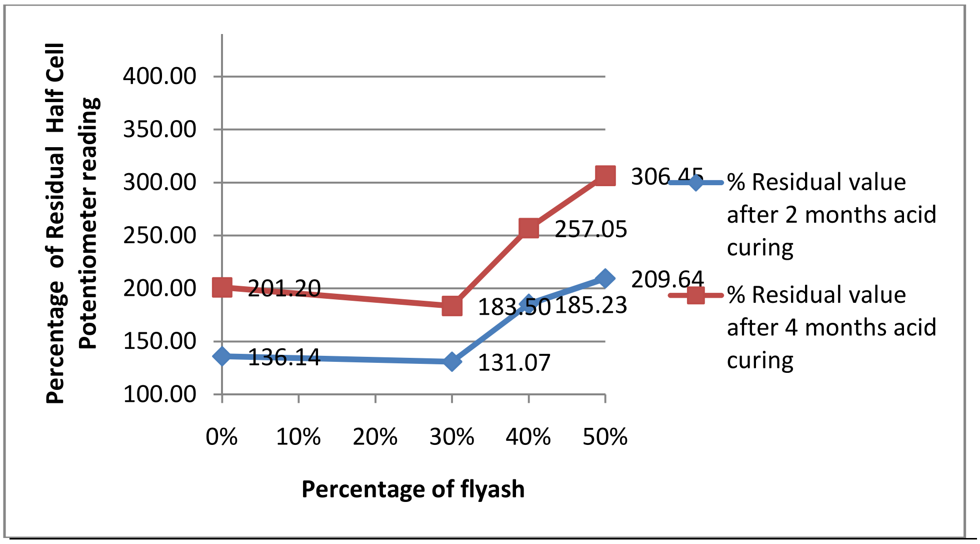


Fig.4.24 Graphical representation Percentage of Residual Half Cell potentiometer value with respect to 28 days Half Cell potentiometer value of 150x150x150 mm cube after HNO_3 acid curing

Discussion on result:

In case of HNO3 acid curing:

It is found that the concrete samples give Half Cell potentiometer value greater than -200 mV which is a indication of low chances of corrosion activity. After 2 months of acid curing the values for all the concrete samples increase to - 200 to -350 mV which is a indication of of intermediate chance of corrosion activity, After 4 months of acid curing the values for all the concrete samples increase to near about to -350 mV or even less than that which is a indication of high chance of corrosion activity.

The chance of corrosion activity of steel increase takes place due to carbonation attack only. In the carbonation attack, due to carbonation of free lime, alkaline environment in the concrete comes down which disturbs the passive iron oxide film on the reinforcement. As the concrete is permeable, during the acid curing the ingress of water and acid infuse to the surface of steel which initiates the electrochemical process and as a result chance of corrosion activity increases.

The results of the concrete samples after HNO_3 acid curing showing more Half Cell potentiometer value than HCl acid curing due to absence of Chloride ion in HNO_3 acid.

4.2.6 Results of Weight of Concrete Cube :

Table :29 Results of weight of 150x150x150 mm cube after water and HCl acid curing

Percentage of Flyash	Weight after 28 days water curing	Wight after 2 months acid curing	Weight after 4 months acid curing
OPC+0%	8.488	8.456	8.394
OPC+30%	8.412	8.408	8.398
OPC+40%	8.333	8.328	8.314
OPC+50%	8.241	8.231	8.208
PPC	8.451	8.434	8.424

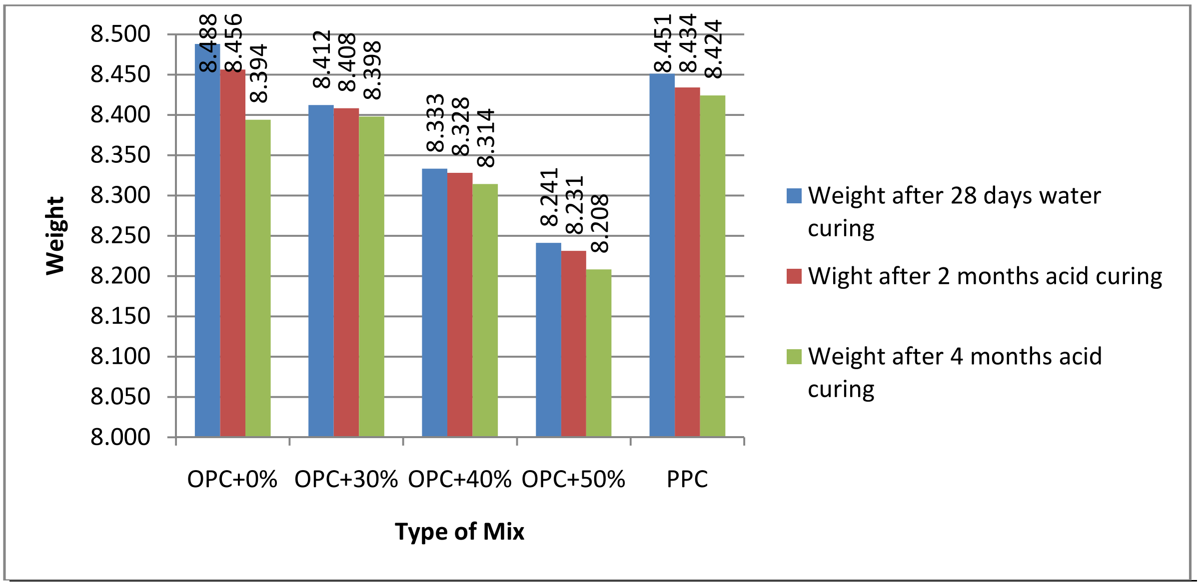


Fig.4.25 Graphical representation of weight of 150x150x150 mm cube after water and HCl acid curing

Table :30 Percentage of Residual weight with respect to 28 days weight of 150x150x150 mm cube after HCl acid curing

Percentage of Flyash	% Residual strength after 2 months acid curing	% Residual strength after 4 months acid curing
0%	99.62	98.89
30%	99.95	99.83
40%	99.94	99.77
50%	99.88	99.60

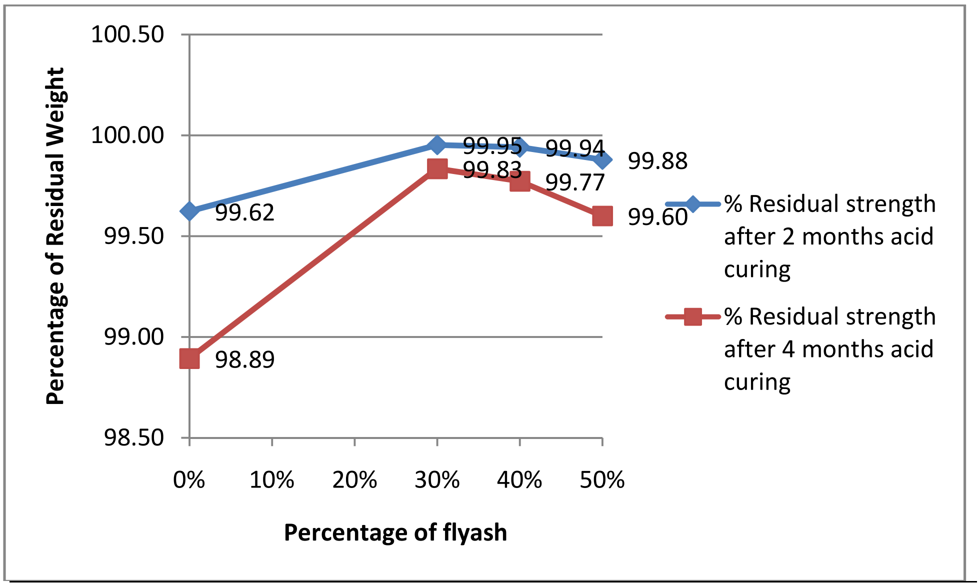


Fig.4.26 Graphical representation of Percentage of Residual weight with respect to 28 days weight of 150x150x150 mm cube after HCl acid curing

Discussion on result:

In case of HCl acid curing:

It is seen from the results that maximum weight loss after acid curing occurred in case of the concrete sample having OPC cement as the acid reacts more strongly with pure OPC cement than OPC cement mixed with flyash due to unreacted free lime generated in the Hydration process of OPC cement. In flyash Concrete these free lime react with the flyash through the pozzolanic reaction reduce the alkaline nature of the concrete.

The maximum residual value of weight observed for the concrete sample having 30% flyash.

Table :31 Results of weight of 150x150x150 mm cube after water and HNO_3 acid curing

Percentage of Flyash	Weight after 28 days water curing	Wight after 2 months acid curing	Weight after 4 months acid curing
OPC+0%	8.488	8.464	8.405
OPC+30%	8.433	8.419	8.406
OPC+40%	8.312	8.297	8.286
OPC+50%	8.241	8.223	8.205
PPC	8.451	8.437	8.419

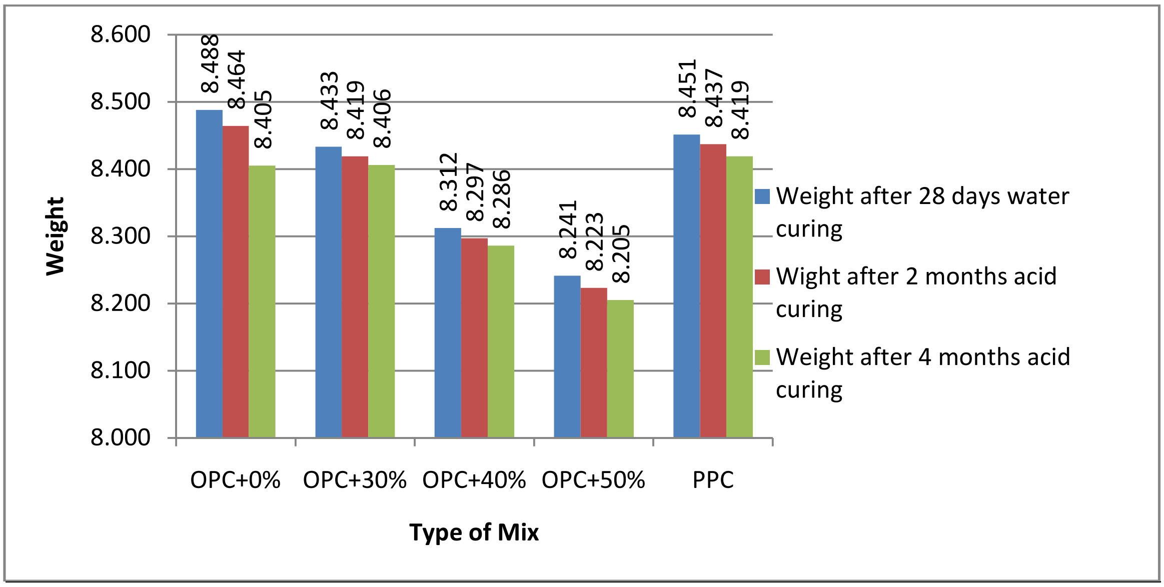


Fig.4.27 Graphical representation of weight of 150x150x150 mm cube after water and HNO_3 acid curing

Table :32 Percentage of Residual weight with respect to 28 days weight of 150x150x150 mm cube after HNO_3 acid curing

Percentage of Flyash	% Residual strength after 2 months acid curing	% Residual strength after 4 months acid curing
0%	99.72	99.02
30%	100.08	99.93
40%	99.57	99.44
50%	99.78	99.56

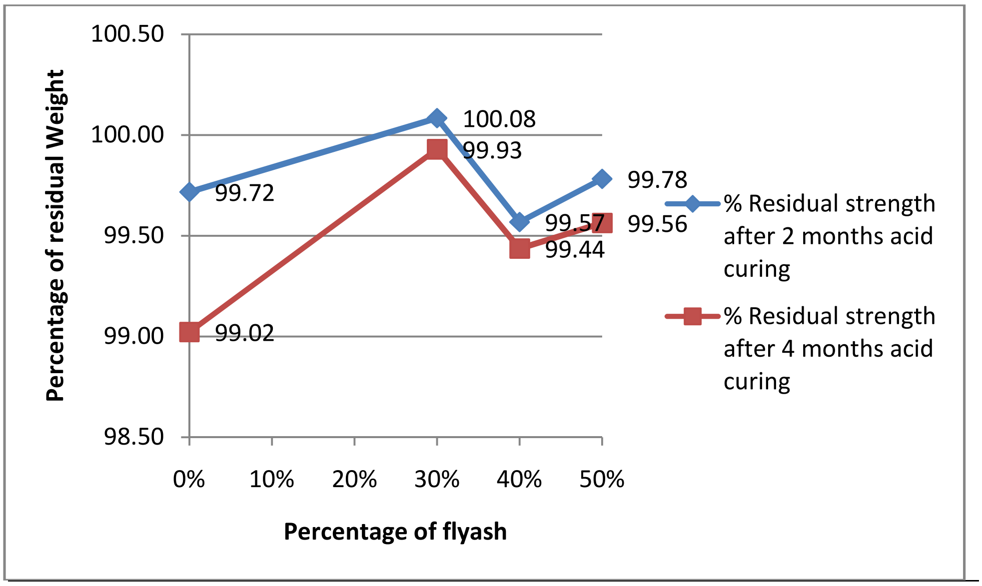


Fig.4.28 Graphical representation of Percentage of Residual weight with respect to 28 days weight of 150x150x150 mm cube after HNO_3 acid curing

Discussion on result:

In case of HNO_3 acid curing:

Same trend of results are seen in case of HNO_3 acid curing due to same reason as HCl acid curing.

4.3 Test results of Sorptivity Test:

Table :33 Result for 50x50x50 mm mortar cube Sorptivity test (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	269.04	0	2500	0.001	0
	60	8	269.19	0.15	2500	0.001	0.060
	300	17	269.27	0.23	2500	0.001	0.092
	600	24	269.43	0.39	2500	0.001	0.156
	1200	35	269.47	0.43	2500	0.001	0.172
	1800	42	269.51	0.47	2500	0.001	0.188
	3600	60	269.61	0.57	2500	0.001	0.228
	7200	85	269.74	0.7	2500	0.001	0.280
	10800	104	269.77	0.73	2500	0.001	0.292
	14400	120	269.87	0.83	2500	0.001	0.332
	18000	134	270.00	0.96	2500	0.001	0.384
	21600	147	270.14	1.1	2500	0.001	0.440
1	86400	294	270.75	1.71	2500	0.001	0.684
2	172800	416	271.01	1.97	2500	0.001	0.788
3	259200	509	271.32	2.28	2500	0.001	0.912
4	345600	588	271.35	2.31	2500	0.001	0.924
5	432000	657	271.48	2.44	2500	0.001	0.976
6	518400	720	271.54	2.5	2500	0.001	1.000
7	604800	778	271.72	2.68	2500	0.001	1.072
8	691200	831	271.97	2.93	2500	0.001	1.172

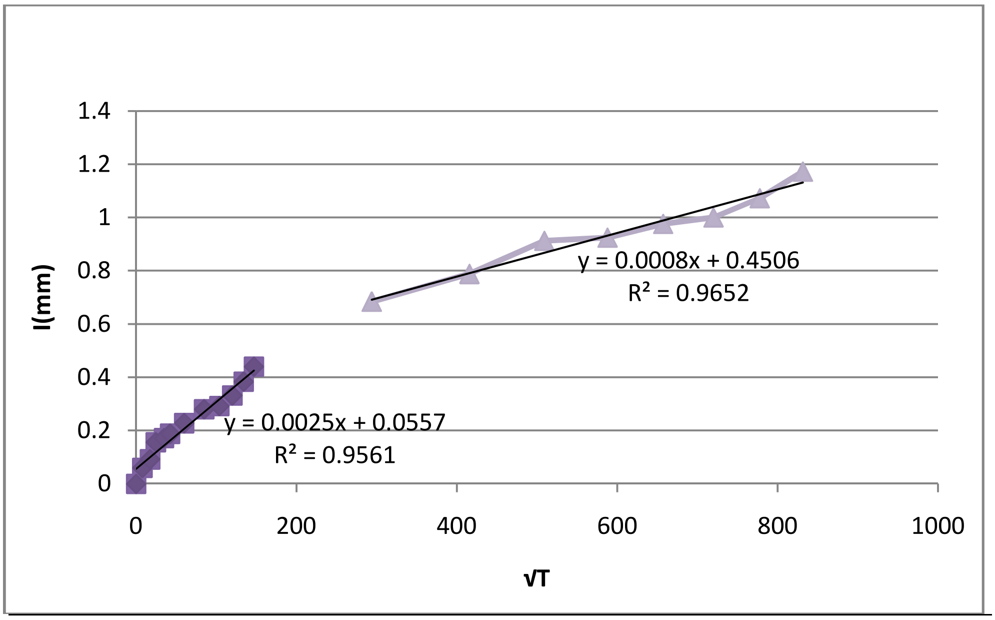


Table :34 Result for 50x50x50 mm mortar cube Sorptivity test (OPC+30% Flyash):

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	263.43	0	2500	0.001	0
	60	8	263.58	0.15	2500	0.001	0.060
	300	17	263.79	0.36	2500	0.001	0.144
	600	24	264.02	0.59	2500	0.001	0.236
	1200	35	264.08	0.65	2500	0.001	0.26
	1800	42	264.26	0.83	2500	0.001	0.332
	3600	60	264.51	1.08	2500	0.001	0.432
	7200	85	264.72	1.29	2500	0.001	0.516
	10800	104	264.80	1.37	2500	0.001	0.548
	14400	120	264.97	1.54	2500	0.001	0.616
	18000	134	265.34	1.91	2500	0.001	0.764
	21600	147	265.48	2.05	2500	0.001	0.820
1	86400	294	266.41	2.98	2500	0.001	1.192
2	172800	416	266.8	3.37	2500	0.001	1.348
3	259200	509	266.83	3.4	2500	0.001	1.360
4	345600	588	266.88	3.45	2500	0.001	1.380
5	432000	657	266.93	3.5	2500	0.001	1.400
6	518400	720	267.02	3.59	2500	0.001	1.436
7	604800	778	267.14	3.71	2500	0.001	1.484
8	691200	831	267.32	3.89	2500	0.001	1.556

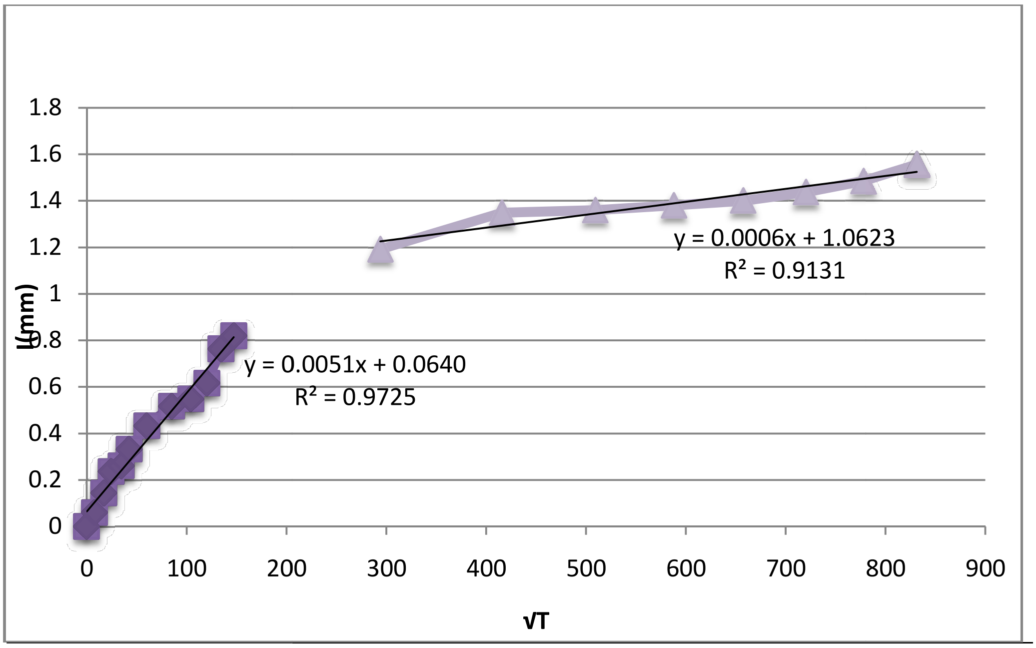


Fig.4.30 Graphical representation of 50x50x50 mm mortar cube Sorptivity test(OPC+30% Flyash

Table :35 Result for 50x50x50 mm mortar cube Sorptivity test (OPC+40% Flyash):

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	260.51	0	2500	0.001	0
	60	8	260.69	0.18	2500	0.001	0.072
	300	17	260.94	0.43	2500	0.001	0.172
	600	24	261.06	0.55	2500	0.001	0.22
	1200	35	261.12	0.61	2500	0.001	0.244
	1800	42	261.28	0.77	2500	0.001	0.308
	3600	60	261.47	0.96	2500	0.001	0.384
	7200	85	261.65	1.14	2500	0.001	0.456
	10800	104	261.73	1.22	2500	0.001	0.488
	14400	120	261.88	1.37	2500	0.001	0.548
	18000	134	262.09	1.58	2500	0.001	0.632
	21600	147	262.33	1.82	2500	0.001	0.728
1	86400	294	263.01	2.50	2500	0.001	1.000
2	172800	416	263.47	2.96	2500	0.001	1.184
3	259200	509	263.48	2.97	2500	0.001	1.188
4	345600	588	263.49	2.98	2500	0.001	1.192
5	432000	657	263.6	3.09	2500	0.001	1.236
6	518400	720	263.64	3.13	2500	0.001	1.252
7	604800	778	263.84	3.33	2500	0.001	1.332
8	691200	831	263.96	3.45	2500	0.001	1.380

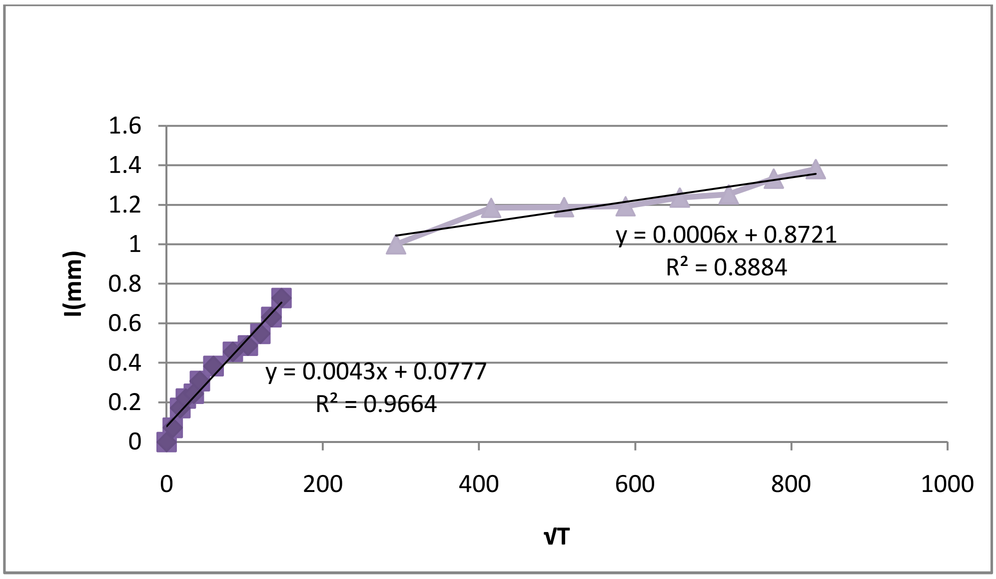


Fig.4.31 Graphical representation of 50x50x50 mm mortar cube Sorptivity test (OPC+40% Flyash)

Table :36 Result for 50x50x50 mm mortar cube Sorptivity test (OPC+50% Flyash):

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	247.42	0.00	2500	0.001	0.000
	60	8	247.58	0.16	2500	0.001	0.064
	300	17	247.72	0.30	2500	0.001	0.120
	600	24	247.9	0.48	2500	0.001	0.192
	1200	35	248.07	0.65	2500	0.001	0.260
	1800	42	248.22	0.80	2500	0.001	0.320
	3600	60	248.43	1.01	2500	0.001	0.404
	7200	85	248.77	1.35	2500	0.001	0.540
	10800	104	248.99	1.57	2500	0.001	0.628
	14400	120	249.29	1.87	2500	0.001	0.748
	18000	134	249.43	2.01	2500	0.001	0.804
	21600	147	249.72	2.30	2500	0.001	0.920
1	86400	294	251.22	3.80	2500	0.001	1.520
2	172800	416	251.90	4.48	2500	0.001	1.792
3	259200	509	252.24	4.82	2500	0.001	1.928
4	345600	588	252.42	5.00	2500	0.001	2.000
5	432000	657	252.72	5.30	2500	0.001	2.120
6	518400	720	252.84	5.42	2500	0.001	2.168
7	604800	778	252.89	5.47	2500	0.001	2.188
8	691200	831	252.97	5.55	2500	0.001	2.220

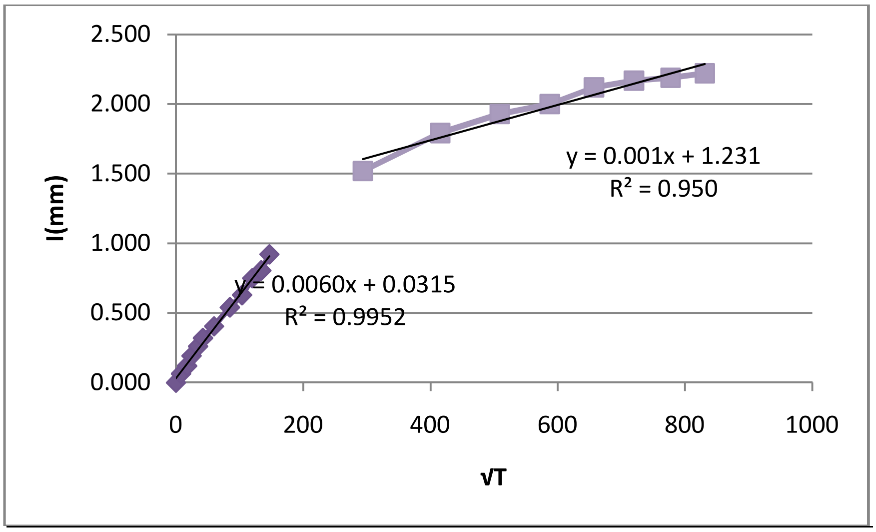


Fig.4.32 Graphical representation of 50x50x50 mm mortar cube Sorptivity test (OPC+50% Flyash)

Table :37 Result for 50x50x50 mm mortar cube Sorptivity test (PPC):

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	266.24	0	2500	0.001	0
	60	8	266.42	0.18	2500	0.001	0.072
	300	17	266.57	0.33	2500	0.001	0.132
	600	24	266.62	0.38	2500	0.001	0.152
	1200	35	266.66	0.42	2500	0.001	0.168
	1800	42	266.72	0.48	2500	0.001	0.192
	3600	60	266.86	0.62	2500	0.001	0.248
	7200	85	266.92	0.68	2500	0.001	0.272
	10800	104	266.98	0.74	2500	0.001	0.296
	14400	120	267.07	0.83	2500	0.001	0.332
	18000	134	267.28	1.04	2500	0.001	0.416
	21600	147	267.41	1.17	2500	0.001	0.468
1	86400	294	268.18	1.94	2500	0.001	0.776
2	172800	416	268.68	2.44	2500	0.001	0.976
3	259200	509	268.78	2.54	2500	0.001	1.016
4	345600	588	268.77	2.58	2500	0.001	1.032
5	432000	657	268.87	2.63	2500	0.001	1.052
6	518400	720	268.93	2.69	2500	0.001	1.076
7	604800	778	269.12	2.88	2500	0.001	1.152
8	691200	831	269.25	3.01	2500	0.001	1.204

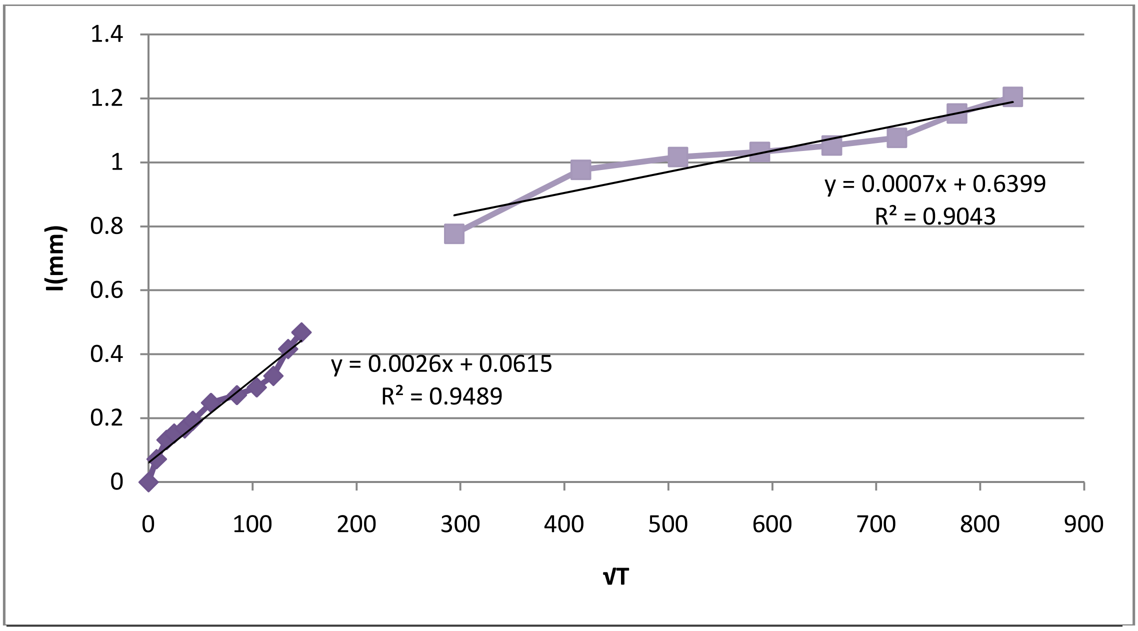


Fig.4.33 Graphical representation of 50x50x50 mm mortar cube Sorptivity test (PPC)

Table :38 Slope of Initial Sorptivity

Percentage of Flyash	Slope for initial sorptivity
OPC+0%	0.0025
OPC+30%	0.0051
OPC+40%	0.0043
OPC+50%	0.0060
PPC	0.0026

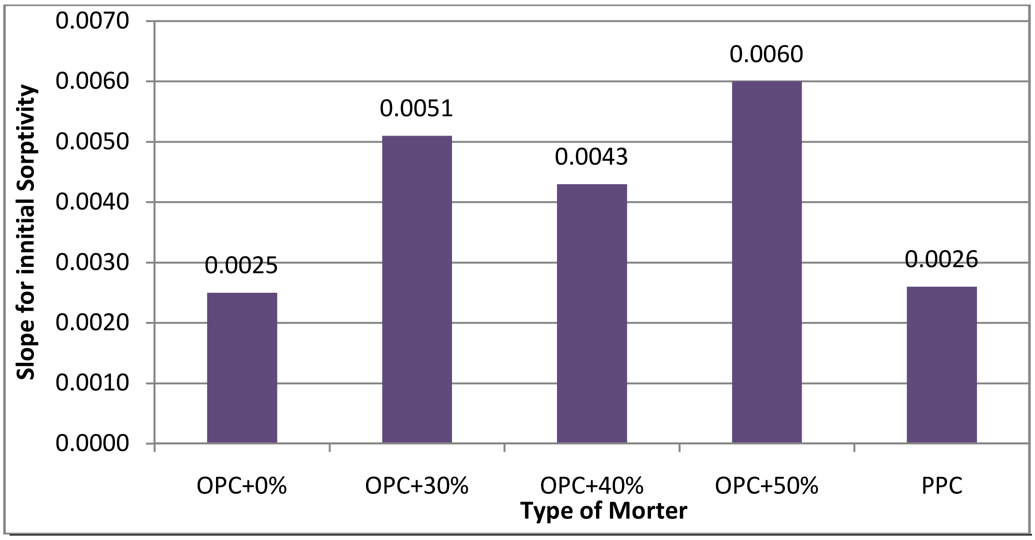


Fig.4.34 Graphical representation of Slope for initial sorptivity

Discussion on result:

Concrete samples having OPC and PPC cement shows very low value of slope for the graph plotted for Initial Sorptivity which is a indication of a compact matrix having very less porosity. Maximum value observed in case of the concrete sample having 50% flyash and it is due to greater water cement ratio used for this concrete during its mixing for not getting proper workability at desired water cement ratio i.e. 0.40 which has been used for all other concrete mixes. concrete sample having 40% flyash gives a moderate value of slope for the graph plotted for Initial Sorptivity i.e. 0.0043.

Table :39 Slope of Secondery Sorptivity

Percentage of Flyash	Slope for secondary sorptivity
OPC+0%	0.0008
OPC+30%	0.0006
OPC+40%	0.0006
OPC+50%	0.0010
PPC	0.0007

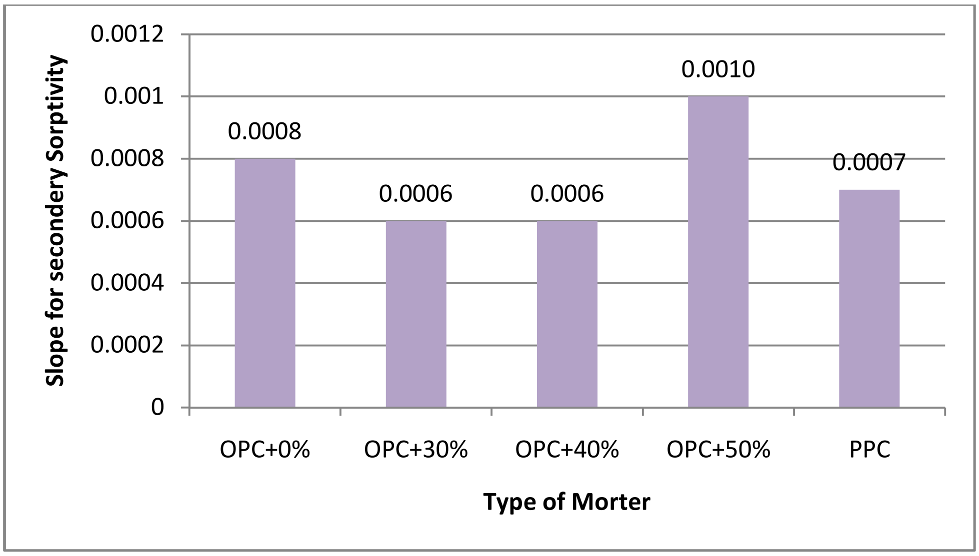


Fig.4.35 Graphical representation of Slope for initial sorptivity

Discussion on result:
Same trend of result but having very small values can be seen in case of Secondary sorptivity and the reason behind the result is same as Initial Sorptivity.

Chapter-5

CONCLUSION

5.1 General:

It has been noticed from various results that the concrete having 40% Flyash replacing the OPC cement has achieved considerable Compressive strength, Tensile Strength and Flexural Strength and the aggressive effect due to acid exposure also very less for this type of concrete which is a indication of adequate durability without only one drawback i.e low initial 7 days compressive strength.

So 40% replacement of Flyash can be considered as a optimal mix which can be commercially used both economically and safely as a sustainable blended concrete upto a grade of M-30 in the construction industry**.**

5.2 Limitation of study:

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

2) Acid exposure was done for 2 and 4 months only which is insufficient to assess long term durability. In long period durability behavior of concrete may be changed.

3) Due to limited period of time, percentage variations of percentage in acid could not be possible. More variations were needed.

4) Micro structural study could not been done. Micro structural study could give more detailed investigation data.

5) Addition of extra quantity of admixture could not be possible in the concrete mix having 30% and 40% flyash to increase the slump and study of the behavior of the mixes.

5.3 Future scope of work:

1) 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.

2) This experiment is done in for a fixed concentration of Hydrochloric and Nitric acid. But experiments in different concentrations of acid solution are needed.

3) Experiments for Flyash replacement percentages upto 100% may be done to see how strength varies.

4) By partial replacements of cement with fly ash the strength of concrete increases. For a fixed target strength redesign of mix is needed to find the specific amount cementitious material.

5) This experiment was performed with fixed amount of water reducing admixture except one mix i.e. with 50% flyash. But water demand varies with different percentage of replacements. Sometimes mix getting stiffer. 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) Sulphate attack, 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 and IS 456:2000)

Stipulations for proportioning

(Applicable to all types of mixes)

a) Maximum nominal size of aggregate	: 20mm
b) Exposure condition	: Severe
c) Minimum cementious material content	: 320 Kg
d) Maximum cementious material content	: 450 kg
e) Maximum water cement ratio	: 0.45
f) Workability	: Very low
g) Type of aggregate	: Crushed angular
h) Chemical Admixture Type	: Super plasticizer
i) Degree of supervision	: Good

Sample calculation of
mix Design for Mix Type-1

MIX :-Only OPC (M-30)

Target Mean strength=Fck+1.65S=	38.250	N/mm^2
W/C ratio=	0.40	
Maximum water content=	186.00	Kg
using chemical admixture water content reduced to=	167.40	Kg
Cement content=	418.50	Kg
Adopt Cement content=	420	Kg
OPC Cement content=	420	Kg
Volume of OPC cement=	0.135	m^3 (Density=3120 kg/m^3)
Water content=	0.168	m^3
	=168	Kg
Chemical admixture (Master Rheobuild 1125)		
@0.70% by weight of cement=	2.940	Kg
Chemical admixture by volume =	0.002371	m^3 (Density=1240kg/m^3)
=	2.371	Lit
Volume of (CA+FA)		
=1-Volume of (Cement+Flyash+Water+Admixture)=	0.695	m3
For W/C ratio of 0.50, Vol. of CA=	0.640	xVol of (CA+FA)
For W/C ratio of 0.40, Vol. of CA=	0.660	xVol of (CA+FA)
Volume of CA=0.660x0.695=	=0.459	m^3
Weight of CA=	1293.56	Kg (Density=2820 kg/m^3)
Weight of 20mm down size CA @60% of CA=	776.14	Kg
Weight of 10mm down size CA @40% of CA=	517.42	Kg
Volume of FA=Volume of (CA+FA)-Volume of CA=	0.236	m^3
Volume of Zone-III sand @100% of FA=	0.236	m^3
Weight of sand=	628.570	Kg (Density=2660 kg/m^3)
Summary		
OPC=	420	Kg
Water=	167	Kg
20mm down Stone chips	776	Kg
10mm down stone chips=	517	Kg
Zone-III sand=	629	Kg
Admixture(Master Rheobuild 1125)=	2.371	Lit

Sample calculation of mix Design for Mix Type-2

MIX :- 70%OPC +30% Flyash (M-30)

Target Mean strength=Fck+1.65S=	38.250	N/mm^2
W/C ratio=	0.40	
Maximum water content=	186.00	Kg
using chemical admixture water content reduced to=	167.40	Kg
Cementitious materials content=	418.50	Kg
Adopt Cementitious materials content=	420	Kg
OPC Cement content=	294	Kg
Flyash content=	126	Kg
Volume of OPC cement=	0.094	m^3 (Density=3120 kg/m^3)
Volume of flyash=	0.056	M^3 (Density=2267 kg/m^3)
Water content=	0.168	m^3
	=168	Kg
Chemical admixture (Master Rheobuild 1125)		
@0.70% by weight of cementitious material=	2.940	Kg
Chemical admixture by volume =	0.002371	m^3 (Density=1240kg/m^3)
=	2.371	Lit
Volume of (CA+FA)		
=1-Volume of (Cement+Flyash+Water+Admixture)=	0.680	m^3
For W/C ratio of 0.50, Volume of CA=	0.640	xVol of (CA+FA)
For W/C ratio of 0.40, Volume of CA=	0.660	xVol of (CA+FA)
Volume of CA=0.660x0.680=	=0.449	m^3
Weight of CA=	1265.28	Kg (Density=2820 kg/m^3)
weight of 20mm down size CA @60% of CA=	759.17	Kg
weight of 10mm down size CA @40% of CA=	506.11	Kg
Volume of FA=Volume of (CA+FA)-Volume of CA=	0.231	m^3
Volume of Zone-III sand @100% of FA=	0.231	m^3
Weight of sand=	614.828	Kg (Density=2660 kg/m^3)
Summary		
OPC=	294	Kg
Flyash=	126	Kg
Water=	167	Kg
20mm down Stone chips	759	Kg
10mm down stone chips=	506	Kg
Zone-III sand=	615	Kg
Admixture(Master Rheobuild 1125)=	2.371	Lit

Sample calculation of mix Design for Mix Type-3

MIX :- 60% OPC +40% Flyash (M-30)

Target Mean strength=Fck+1.65S=	38.250	N/mm2
W/C ratio=	0.40	
Maximum water content=	186.00	Kg
using chemical admixture water content reduced to=	167.40	Kg
Cementitious materials content=	418.50	Kg
Adopt Cementitious materials content=	420	Kg
OPC Cement content=	252	Kg
Flyash Content=	168	Kg
Volume of OPC cement=	0.081	m^3 (Density=3120 kg/m^3)
Volume of Flyash=	0.074	m^3 (Density=2267 kg/m^3)
Water content=	0.168	m^3
=	168	Kg
Chemical admixture (Master Rheobuild 1125)		
@0.70% by weight of cementitious material =	2.940	Kg
Chemical admixture by volume =	0.002371	m^3 (Density=1240 kg/m^3)
=	2.371	Lit
Volume of (CA+FA)		
=1-Volume of (Cement+Flyash+Water+Admixture)=	0.675	m3
For W/C ratio of 0.50, Volume of CA=	0.640	xVol of (CA+FA)
For W/C ratio of 0.40, Volume of CA=	0.660	xVol of (CA+FA)
Volume of CA=0.660x0.675=	=0.445	m^3
Weight of CA=	1255.85	Kg (Density=2820 kg/m^3)
weight of 20mm down size CA @60% of CA=	753.51	Kg
weight of 10mm down size CA @40% of CA=	502.34	Kg
Volume of FA=Volume of (CA+FA)-Volume of CA=	0.229	m3
Volume of Zone-III sand @100% of FA=	0.229	m3
Weight of sand=	610.247	Kg (Density=2660 kg/m^3)
Summary		
OPC=	252	Kg
Flyash=	168	Kg
Water=	167	Kg
20mm down Stone chips	754	Kg
10mm down stone chips=	502	Kg
Zone-III sand=	610	Kg
Admixture(Master Rheobuild 1125)=	2.371	Lit

Sample calculation of mix Design for Mix Type-4

MIX:- 50% OPC +50% Flyash (M-30)

Target Mean strength=Fck+1.65S=	38.250	N/mm2
W/C ratio=	0.45	
Maximum water content=	186.00	Kg
using chemical admixture water content reduced to=	167.40	Kg
Cementitious materials content=	372.00	Kg
Adopt Cementitious materials content=	372.00	Kg
OPC Cement content=	186.00	Kg
Flyash Content=	186.00	Kg
volume of OPC cement=	0.060	m3 (Density=3120 kg/m^3)
Volume of Flyash=	0.082	m3 (Density=2267 kg/m^3)
Water content=	0.168	m3
=	168	Kg
Chemical admixture (Master Rheobuild 1125)		
@1.00% by weight of cementitious materials=	3.720	Kg
Chemical admixture by volume =	0.003	m3 (Density=1240 kg/m^3)
=	3.000	Lit
Volume of (CA+FA)		
=1-Volume of (Cement+Flyash+Water+Admixture)=	0.687	m3
For W/C ratio of 0.50, Volume of CA=	0.640	xVol of (CA+FA)
For W/C ratio of 0.40, Volume of CA=	0.650	xVol of (CA+FA)
Volume of CA=0.650x0.687=	0.447	m3
Weight of CA=	1260.54	Kg (Density=2820 kg/m^3)
weight of 20mm down size CA @60% of CA=	756.32	Kg
weight of 10mm down size CA @40% of CA=	504.22	Kg
Volume of FA=Volume of (CA+FA)-Volume of CA=	0.241	m3
Volume of Zone-III sand @100% of FA=	0.241	m3
Weight of sand=	638.400	Kg (Density=2660 kg/m^3)

Summary

OPC=	186	Kg
Flyash=	186	Kg
Water=	167	Kg
20mm down Stone chips	756	Kg
10mm down stone chips=	504	Kg
Zone-III sand=	638	Kg
Admixture(Master Rheobuild 1125)=	3.000	Lit

Sample calculation of mix Design for Mix Type-5

MIX:- Only PPC (M-30)

Target Mean strength=Fck+1.65S=	38.250	N/mm2
W/C ratio=	0.40	
Maximum water content=	186.00	Kg
using chemical admixture water content reduced to=	167.40	Kg
Cement content=	418.50	Kg
Adopt Cement content=	420	Kg
PPC Cement content=	420	Kg
volume of PPC cement=	0.135	m3 (Density=2900 kg/m^3)
Water content=	0.168	m3
=	168	Kg
Chemical admixture (Master Rheobuild 1125)		
@0.70% by weight of cement=	2.940	Kg
Chemical admixture by volume =	0.002371	m3 (Density=1240 kg/m^3)
=	2.371	Lit
Volume of (CA+FA)		
=1-Volume of (Cement+Flyash+Water+Admixture)=	0.685	m3
For W/C ratio of 0.40, Volume of CA=	0.640	xVol of (CA+FA)
For W/C ratio of 0.50, Volume of CA=	0.660	xVol of (CA+FA)
Volume of CA=0.660x0.685=	=0.459	m^3
0.447	=0.452	m^3
Weight of CA=	1274.55	Kg (Density=2820 kg/m^3)
weight of 20mm down size CA @60% of CA=	764.73	Kg
weight of 10mm down size CA @40% of CA=	509.82	Kg
Volume of FA=Volume of (CA+FA)-Volume of CA=	0.233	m3
Volume of Zone-III sand @100% of FA=	0.233	m3
Weight of sand=	619.334	Kg (Density=2660 kg/m^3)

Summary

PPC=	420	Kg
Water=	167	Kg
20mm down Stone chips	765	Kg
10mm down stone chips=	510	Kg
Zone-III sand=	619	Kg
Admixture(Master Rheobuild 1125)=	2.371	Lit

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