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# EFFECT OF MINERAL ADMIXTURES ON STRENGTH & DURABILITY OF REACTIVE POWDER CONCRETE

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**ABSTRACT -----**Recently the High Strength Concrete (HSC) and High Performance Concrete (HPC) have been widely used in construction projects. The construction industries focus on how to eliminate the contraction and brittleness of high strength concrete and high performance concrete and also how to improve the strength of concrete. HSC and HPC is not just a simple mixture of cement, water and aggregates. Quite often, it contains mineral components and chemical admixtures having very specific characteristics, which impart specific properties to the concrete. HSC and HPC lead to achieve the maximum compressive strength of 120 to 150 MPa. At such level of strength the coarse aggregate becomes the weakest link in concrete. In order to improve the strength and durability of concrete by the way of removing the coarse aggregate and employing the mineral admixtures and steel fibers is the philosophy to develop Reactive Powder Concrete (RPC). In this project the development of incorporated Reactive Powder Concrete (RPC) with several mineral admixtures and micro steel fiber. Four different mineral admixtures were added in RPC such as fly ash, ground granulated glass furnace slag (GGBS), Quartz powder and silica fumes, also the micro steel fibers were used. The specimens were casted for finding various properties like mechanical and durability of RPC was studied and discussed.

**Keywords—** High Performance Concrete**,** Reactive Powder Concrete, ground granulated glass furnace slag. Quartz powder, silica fumes.

## I. INTRODUCTION

### 1.1 GENERAL

Reactive powder concrete (RPC) is a new generation concrete and it was developed through microstructure enhancement techniques for cementations materials. The original concepts of Reactive powder concrete (RPC) was developed in the year of 1990s, by P.Richards and M.Cheyrezy at Bouygues laboratory in France. Reactive powder concrete is an ultra high strength, ultra high performance and high ductility composite material with advanced mechanical and durability properties. As compared to ordinary cement based materials, the primary improvements of RPC include the particle size homogeneity, porosity, and microstructures. The mechanical properties that can be achieved include the compressive strength of the range between 200 and 800 MPa, fracture energy of the range between 1200 and40,000 J/m2, and ultimate tensile strain at the order of 1%.This is generally achieved by micro-structural Engineering approach, including limination of the coarse aggregates, reducing the water-to-cementitious material ratio, lowering the CaO to $SiO_2$ ratio by introducing the silica components, and in corporation of micro steel fibers. It was reported that RPC has a remarkable flexural strength and very high ductility. Its ductility is about 250 times higher than that of conventional concrete. Low permeability, dense micro-structure and superior mechanical properties (very high compressive strength, flexural strength, fracture energy and toughness) define the RPC as an ultra-high performance concrete. RPC seems to be a promising material for special pre-stressed and precast concrete members. This material can therefore be used for industrial and nuclear waste storage facilities. Although production costs of RPC are generally high, some economical advantages also exist in RPC applications. It is possible to reduce or eliminate passive reinforcement using with steel fibers. And, due to ultra-high mechanical performance of RPC, the thickness of concrete elements can be reduced, which results in materials and cost savings.

**1.2 OBJECTIVES**

To study on effect of adding several admixtures (mineral & chemical) and micro steel fibers on mechanical and durability properties of concrete by making them light weight with ultrahigh strength.

**1.3 PRINCIPLES FOR DEVELOPING RPC**

- Eliminating of coarse aggregate for enhancement of homogeneity.
- Utilization of pozzolanic properties of silica fume.
- Optimisation of the granular mixture for the enhancement of compacted density.
- The optimal usage of super plasticizer to reduce water content in concrete and improve workability.
- Application of pressure (before and during setting) to improve compaction.

**1.4 BENEFITS OF RPC**

- RPC is a better alternative to high performance concrete and has potential to structurally compete with steel. Its superior strength combined with higher shear capacity results in significant dead load reduction and less limited shapes of structural members.Withits ductility tension failure mechanism.RPC can be used to resist all but direct primary tensile stresses. This eliminates the need for supplemental shear and other auxiliary reinforcing steel.
- RPC provides improved seismic performance by reducing inertia loads with lighter members. Allow larger elastic deflections by reducing cross sections, providing higher energy absorption and improved confinement.
- Its low and none interconnected porosity diminishes mass transfer making penetration of liquid/gas or radioactive elements nearly nonexistent.

**1.5 LIMITATIONS OF RPC**

- In RPC the least costly components of conventional concrete are basically eliminated or replaced by more expensive elements.
- The cost mineral components are higher than that of conventional concrete (5 to 10 times higher than HPC).

**1.6 APPLICATIONS OF RPC**

- Long span foot bridges.
- Light rail transit bridges.
- Precast sewer/culvert.
- Pressure pipes withstand high pressures up to 20 MPa.
- Internal beams of high cooling towers.
- Facades of buildings in aggressive environments.
- RPC are perfect material to make container for bulk packaging of nuclear wastes.

## II. LITERATURE REVIEW

**2.1 INTRODUCTION**

This chapter present an overview of literature collected from various journals, past researches and studies on Reactive Powder Concrete. The most noteworthy ofThem which are relevant to the current study are being reviewed.

**Haileyazoic, Anil.S, "MECHANICAL PROPERTIES OF RPC CONTAININGMINERAL ADMIXTURES UNDER DIFFERENT CURING REGIMES",Construction & Building Materials, 23, 2009.Ingredients**

Ordinary Portland cement, Quartz powder (0-0.4mm), Quartz sand (0.5-1.0& 1.0-3.0mm), Silica fume, Superplasticizer (Polycarboxylated based), Brass coated steel fibers (L: 6mm & Dia: 0.15mm), GGBS & Fly ash for the replacement of cement(10 % to 20%)

**Experiments**

Compressive Strength, Flexural Properties, Modulus of Elasticity for reactive powder concrete on different curing conditions.

**Conclusion**

- Compressive strength exceeded 200 MPa after standard water curing, 234 MPa after steam curing and 250 MPa attained by autoclaving.
- Steam and autoclave curing are reduced the flexural strength compared to the 28-days standard curing.

- GGBS and Fly ash are added to improve the flexural performance of RPC under steam and autoclave curing.

**SerdarAydin, halityazici, and HuseyinYigiter**, "**EFFECT OF AGGREGATE TYPEON MECHANICAL PROPERTIES OF REACTIVE POWDER CONCRETE", ACIMaterial Journal, Vol.107, Oct, 2010.**

**Ingredients**
Ordinary Portland cement, Silica fume, Aggregate (koruna, Basalt, Lime stone, Quartz,Sinteredbauxite,Granite), Fine quartz, Steel fiber, Superplasticizer, Water.
**Experiments**
Compressive strength, Flexural behavior and fracture energy, Microstructure investigations, Fiber distribution for different types of aggregates used in reactive powder concrete.
**Conclusion**

- Test results indicate that the mechanical performance of RPC can be improved by using high-strength, rough-surface aggregate.
- The compressive strength of RPC can be increased by steam curing.
- Atmospheric steam curing and autoclaving did not improve flexural performance, possibly due to the weaker bond between the fibers and matrix after these curing regimes.

Although very high compressive strength can be achieved with low-strength or smooth-surface aggregate a satisfactory flexural performance requires high strength, rough-surface textured aggregate.A micro-structural investigation revealed the very dense microstructure of RPC.

**LIU Juanhong, "DURABILITY AND MICRO-STRUCTURE OF REACTIVEPOWDER CONCRETE", WANG Lin, Vol.24, No.3, 2008.**

**Ingredients**
Ordinary Portland cement, Silica fume (Dia: 0.12 micron), Fly ash (1st class grade-45 micron sieve residue), Sand (0.16 to 0.315mm and 0.315 to 0.40mm), Water, Superplasticizer, Steel fibers (Dia: 0.12mm, L: 12-13mm).
**Experiments**
Volume shrinkage, Chlorine ion permeation experiment, Carbonization resistance of RPC, Sulphate resistance of RPC, Freezing resistance of RPC,Analysis of X-ray diffraction, analysis of EMS.
**Conclusion**

- Volume shrinkage is less than 0.04% at 28th day (In general limit of ordinary concrete shrinkage is 0.05% to 0.09%)
- Carbonization depth of RPC is zero in the condition of CO2 concentration of 20%, temperature 20'c at 28th day.
- RPC has a strong sulphate resistance and super high freezing resistance.

**3.2 METHODOLOGY CHART**

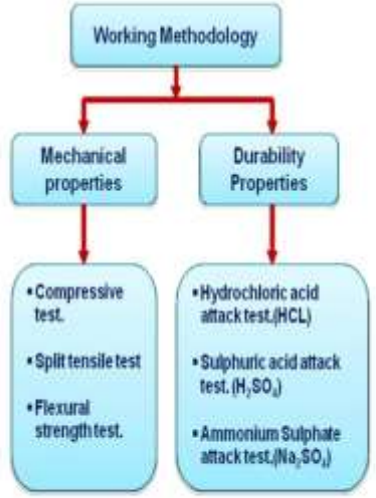


**Fig.3.2 Methodology chart**

## III. STUDIES ON INGREDIENTS

**4.1 INGREDIENTS**

The RPC considered here is prepared by the following ingredients ASTMType II Portland cement, fine sand (approximately 150–500 •m), crushed quartzpowder (approximately 5–20 µm), undensified silica fume (approximately 0.1–0.2µm), Acrylic graft–copolymer superplasticizer, and short steel fibers (approximately0.16 mm dia& 13 mm length).

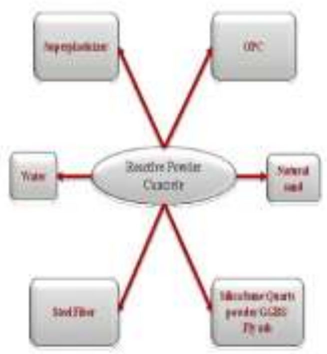

Fig.4.1 Ingredients of RPC

**4.2 CEMENT**

In the most general sense of the word, cement is a binder, a substance thatsets and hardens independently, and can bind other materials together. The mostimportant use of cement is the production of mortar and concrete to make bonding ofnatural or artificial aggregates to form a strong building material that is durable in theface of normal environmental effects.

**4.2.1 PORTLAND CEMENT**

Cement is made by heating limestone (calcium carbonate), with smallquantities of other materials (such as clay) to 1450 °C in a kiln, in a process knownas calcinations, whereby a molecule of carbon dioxide is liberated from the calciumcarbonate to form calcium oxide, or quicklime, which is then blended with the othermaterials that have been included in the mix . The resulting hard substance, called'clinker', is then ground with a small amount of gypsum into a powder to make'Ordinary Portland Cement', the most commonly used type of cement (often referredto as OPC).Portland cement is a basic ingredient of concrete, mortar and most nonspecialitygrout. The most common use for Portland cement is in the production ofconcrete. Concrete is a composite material consisting of aggregate (gravel andsand), cement, and water. As a construction material, concrete can be cast in almostany shape desired, and once hardened, can become a structural (load bearing)element. Portland cement may be grey or white.

**4.3 FINE AGGREGATE**

Sand is either round or angular grain and is often found mixed in various grading of fineness at different zones. Fine aggregate properties are evaluated as per the IS methods. The four zones of river sand are used for the preparation of mortar cubes. Though it contains impurities it has to be cleaned and well sieved so that the mortar will not affect the structure. Fine aggregate properties are evaluated as per the IS methods. The flow chart mentioned below says the tests are to be conducted for fine aggregate to know its material property.

**4.4 SILICA FUME**

In recent years significant attention has been given to the use of the pozzolansilica fume as a concrete property-enhancing material, as a partial replacement for Portland cement, or both. Silica fume has also been referred to as silica dust,condensed silica fume, microsilica, and fumed silica.Microsilica is a highly reactive pozzolan which is processed from a natural white color, it is very fine amorphous silica from the micro silica family of products. When mixed with Portland cement, Microsilica facilitates high performance concreteby achieving,

- Very low chloride ion diffusion
- Increased compressive strength
- Reduced water permeability
- Improved sulphate resistance
- Improved abrasion resistance
- Improved resistance to chemical attack
- Improved stability in geothermal environments
- Reduced efflorescence

The initial interest in the use of silica fume was mainly caused by the strict enforcement of air-pollution control measures in various countries to stop release ofthe material into the atmosphere. More recently, the availability of high range waterreducingadmixtures (HRWRA) has opened up new possibilities for the use of silicafume as part of the cementing material in concrete to produce very high strengths orvery high levels of durability or both.

**4.5 QUARTZ POWDER**

Quartz, most common of all minerals is composed of silicon dioxide or silica,$SiO_2$.It is essential component of igneous and metamorphic rock.

**4.6 GROUND GRANULATED BLAST FURNACE SLAG (GGBS)**

Blast Furnace Slag is a by product obtained in the manufacturing of pig iron in the Blast furnace and is formed by the combination of earthy constituents of iron ore with lime stone flux. Quenching process of molten slag by water is converting it into afine, granulated slag of whitish color. This granulated slag when finely ground and combined with OPC has been found to exhibit excellent cementitious properties. Glass particles of GGBS are the active part and consist of Mono-silicate, like those in OPC clinker, which dissolve on activation by any medium. Glass content in GGBS isnormally more than 85% of total volume. Specific gravity of GGBS is approximately2.7-2.90, which is lower than of OPC. Bulk density of GGBS is varying from 1200-1300 kg/m3. Normal chemical composition of Indian GGBS is shown in Table.4.6 (a)GGBS is more closure to OPC in chemical composition in compare to other mineral admixtures.
Hydration products of GGBS are poorly crystalline Calcium Silicate Hydrate broadly similar to that formed from hydration of OPC, but with lower Ca/Si ratio. Due to lower Ca/ Si ratio, these hydrates have more alkali retention capacity. Hydration products of GGBS effectively fill up the pores and increase the strength and durability of concrete. GGBS requires

activation to initiate hydration and theavailability of a medium for continuing the hydration process. Slag hydration can be activated by using alkalies, lime, sulphate etc (Chemically activation), or by fine grinding (Mechanically activation) or by increasing temperature of concrete (Thermalactivation). Various alkalies activators like Sodium hydroxide, Sodium carbonate,Sodium sulphate, Sodium silicate (Water glass) etc., can be used for slag. Waterglass activated slag produced most cross-linked structures that results in increasedmechanical strength of hydration products, while Sodium hydroxide make hydration process of slag more intensive. Due to higher activation energy of blast furnace slagrelative to OPC, it has advantage of thermal activation on its hydration.

**4.7 FLY ASH**

The term "fly ash" is often used to describe any fine paniculate material precipitated from the stack gases of industrial furnaces burning solid fuels. The characteristics and properties of different fly ashes depend on the nature of the fue land the size of furnace used. Fly ash generally falls into one of two categories,depending on their origin and their chemical and mineralogical composition. Two classes of fly ash defined by ASTM C618 are Class F fly ash and Class C fly ash. The chief difference between these classes is the amount of calcium,silica, alumina, and iron content in the ash. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned (i.e., anthracite,bituminous, and lignite).

**4.7.1 CLASS F FLY ASH**

The burning of harder, older anthracite and bituminous coal typically producesClass F fly ash. This fly ash is pozzolanic in nature, and contains less than 10% lime(CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F flyash requires a cementing agent, such as Portland cement, quicklime, or hydratedlime, with the presence of water in order to react and produce cementitious compounds.

**4.7.2 CLASS C FLY ASH**

Fly ash produced from the burning of younger lignite or sub bituminous coal,in addition to having pozzolanic properties, also has some self-cementing properties.In the presence of water, Class C fly ash will harden and gain strength over time.Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, selfcementingClass C fly ash does not require an activator. Alkali and sulfate ($SO_4$)contents are generally higher in Class C fly ashes.

**4.8 STEEL FIBER**

Fibers are playing an increasing role as the reinforcing medium of choice forconcrete construction. Steel fiber reinforced used now expanding beyond pavementapplications, into areas where the reinforcing specification has historically beenbars or fabric. With development in steel fiber technology steel fiber reinforcedconcrete performance characteristics include significant ductile behavior andenhanced tensile, flexural, shear and comprehensive strengths.

Steel fiber is a primary and secondary reinforcing medium and is most suited

to thin section and plates where stresses are highly variable. These typically occur inpavement, short Crete, bored piers and pre cast elements.

**4.8.1 TYPES OF STEEL FIBER**

- Round flat steel fiber
- Crimpled steel fiber
- Flat crimpled steel fiber
- Hook end steel fiber

**4.9 SUPERPLASTICIZER**

A study of four commercially available super plasticizer used in type I Portland cement concrete mixes was done by Whiting (1979). They represented both melamine- and naphthalene based formaldehyde condensation products. Hardened concrete specimens were prepared and tested for compressive strength development, drying shrinkage, freeze-thaw resistance, and resistance to deicing scaling. From his research, Whiting found out that high range water reducers werecapable of lowering the net water content of concrete mixtures from 10% to 20%when used in dosages recommended by the manufacturers. Also it was found outthat one- and three-day compressive strengths could be substantially increasedthrough use of high range water reducers. Workability of concrete was measured byslump flow test and in situ tests were undertaken to find out the pumping ability ofsuperplasticized concrete. The coarse aggregate was crushed stone with themaximum size of 25 mm. By using this chemical admixture, which was a little bitdifferent from the conventional ones, the ability of water reduction was increasedalong with the retention of high workability for a longer time. For mixtures with watercementratios between 0.3 and 0.45, the slump diameters were between 500 mmand 740 mm and the compressive strength varied between 53 MPa and 68 MPa at28 days of age.

**4.10 WATER**

Water is an important ingredient of concrete as it actively participates in thechemical reaction with cement. The quantity and quality of water is required to be watched in to carefully so that it can form the strength giving cement gel. Portable water is used for making mortar. The pH value of water lies between 6 and 8 that indicate the water is free from organic matters.

**4.11 PHYSICAL PROPERTIES OF INGREDIENTS USED**

**Table 4.11 Physical properties of ingredients used**

| | | |
|---|---|---|
| **Cement** | Type | OPC 53 |
| | Initial Setting Time | 30 |
| | Final Setting Time | 600 |
| | Specific gravity | 3.15 |
| | Consistency test (%) | 29 |
| | Fineness | 225 |
| | Average particle size | 90 µ |
| **Fine sand** | Specific gravity | 2.67 |
| | Fineness modulus | 2.92 |
| **Steel Fiber** | Shape | Crimpled |
| | Diameter | 1mm |
| | Length | 25mm |
| | Aspect ratio (L/D) | 25 |
| | Tensile strength | min 1100 N/mm2 |
| | Elongation | max 4% |
| **Micro Silica** | Color | Grayish white |
| | Average particle size | 45 µ |
| | Specific gravity | 2.629 |
| **Quartz Powder** | Color | Grayish white |
| | Specific Gravity | 2.5 |
| | Average particle size | 45µ |
| **GGBS** | Specific Gravity | 2.9 |
| | Average particle size | 300µ |
| **Super plasticizer** | Specific Gravity | 1.25 |
| | Type | Modified Melamine Formaldehyde Condensate |
| | Color | Clear & Transparent |

## IV. MIX PROPORTION

### 5.1 MIX DESIGN OF RPC

In this project specimens were casted as per trail mix ratio to attain themaximum strength without coarse aggregate in the concrete. Here four types of trialmixes were prepared. Mix design of reactive powder concrete was referred fromConcrete Construction Engineering hand book by Edward G Nawy. Based on thismix design the trial mixes were prepared.

**Trial I** -Mix design of RPC for no replacement of fine aggregate by mineral admixtures.

**Trial II**-Mix design of RPC for 20% replacement of fine aggregate by quartz power.

**Trial III**-Mix design of RPC for 20% replacement of fine aggregate by GGBS.

**Trial IV**-Mix design of RPC for 20% replacement of fine aggregate by fly ash.

**Table 5.1 Mix design as per Concrete Construction Engineering hand book, Edward G Nawy.**

| **Mix Composition of RPC (Trial-I)** | | | |
|---|---|---|---|
| **SI.No** | **Ingredients** | **Kg/m3** | **Ratio** |
| 1 | OPC | 995 | |
| 2 | Fine sand | 1051 | 1.06 |
| 3 | Silica fume | 229 | 0.23 |
| 4 | Super plasticizer | 24 | 0.02 |
| 5 | Steel fiber | 297 | 0.30 |
| 6 | Water | 303 | 0.30 |

**Table 5.1(a) Typical mix design for 20% replacement of fine sand by quartz powder.**

| **Mix Composition of RPC (Trial-II)** | | | |
|---|---|---|---|
| **SI.No** | **Ingredients** | **Kg/m3** | **Ratio** |
| 1 | OPC | 995.00 | |
| 2 | Fine sand | 840.80 | 0.85 |
| 3 | Silica fume | 229.00 | 0.23 |
| 4 | Quartz powder (20% of fine sand) | 210.20 | 0.21 |
| 5 | Superplasticizer | 24.00 | 0.02 |
| 6 | Steel fiber | 297.00 | 0.30 |
| 7 | Water | 303.00 | 0.30 |

**Table 5.1(b) Typical mix design for 20% replacement of fine sand by GGBS.**

| **Mix Composition of RPC (Trial-III)** | | | |
|---|---|---|---|
| **SI.No** | **Ingredients** | **Kg/m3** | **Ratio** |
| 1 | OPC | 995.00 | |
| 2 | Fine sand | 840.80 | 0.85 |
| 3 | Silica fume | 229.00 | 0.23 |
| 4 | GGBS (20% of fine sand) | 210.20 | 0.21 |
| 5 | Superplasticizer | 24.00 | 0.02 |
| 6 | Steel fiber | 297.00 | 0.30 |
| 7 | Water | 303.00 | 0.30 |

**Table 5.1(c) Typical mix design for 20% replacement of fine sand by fly ash.**

| **Mix Composition of RPC (Trial-IV)** | | | |
|---|---|---|---|
| **SI.No** | **Ingredients** | **Kg/m3** | **Ratio** |

| | | | |
|---|---|---|---|
| 1 | OPC | 995.00 | |
| 2 | Fine sand | 840.80 | 0.85 |
| 3 | Silica fume | 229.00 | 0.23 |
| 4 | Fly ash (20% of fine sand) | 210.20 | 0.21 |
| 5 | Superplasticizer | 24.00 | 0.02 |
| 6 | Steel fiber | 297.00 | 0.30 |
| 7 | Water | 303.00 | 0.30 |

### 5.2 MIXING AND PLACING

Concrete was mixed by hand mixing. Initially the dry powders were mixedhomogeneity with steel fiber for a period of 5 minutes and the homogeneity of mixwas identified by the color the mix. Then, the mixing water was containing halfamount of superplasticizer added for wet mixing. A small amount of mixing waterwas kept to dilute the remaining half of the superplasticizer to apply for wet mixing aperiod of 10 minutes. Workability of RPC's cannot be characterized by slumpmeasurement. The mixture looks like plastic tar rather than the conventionalconcrete mix.

## V. RESULTS AND DISCUSSIONS

### 6.1 COMPRESSIVE STRENGTH OF TRIAL MIXES

According to Indian Standard specifications (IS: 516 – 1959), the 7 dayscompressive strength test was conducted on casted specimens prepared as per thetrial mix ratio. The comparison of the results was made to evaluate the maximumcompressive strength attained by the trial mixes.

**Table 6.1 Compressive strength of trial mixes**

| Trials | Compressive Strength (MPa) |
|---|---|
| T1 | 22.50 |
| T2 | 21.62 |
| T3 | 25.33 |
| T4 | 30.00 |

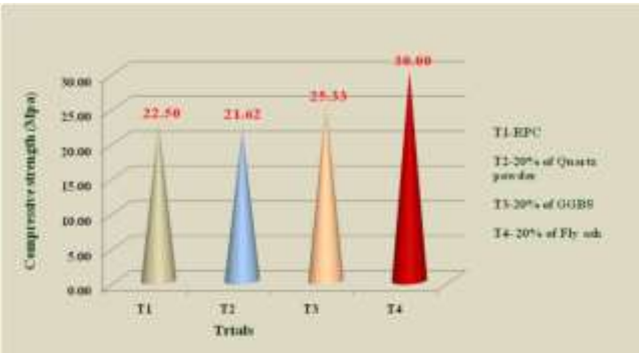


**Fig 6.1 Compressive strength of trial mixes**

This graph shows the 7 days compressive strength for trial mixes and in this the maximum compressive strength has been obtained by the 4th trial mix. Hence this trial mix was taken for the further experimental studies.

### 6.2 COMPRESSIVE STRENGTH

Cubes were casted as per the 4th trial mix ratio and the specimens were curedby standard water curing for 7 days, 14 days and 28 days to conduct thecompressive strength test. The test was conducted on the specimens by the Universal Testing Machine. The following table shows the compressive strength results for reactive powder concrete in which 20% of fine aggregate was replaced byfly ash

**Table 6.2 Test results for compressive strength**

| Compressive strength of cube (MPa) | | | | |
|---|---|---|---|---|
| **No of days** | | **7** | **14** | **28** |
| **RPC (20% of Fly ash)** | **Spe-1** | 31.26 | 43.52 | 59.21 |
| | **Spe-2** | 32.71 | 44.21 | 58.01 |
| | **Spe-3** | 34.12 | 41.89 | 58.01 |
| | **Avg** | **32.70** | **43.21** | **58.44** |

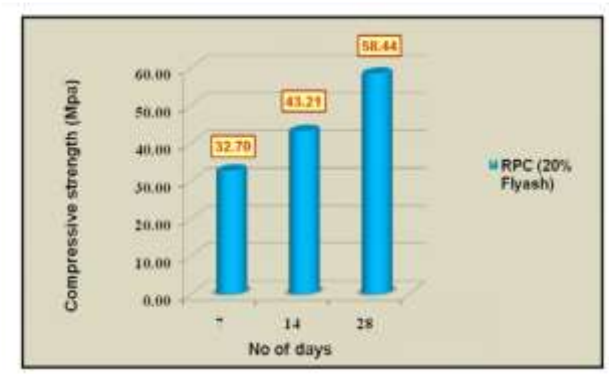


**Fig.6.2 Result of Compressive strength**

### 6.3 SPLIT TENSILE STRENGTH

Cylinders were casted as per the 4th trial mix ratio and the specimens werecured by standard water curing for 7 days, 14 days and 28 days to conduct the splittensile strength test. The testing of the specimens were done as per therecommendations of IS 5816: 1999. The test was conducted on the specimens bythe Universal Testing Machine. The following table shows the split tensile strengthresults for reactive powder concrete in which 20% of fine aggregate was replaced byfly ash.

**Split tensile strength=2P/•bd**

Where, P = Load applied to the specimen in N

b = Breadth of the specimen in mm
d = depth of the specimen in mm

**Table 6.3 Test results for split tensile strength**

| Split tensile strength (MPa) | | | | |
|---|---|---|---|---|
| **No of days** | | **7** | **14** | **28** |
| **RPC (20% of Fly ash)** | **Spe-1** | 2.9 | 4.21 | 5.78 |
| | **Spe-2** | 3.04 | 4.76 | 5.87 |
| | **Spe-3** | 3.18 | 3.95 | 5.98 |
| | **Av** | **3.04** | **4.31** | **5.88** |


**Fig.6.3 Result of Split tensile strength**

### 6.4 FLEXURAL STRENGTH

Specimens were casted as per the 4th trial mix ratio and the specimens werecured by standard water curing for 7 days, 14 days and 28 days to conduct the flexural strength test. The testing of the specimens was done as per therecommendations of IS: 516 – 1959.

**Flexural strength, fb = (Pxl) / (bxd2)**

Where, P = Load applied to the specimen in N,
l = length of the specimen in mm
b = Breadth of the specimen in mm,
d = depth of the specimen in mm

**Table 6.4 Test results for flexural strength**

| Flexural strength (MPa) | | | | |
|---|---|---|---|---|
| **No of days** | | **7** | **14** | **28** |
| **RPC (20% of Fly ash)** | **Spe-1** | 8.23 | 12.01 | 16.02 |
| | **Spe-2** | 8.02 | 11.23 | 15.99 |
| | **Spe-3** | 7.99 | 11.99 | 15.56 |
| | **Avg** | **8.08** | **11.74** | **15.86** |


**Fig.6.4 Result for flexural strength**

### 6.5 ACID ATTACK

After the completion of 28 days curing the initial weight of the specimenswere noted. The specimens were immersed in 5% of HCl, H2SO4 and Na2SO4 Diluted solutions. After the specimens immersed in diluted solution and the change in Weights of specimens were taken at every 3 days interval of cyclic period up to 30days. Finally the change in weight of specimens due to acid attack and the strength deterioration factor also was calculated.

**Table 6.5 Weight loss of specimen under Na2SO4 attack**

| Cyclic Duration | Weight of specimen | Changes in Weight | % of cum weight change |
|---|---|---|---|
| 0 | 8.312 | 0.000 | 0.00% |
| 3 | 8.312 | 0.000 | 0.00% |
| 6 | 8.313 | 0.001 | 0.01% |
| 9 | 8.313 | 0.001 | 0.01% |
| 12 | 8.314 | 0.002 | 0.02% |
| 15 | 8.315 | 0.003 | 0.03% |
| 18 | 8.315 | 0.003 | 0.04% |
| 21 | 8.316 | 0.004 | 0.04% |
| 24 | 8.317 | 0.006 | 0.07% |
| 27 | 8.317 | 0.007 | 0.07% |
| 30 | 8.318 | 0.008 | 0.10% |

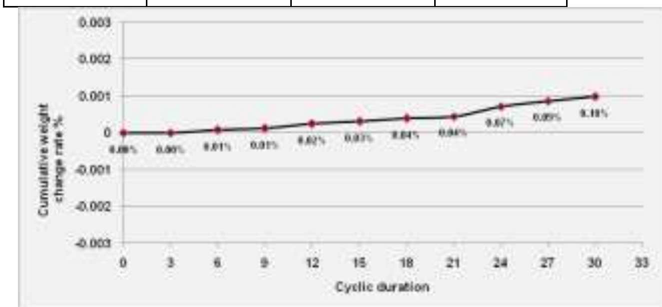


**Fig 6.5 Weight loss of specimen under Na2SO4 attack**

**Table 6.5(a) Weight loss of specimen under HCL attack**

| Cyclic Duration | Weight of specimen | Changes in Weight | % of cum weight change |
|---|---|---|---|
| 0 | 8.310 | 0.000 | 0.00% |
| 3 | 8.310 | 0.000 | 0.00% |
| 6 | 8.311 | 0.0011 | 0.01% |
| 9 | 8.312 | 0.0014 | 0.03% |
| 12 | 8.314 | 0.0041 | 0.05% |
| 15 | 8.316 | 0.0061 | 0.07% |
| 18 | 8.317 | 0.0070 | 0.08% |
| 21 | 8.319 | 0.0087 | 0.10% |
| 24 | 8.320 | 0.0096 | 0.12% |
| 27 | 8.321 | 0.0110 | 0.13% |
| 30 | 8.323 | 0.0125 | 0.15% |

| Cyclic Duration | Weight of specimen | Changes in Weight | % of cum weight change |
|---|---|---|---|
| 0 | 8.312 | 0.000 | 0.00% |
| 3 | 8.308 | -0.004 | -0.05% |
| 6 | 8.302 | -0.010 | -0.12% |
| 9 | 8.294 | -0.018 | -0.22% |
| 12 | 8.289 | -0.023 | -0.28% |
| 15 | 8.281 | -0.031 | -0.37% |
| 18 | 8.276 | -0.036 | -0.45% |
| 21 | 8.285 | -0.054 | -0.65% |
| 24 | 8.244 | -0.068 | -0.82% |
| 27 | 8.232 | -0.080 | -0.97% |
| 30 | 8.221 | -0.091 | -1.11% |

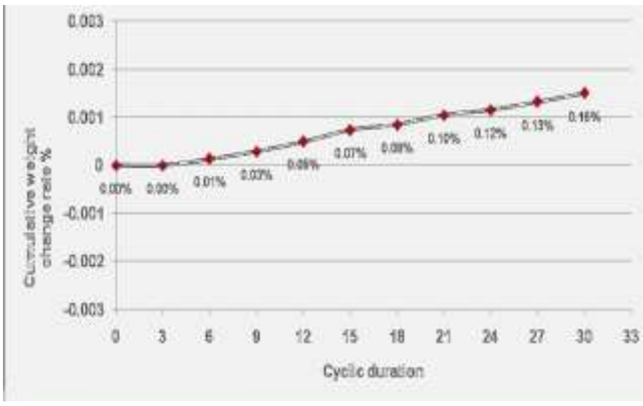


**Fig 6.5(a) Weight loss of specimen under HCL attackTable**

**6.5(b) Weight loss of specimen under H2SO4 attack**

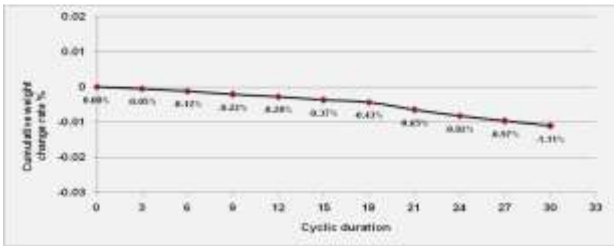


**Fig.6.5 (b) Weight loss of specimen under H2SO4 attack**

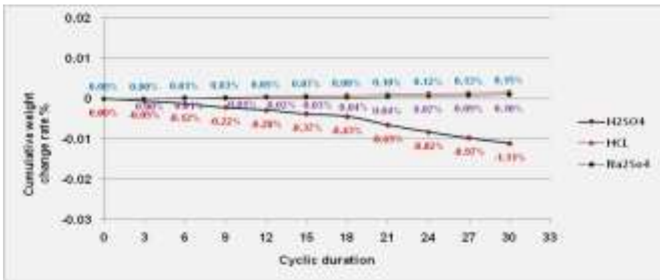


**Fig.6.5(C) Comparison of Weight loss of under HCL, H2SO4 & Na2SO4 attack**

## 6.6 STRENGTH DETERIORATION FACTOR (SDF)

Strength deterioration factor was defined as the ratio of change in compressive strength to initial compressive strength. The deterioration of casted specimens was investigated by measuring the strength deterioration factor expressed in percentage and it was calculated by using the equation.

$$SDF = \frac{\text{INTIAL– FINAL COMPRESSIVE STRENGTH}}{\text{INTIAL COMPRESSIVE STRENGTH}}$$

**Table 6.6 Comparison of Initial & Final compressive and split tensile strength under HCL attack**

| Type of attack | Days | compressive strength(MPa) | | % of Deterioration |
|---|---|---|---|---|
| | | Initial | Final | |
| HCL | 7 | 32.70 | 32.13 | 1.73 |
| | 14 | 43.21 | 41.64 | 3.62 |
| | 28 | 58.44 | 55.15 | 5.62 |

| Type of attack | Days | Split tensile strength(MPa) | | % of Deterioration |
|---|---|---|---|---|
| | | Initial | Final | |
| HCL | 7 | 3.04 | 2.99 | 1.65 |
| | 14 | 4.31 | 4.15 | 3.62 |
| | 28 | 5.88 | 5.59 | 4.92 |

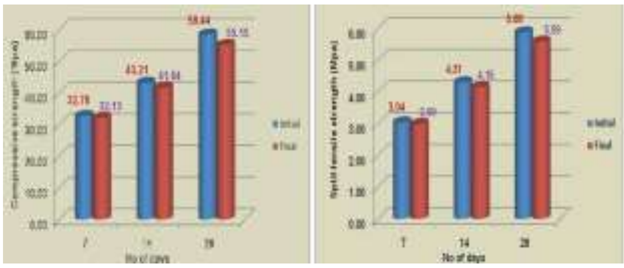

**Fig.6.6 Comparison of Initial & Final compressive and split tensile strength under HCL attack**

**Table.6.6 (a) Comparison of Initial & Final compressive and split tensile strength under H2SO4 attack**

| Type of attack | Days | compressive strength(MPa) | | % of Deterioration |
|---|---|---|---|---|
| | | Initial | Final | |
| $H_2so_4$ | 7 | 32.70 | 31.83 | 2.65 |
| | 14 | 43.21 | 40.98 | 5.15 |
| | 28 | 58.44 | 53.58 | 8.52 |

| Type of attack | Days | Split tensile strength(MPa) | | % of Deterioration |
|---|---|---|---|---|
| | | Initial | Final | |
| $H_2so_4$ | 7 | 3.04 | 2.98 | 1.97 |
| | 14 | 4.31 | 4.09 | 5.02 |
| | 28 | 5.88 | 5.41 | 5.90 |

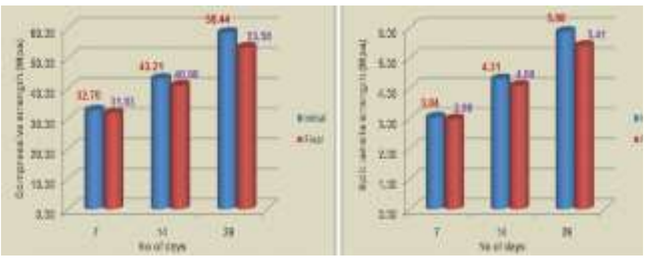

**Fig 6.6 (a) Comparison of Initial & Final compressive and split tensile strength under H2SO4 attack**

**Table 6.6(b) Comparison of Initial & Final compressive and split tensile strength under Na2SO4 attack**

| Type of attack | Days | compressive strength(MPa) | | % of Deterioration |
|---|---|---|---|---|
| | | Initial | Final | |
| $Na_2so_4$ | 7 | 32.70 | 32.36 | 1.02 |
| | 14 | 43.21 | 42.08 | 2.61 |
| | 28 | 58.44 | 56.26 | 4.73 |

| Type of attack | Days | Split tensile strength(MPa) | | % of Deterioration |
|---|---|---|---|---|
| | | Initial | Final | |
| $Na_2so_4$ | 7 | 3.04 | 3.01 | 0.85 |
| | 14 | 4.31 | 4.26 | 1.15 |
| | 28 | 5.88 | 5.70 | 3.02 |

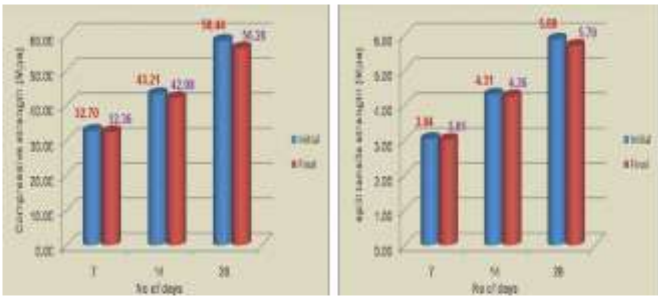

**Fig 6.6(b) Comparison of Initial & Final compressive and split tensile strength under Na2SO4 attack**

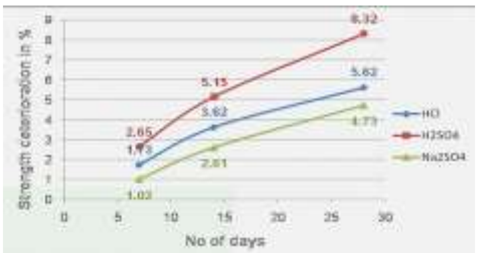


**Fig 6.6(c) Comparison of deterioration % for compressive strength under HCL, H2SO4 & Na2SO4 attack.**

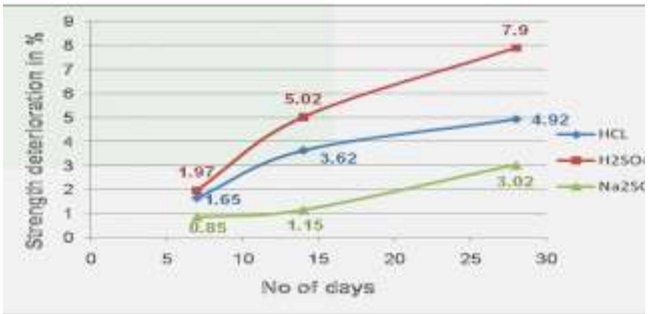


**Fig 6.6(d) Comparison of deterioration % for split tensile strength under HCL, H2SO4 & Na2SO4 attack**

### 6.7 DISCUSSIONS

#### 6.7.1 DISCUSSIONS ON MECHANICAL PROPERTIES

- The maximum compressive strength of controlled specimen is 58.44 MPa at 28 days. It is nearly 70% less where compared to the literature value. This is in the range of 175 MPa to 225 MPa.
- The maximum flexural strength attained on the controlled specimen at 28 days is 15.86 MPa. It is also 28% lesser than the literature value.
- The split tensile strength of controlled specimen is about 5.88 MPa at 28 days.
- The possible reasons for results are lower than the values quoted in literature is the higher length and diameter of steel fibers used in this study.

#### 6.7.2 DISCUSSIONS ON DURABILITY PROPERTIES

- The specimens were immersed in diluted solution of HCL, H2SO4 and Na2SO4 for 30 days, the weight changes of specimens immersed in HCL was increased about 0.15%, in H2SO4 the weight was decreased about -1.11% and in Na2SO4 the weight was increased about 0.10% from its initial weight. The limitation of weight change for RPC under acid attacks is maximum 1% to 2%.
- The maximum strength deterioration factor for compressive strength attained on specimen was 8.32% under H2SO4 attack. The same for split tensile strength attained on specimen is 7.9% under H2SO4 attack.

## VI. TEST PHOTOGRAPHS

### 7.1 INCREDIENTS

### 7.4 COMPRESSIVE STRENGTH

### 7.5 SPLIT TENSILE STRENGTH

### 7.6 FLEXURAL STRENGTH

### 7.7 DURABILITY PROPERTIES

#### 7.7.1 HCl ATTACK

#### 7.7.2 Na2SO4 ATTACK

#### 7.7.3 H2SO4 ATTACK

### 7.8 STRENGTH DETERIORATION TEST

## VII. CONCLUSIONS

Based on the experimental investigations carried out the following conclusions are made:-

- The round crimpled steel fiber its diameter 0.1mm to 0.2mm and length 13mm to 25mm where used it increase the energy absorption capacity and improve the mechanical properties of RPC. The required limitation of aspect ratio to the fiber is 100 to 250.
- To choose the closed environment for mixing and placing of RPC, while mixing the concrete.
- In RPC, the Pan Mixer method is required for homogeneity mix of fine mineral admixtures and steel fibers in concrete.
- The external vibration is needed to compact the RPC as dense packing and to avoid the settlement of fibers in the bottom of specimen and also to avoid the formation of air voids while casting the specimen. Steam curing system is required to improve the mechanical properties of reactive powder concrete.
- Compared to high strength concrete the durability property of RPC under acid attack is so good due to micro silica was used. It improves the interface structure between fine aggregate and cement paste for resist the permeability of acids in to the interface of concrete.

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