

**EFFECT OF FLY ASH & GROUND GRANULATED BLAST
FURNACE SLAG AS CEMENT REPLACEMENT MATERIALS ON
STRENGTH AND DURABILITY CHARACTERISTICS OF
PAVEMENT QUALITY CONCRETE (PQC)**

A dissertation submitted
in partial fulfillment of the requirements for
the award of the degree of

**MASTER OF ENGINEERING
IN
STRUCTURAL ENGINEERING**

Submitted by:

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DECLARATION

The author hereby declares that this thesis entitled "**Effect of fly ash & ground granulated blast furnace slag as cement replacement materials on strength and durability characteristics of Pavement Quality Concrete (PQC)**", in whole or part has not been used to obtain any degree in this, or any other, institute, except where references have been given in text, it is entirely the authors own work. The author conforms that the library may lend or copy this upon request for academic purposes.



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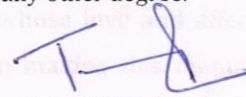
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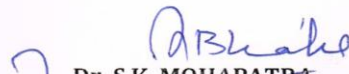
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INDEX			
DECLARATION			[i]
CERTIFICATE			[ii]
ACKNOWLEDGEMENT			[iii]
ABSTRACT			[vii]
LIST OF TABLES			[viii]
LIST OF FIGURES			[ix]
CHAPTER - 1	INTRODUCTION		
	1.1	GENERAL	1
	1.2	CONCRETE PAVEMENTS	1
		1.2.1 Types of Concrete Pavements	2
		1.2.2 Merits of Concrete Pavements	3
		1.2.3 Demerits of Concrete Pavements	4
	1.3	SELECTION OF MATERIALS IN PQC AS PER MORTH SPECIFICATIONS	4
		1.3.1 Cement	5
		1.3.2 Aggregates	5
		1.3.3 Water	7
		1.3.4 Admixtures	7
	1.4	SCOPE OF PRESENT WORK	10
CHAPTER - 2	LITERATURE REVIEW		11
	2.1	GENERAL	11
	2.2	USE OF FLY-ASH IN CONCRETE	11
	2.3	USE OF GLASS GRANULATED BLAST FURNACE SLAG IN CONCRETE	13
	2.4	USE OF SUPERPLASTICIZERS IN CONCRETE	16
CHAPTER 3	MATERIAL AND DESIGN METHODOLOGY		18

	3.1	GENERAL	18
	3.2	MATERIALS USED	18
		3.2.1 Portland Cement	18
		3.2.2 Aggregates	20
		3.2.3 Water	23
		3.2.4 Fly Ash	24
		3.2.5 Ground Granulated Blast Furnace Slag	24
		3.2.6 Super plasticizer	26
	3.3	MIX DESIGN OF PAVEMENT QUALITY CONCRETE (PQC)	26
		3.3.1 Design Parameters	27
		3.3.2 Steps involved in the mix design as per IRC 44	27
	3.4	CASTING OF SPECIMENS	30
		3.4.1 Specimens for compressive strength test	30
		3.4.2 Specimens for flexural strength	30
		3.4.3 Specimens for Rapid Chloride Permeability Test	31
	3.5	TESTING OF SPECIMENS	31
		3.5.1 Setup for Compressive Strength Test	31
		3.5.2 Setup for Flexural Strength Test	32
		3.5.3 Setup for Rapid Chloride Permeability Test	33
CHAPTER 4		RESULT AND DISCUSSION	36
	4.1	GENERAL	36
	4.2	COMPRESSIVE STRENGTH OF CONCRETE	36
		4.2.1 General	36
		4.2.2 Test procedure and results for	36

		compressive strength	
		4.2.3 Discussion of compressive strength test results	37
	4.3	FLEXURAL STRENGTH	42
		4.3.1 General	42
		4.3.2 Test procedure and results for flexural strength	43
		4.3.3 Discussion of flexural strength test results	43
	4.4	RAPID CHLORIDE PERMEABILITY TEST	49
		4.4.1 General	49
		4.4.2 Test Procedure and Results	49
		4.4.3 Effect of fly ash and ground granulated blast furnace slag replacement on rapid chloride permeability test of PQC	51
CHAPTER 5		CONCLUSIONS	52
	5.1	GENERAL	52
	5.2	COMPRESSIVE STRENGTH OF PAVEMENT QUALITY CONCRETE	52
	5.3	FLEXURAL STRENGTH OF PAVEMENT QUALITY CONCRETE	53
	5.4	RAPID CHLORIDE PERMEABILITY TEST	53
	5.5	SCOPE FOR FURTHER WORK	53
REFERENCES			54

ABSTRACT

The major problem the world is facing today is the environmental pollution. The best way to dispose any waste material is to use it as one or the other forms like construction material. The Ordinary Portland Cement (OPC) is one of the main ingredients used for the production of concrete. Unfortunately, production of cement causes emission of large amount of carbon-dioxide gas into the atmosphere, a major contributor for greenhouse effect and the global warming. Also, Portland cement being very expensive material affects the total cost of construction of any project. Hence, the researchers are currently focused on use of waste material having cementing properties, which can be added in cement concrete as partial replacement of cement, without affecting its strength and durability, which will result in decrease of cement production thus reduction in emission of greenhouse gases, global warming and the cost of construction.

The ground granulated blast furnace slag and fly ash are the waste products from the iron manufacturing and thermal plant industry respectively, which may be used as partial replacement of cement in concrete due to its inherent cementing properties.

The present study aims at, developing pavement quality concrete mixtures incorporating ground granulated blast furnace slag and fly ash as partial replacement of cement. In this study, the flexural, compressive and rapid chloride permeability test for pavement quality concrete mixtures for different percentage of GGBS and fly ash as replacement of cement are reported. It is found out the maximum increase in flexure strength is for 20% fly ash and 60% GGBS. The increase in compressive strength is maximum for 10% fly ash and 50% GGBS. From durability point of view, we can use all the mixes as their permeability is very low.

LIST OF TABLES

Table No.	Title	Page No.
1.1	Type of cement conforming to Indian standard code	5
3.1	Properties of OPC 43 Grade Cement	19
3.2	Properties of Coarse Aggregates	21
3.3	Sieve Analysis of Coarse Aggregates (20mm)	21
3.4	Sieve Analysis of Coarse Aggregate (10mm)	22
3.5	Physical Properties of fine aggregates	23
3.6	Sieve Analysis of Fine Aggregate	23
3.7	Physical properties of fly ash	24
3.8	Chemical properties of fly ash	24
3.9	Properties of superplasticizer	26
3.10	Proportion for Pavement Quality Concrete Mixture (control mix)	29
3.11	Quantity of materials in kg/m ³ for different Mixes	29
3.12	Chloride Ion Penetrability Based on Charge Passed (ASTM 1202-97)	34
4.1	Compressive Strength Test Results	37
4.2	Effect of Age on Compressive Strength of PQC	41
4.3	Flexural Strength at 28 & 56 days	43
4.4	Effect of Age on Flexural Strength of PQC	48
4.5	Rapid chloride permeability of samples at 28 days	50

LIST OF FIGURES

Figure no.	Title	Page No.
3.1	Testing of concrete cubes for compressive strength	32
3.2	Testing of concrete beams in flexure	33
3.3	Vacuum Desiccator's Bowl	34
3.4	Rapid Chloride Permeability Test	35
4.1	Compressive strength variation for different mixes	38
4.2	Effect of 50% replacement on compressive strength of concrete	39
4.3	Effect of 60% replacement on compressive strength of concrete	39
4.4	Effect of 70% replacement on compressive strength of concrete	40
4.5	Effect of 80% replacement on compressive strength of concrete	41
4.6	Percentage variation in compressive strengths of 28 days to 56 days w/b = 0.36	42
4.7	Flexural strength variation for different mixes	45
4.8	Effect of 50% replacement on flexural strength of concrete	45
4.9	Effect of 60% replacement on flexural strength of concrete	46
4.10	Effect of 70% replacement on flexural strength of concrete	47
4.11	Effect of 80% replacement on flexural strength of concrete	47
4.12	Percentage variation in flexural strengths of 28days to 56 days	49
4.13	Total charge passed in coulombs at 28 days	51

1.1 GENERAL

The two basic components, which concrete is mainly composed of are binder (paste) and aggregates. The paste, which mainly consists of cement, water and supplementary cementitious materials, has main functions of binding up the aggregates, filling up the voids and thus making concrete strong and dense. The aggregates, both coarse and fine, provide volume to concrete. The voids in coarse aggregates are filled up by the fine aggregates and voids in the fine aggregates are filled up by cement, thus helping in making concrete a densely packed system. The strength of concrete increases with the decrease in voids.

As compared to other road making materials concrete pavements have higher modulus of elasticity and rigidity. Due to this property the pressure on the subgrade gets limited. The thickness of the concrete pavement is mainly determined by the magnitude of the wheel or axle loads and by the flexural strength of the concrete and there is no significant contribution provided by sub-bases.

In flexible pavements, a much deeper depth is needed to diminish the intensity of the stresses due to traffic loads. In this both the base and the sub-base contribute significantly to the structural properties of the pavements. Hence less pressure is applied to the material below the concrete.

1.2 CONCRETE PAVEMENTS

A structure that consists of a layer of ordinary Portland cement concrete which is generally supported by a sub-base layer on the sub-grade is known as concrete pavement. This type of pavement can be used as reinforced or unreinforced pavement. Its type of use usually depends upon the designer's preference as to how he needs to control shrinkage cracking.

1.2.1 Types of Concrete Pavements

The concrete pavements can be classified into the following types:

- Jointed Reinforced Concrete pavement – JRCP
- Jointed Unreinforced or plain Concrete pavement – JPCP
- Steel Fibre Reinforced Concrete Pavement – SFCP
- Continuously Reinforced Concrete Pavement – CRCP

1) **Jointed Reinforced Concrete pavement (JRCP):-** In this pavement cracking is controlled by contraction joints, dowel bars and reinforcing steel. The spacing of the transverse joints is more than concrete pavement contraction design (CPCD). A minimum amount of steel is included in the mid-slab so that it can hold the cracks together tightly. Dowel bars help in load transfer across transverse joints while reinforcing steel helps in load transfer across mid-panel cracks.

2) **Jointed plain (unreinforced) concrete pavement (JPCP):-** In this pavement cracking is controlled by contraction joints. Tie bars are used mainly at longitudinal joints. The spacing of transverse joints lies between 3.7 m to 6.1 m. The load is transferred by interlocking of aggregates and dowel bars. Aggregate interlock is suitable for low volume roads. But for high volume roads dowel bars are used in each transverse joint to prevent excessive faulting.

3) **Steel Fiber Reinforced Concrete Pavement (SFCP):-** Steel fibers are used to increase the flexural and tensile strength of the concrete. Steel fibers with 0.5 to 1.0% of the weight of cement are used in pavement quality concrete. With the use of steel fibers, the ultimate strength can be increased up to 3 times the strength of plain concrete. In the third-point bending test it is found that the flexural strength SFRC is about 50 to 70 percent more than that of the plain concrete mix. By using steel fibers, the slab thickness gets reduced and hence is very economical. By incorporating steel fibers in

concrete, there is delay and control in tensile cracking of the composite material. This influences the mechanical properties of the concrete in the positive way. Thus SFRC is a feasible material for the concrete pavements.

- 4) **Continuously Reinforcement Concrete Pavement (CRCP)**:- This pavement provides joint-free design that is it does not require any construction joint. In this pavement transverse cracks are formed at close intervals. These cracks are held tightly by the reinforcement and should be of no concern as long as the cracks are uniformly spaced, do not spall excessively and a uniform non-erosive base is provided. The reinforcement is provided near the mid-depth in the slab and its value is about 0.6 – 0.7 percent of the cross-sectional pavement area.

1.2.2 Merits of Concrete Pavements

The various merits of use of concrete pavements are highlighted below:

- i) Pavement maintenance costs are up to 10 times cheaper than the same for flexible pavements.
- ii) High sustainability rating through use of local materials.
- iii) Heavy duty Pavements has generally the lowest cost.
- iv) Not susceptible to high or low temperatures.
- v) Not affected by weather, inert to spills and fire.
- vi) Profile durability.
- vii) Can be slip formed up to 13 m.
- viii) High abrasion durability.
- ix) Can be constructed over poor sub-grades.
- x) Less energy for street lighting (up to 30%).
- xi) Light colour enhances night visibility.
- xii) Use of waste products like fly-ash and slag.
- xiii) Riding quality does not deteriorate.
- xiv) Completely recyclable.
- xv) Resistant to abrasion from turning actions.
- xvi) Thinner overall pavement thickness = lower consumption of raw materials.

- xvii) Less heat-sink effect (avg. 8°C lower than asphalt = less air conditioning energy in urban areas).
- xviii) Saving of fuel costs of at least 1.1% over asphalt (VTI Sweden – 1.1% 2008, NRC Canada – 0.8 to 6.9%).
- xix) Minimum maintenance requirements result in less traffic disruption, minimum congestion time and results Work Zone safety.
- xx) Safer because it maintains its shape, no deformation, resistance to rutting and potholes and excellent skid resistance.
- xxi) Longitudinal diamond grinding, called Next Generation Concrete Surfacing (NGCS) now provides quieter surface than for example Open Graded Asphalt overlay.
- xxii) Long lasting – 40 year Design Life
- xxiii) Lowest Life Cycle Cost of all Heavy Duty pavements and highest salvage value.

1.2.3 Demerits of Concrete Pavements

As there are many merits of use of concrete pavements in road and airport works, there are some demerits too, which are highlighted as below:

- i) Cement concrete road surface after some time of use becomes very smooth and slippery.
- ii) Lots of joints need to be provided which prove additional places of weakness.
- iii) It makes for noisy road, as bullock carts or steel tyres vehicles cause lot of noise while moving on them.
- iv) It is not possible to adopt stage construction programmed in these roads.
- v) They involve heavy initial investment.
- vi) 28 days curing is required after completion before they can be opened to traffic.

1.3 SELECTION OF MATERIALS IN PQC AS PER MORTH SPECIFICATIONS.

The Contractor shall specify to the Engineer the source of all materials to be used in the concrete work with related test data effectively in advance, and the sanction of the Engineer for the same shall be achieved at least 45 days before the scheduled

initiation of the work in trial length. If the Contractor successively recommends obtaining materials from a different source during the execution of main work, he shall inform the Engineer, with appropriate test data, for his approval, at least 45 days before such materials are to be used.

The details and specifications of various materials to be used in development of Pavement Quality Concrete (PQC) are provided in the succeeding sub-sections:

1.3.1 Cement

To achieve the desired strength of PQC, the type of cement to be used should satisfy the requirements of the laid down Indian Standards. The various types of cement, listed in the table below, can be used for development of Pavement Quality Concrete:

Table 1.1 Type of cement conforming to Indian standard code

Sr. No.	Type	Confirming to :
1	Ordinary Portland Cement 43 Grade	IS:8112
2	Portland Blast Furnace Slag Cement	IS:455
3	Portland Pozzolana Cement	IS:1489-Part I
4	Ordinary Portland Cement 53 Grade	IS:12269

1.3.2 Aggregates

Aggregates for pavement concrete shall be natural material complying with IS: 383 but with a Los Angeles abrasion test results not more than 35 percent. The aggregates should be free from dirt, flint or other silica in a form that can react with the alkalis in the cement. In addition, the total chlorides content expressed as chloride ion content shall not exceed 0.06 percent by weight and the total sulphate content shall not exceed 0.25 percent by weight.

a) *Coarse aggregates:* Coarse aggregates make up the bulk of a concrete mixture. Sand natural gravel and crushed stone are used mainly for this purpose. Carefully consideration should be adopted at the time of giving proper size, shape, mineralogy and surface texture. Coarse aggregates shall be clean, hard, strong, dense, non-porous and durable pieces of crushed stone or crushed gravel. For pavement concrete the maximum size of coarse aggregate should be up to 35mm. Aggregate with more than 2% water absorption should not be used in the concrete mix. The combined flakiness and elongation index of aggregate shall be up to 35 percent. High strength aggregate are not suitable for concrete because of their very high modulus of elasticity as compared with the modulus of a cement paste due to this contrary stress concentrations occur which damages the concrete in mechanical behavior.

The presence of aggregates greatly increases the robustness of concrete above that of cement, which otherwise is a brittle material and thus concrete is a true composite material. It was observed that the size of coarse aggregate regulate the concrete strength apart from W/b ratio. For a given W/b ratio, the strength of concrete is decreased as the maximum size of coarse aggregate is increased.

It was also observed that for optimum compressive strength with high cement contents and low water cement ratios, the maximum size of coarse aggregate should be kept minimum at the rate of 12.5 mm or 9.5 mm.

b) *Fine aggregates:* The fine aggregates should contain clean natural sand or crushed stone sand or a combination of the two and shall conform to IS: 383. Fine aggregate shall be free from mica, soft particles, clay, cemented particles, loam and organic and other foreign matter.

The properties of fresh and hardened concrete are influenced by the characteristic properties and by quality of fine aggregates. Rearrangement of aggregates after compaction often creates in evenness due to the effect of vibration. This can lead to strength gradients.

1.3.3 Water

Water used for mixing and curing of concrete shall be clean and free from injurious amount of oil, salt, acid, vegetable matter or other substances harmful to the finished concrete. It shall meet the requirements stipulated in IS: 456 – 2000.

1.3.4 Admixtures

Concrete is mainly composed of air, water, cement, fine aggregate, and coarse aggregates. When air, cement and water are mixed together the binder paste is formed. On further addition of fine aggregates the material formed is mortar. An admixture is a material added to the batch of concrete before or during its mixing to modify its freshly mixed, setting or hardened properties. About 80% of concrete produced in North America have one or more admixtures. About 70% of concrete produced contains a water-reducer admixture. We can add one or two admixtures to a mix in order to achieve the desired results. The main reasons for using admixtures are as given below:-

- To increase slump and workability
- To retard or accelerate initial setting;
- To prevent shrinkage
- To reduce segregation
- To reduce heat evolution during early hardening;
- To accelerate the rate of strength development at early ages
- To increase strength (compressive, tensile, or flexural)
- To increase durability or resistance to severe conditions of exposure
- To decrease permeability of concrete
- To increase bond between steel reinforcement and concrete
- To increase bond between existing and new concrete
- To improve impact and abrasion resistance

These admixtures are mainly classified into two groups, viz. chemical admixtures and mineral admixtures, respectively.

(i) *Chemical admixtures*: Chemical admixtures decline the cost of construction, modify the properties of concrete and advance the quality of concrete during mixing, transportation, placing and curing. In production of High strength concrete, decreasing the W/B by decreasing the total cementitious materials content will usually produce higher compressive strength. Thus we can use chemical admixture for developing High strength concrete. On the basis of use in concrete, the various types of chemical admixtures are classified as follows :-

- a. Accelerating
- b. Alkali-silica reactivity reducers
- c. Air-entrainment
- d. Corrosion-inhibitors
- e. Set-retarding
- f. Shrinkage-reducers.
- g. Super-plasticizers
- h. Water-reducing

The water reducers which are capable of reducing water content by about 30 percent are popularly known as Super-plasticizers (SPs) or High range water reducers (HRWR).

In High strength concrete, the normal dosage of super-plasticizers lies between 0.3 % and 1.5% by weight of cement. The advantages of Super-plasticizers include significant water reduction; reduced cement contents; increased workability; rapid rate of early strength development; increased long-term strength; and reduced permeability. Some of the demerits of using chemical admixtures include:

- Additional admixture cost
- Slump loss greater than conventional concrete
- Modification of air-entraining admixture dosage

(ii) *Mineral admixtures*: Mineral admixtures reduce cost, reduce permeability, increase strength and change other concrete properties. The three main mineral admixtures, which are very frequently used in concrete, are given as below:

1. Fly ash
2. Silica fume
3. Ground Granulated Blast Furnace Slag.

1) Fly Ash: Fly ash is a by-product of electrical coal-fired power plants and can vary widely depending on the source. Fly ash particles are usually finer than cement and are mainly made of glassy-spherical particles. It should meet the requirements of ASTM C 618. Fly ash inhibits alkali-silica reaction (ASR) in hardened concrete. Fly ash reduces the early age strength of concrete but may increase the strength of the same concrete at age of 90 days. The two main classes of fly ash specified in ASTM C 618 are Class F and Class C. Class F fly ash is usually obtained from burning anthracite or bituminous coal whereas Class C fly ash is obtained from burning sub-bituminous coal and lignite.

2) Silica Fume: Silica fume admixtures are used to meet high strength and low permeability requirements. They are added in slurry or in dry form at the batching plant. Silica fume is extremely fine. The particles are about 100 times smaller than cement particles. It should meet the requirements of ASTM C 1240. The higher the percentage of silica fume used, higher is the amount of super-plasticizer needed. The mix may become sticky.

Merits:

- Reduces permeability
- Improves bonding within the concrete
- Improves resistance to corrosion
- Reduces alkali-silica reactivity (ASR)
- Increases compressive and flexural strengths and durability

3) Ground Granulated Blast Furnace Slag (GGBS):The blast furnace slag is a by-product of the iron manufacturing industry. Iron ore, coke and limestone are served into the furnace and the resultant molten slag floats above the molten iron at a temperature of about 1500°C to 1600°C.The molten slag comprises of about 30% to 40% SiO₂ and 40% CaO. After the molten iron is tapped off, the residual molten slag,

which contains mainly siliceous and aluminous residue is then water-quenched rapidly, resulting in the creation of a glassy granulate. This glassy granulate is dried and ground to the essential size which is known as ground granulated blast furnace slag (GGBS). As compared to Portland cement, some additional energy is needed for the production of GGBS. GGBS is an environmentally friendly construction material because in this emission of carbon dioxide is less. GGBS concrete has better water impermeability characteristics as well as improved resistance to corrosion and sulphate attack. As a result, the service life of a structure is healthier and the maintenance cost reduced.

GGBS concrete generally has a low permeability resulting in reduced chloride penetration, enhanced resistance to sulphate attack and alkali silica reaction as compared with ordinary Portland cement concrete. It has been reported that a higher calcium hydrate (CH) content will in general produce concrete of poor durability due to an inhomogeneous mix with poor bonding between calcium silicate hydrate (CSH) and CH. Higher CH contents will lead to a enhanced permeability and a lower durability. The GGBS particles are retained in calcium silicate hydrate (CSH) form resulting in a hardened paste of greater density and smaller pore size as compared to Portland cement paste. Smaller pore size gives rise to a lower permeability and hence a higher durability.

GGBS concrete has lower early strengths because the rate of initial reaction of GGBS is slower than that of Portland cement. GGBS is therefore generally grounded to a finer state than Portland cement. Concrete containing GGBS has slower reaction rates.

1.4 SCOPE OF PRESENT WORK

The main objective of the proposed work is to study the effect of use of fly ash and Ground Granulated blast Furnace Slag (GGBS) as partial replacement of cement for the production of Pavement Quality Concrete. The effect of fly ash and GGBS has been studied on the strength and durability characteristics of Pavement Quality Concrete.

2.1 GENERAL

The relevant literature pertaining to the use of fly ash, glass granulated blast furnace slag and super-plasticizer in concrete carried out in India and abroad has been reviewed and presented in the sub-sections below.

2.2 USE OF FLY-ASH IN CONCRETE

Low calcium Class F fly ash normally acts as a fine aggregate of spherical form in early stages of hydration whereas high calcium Class-C fly ash may contribute to the early cementing reactions in addition to its presence as fine particulate in the concrete mix. Hydration of cement is an exothermic reaction and the released heat causes a rise of temperature of fresh concrete.

Brown (1982) conducted several studies with fly ash replacing cement and fine aggregate at levels of 10-40% by volume. He concluded that for each 10% of ash substituted for cement, the compacting factor or workability changed to the same order as it would by increasing the water content of the mix by 3-4%. When fly ash was substituted for sand or total aggregate, workability increased to reach a maximum value at about 8% ash by volume of aggregate. Further substitution caused rapid decrease in workability.

Gebler and Klieger (1983) investigated the requirements of Air Entraining Agent (AEA) for Class-C and Class-F fly ashes. They reported that (1) concretes made with Class C fly ash generally require less AEA than those made with Class F fly ashes; (2) for 6% air content in concrete, the AEA varied from 126 to 173% for fly ashes having more than 10% CaO, whereas it was in the range of 177 to 553% for fly ashes containing less than 10% CaO; and (3) increase in both total alkalies and SO₃ contents in fly ash affect the air entrainment favorably. A concrete containing a Class

Fly ash that has relative high CaO content and less organic matter or carbon tends to be less vulnerable to loss of air.

Owens, (1989) reported that with the use of fly ash containing large fraction of particles coarser than $45\mu\text{m}$ or a fly ash with high amount of unburned carbon, exhibiting loss on ignition more than 1%, higher water demand was observed.

Sivasundram, et al. (1990) investigated the setting time of high-volume fly ash concrete mixes, and concluded that the initial setting time of 1.50 hours was comparable to that of the control concrete, whereas the final setting time was extended by about 3 hours as compared to that of the control concrete.

Carette and Malhotra(1983) studied the effect of Canadian fly ashes on the compressive strength of concrete mixes. Cement was replaced with 20% fly ash in all the mixes. Compressive strength was measured up to the age of 365 days. It was seen that compressive strength continued to increase with age, indicating pozzolanic action of fly ashes.

Joshi and Lohtia(1993) tested a large number of fly concrete mixes made by using three different fly ashes containing about 10% calcium oxide. The replacement level varied between 40 and 60% by weight of cement. The mixes were super-plasticized and air-entrained to obtain 100 to 120 mm slump and $6 \pm 1\%$ air content. The cementitious material content varied from 380 to 466 kg/m^3 , water to cementitious material ratio from 0.27 to 0.37, coarse aggregate ranged from 1,012 to 1,194 kg/m^3 , and fine aggregate or sand varied from 712 to 643 kg/m^3 . They reported that

(1) at 7 days, the fly ash concretes obtained strength between 27.9 and 41.0 MPa compared to 44.1 MPa of control concrete. However at the age of 28 days, the fly ash concretes developed strength varying from 37.6 to 50.7 MPa against 58.7 MPa for control concrete;

(2) at 120 days, strength of fly ash concrete ranged from 54.8 to 74.6 MPa whereas it was 74.6 MPa of control concrete.

Saraswathy et al. (2003) investigated the influence of activated fly ash on the compressive strength of concrete. Various activation techniques, such as physical, thermal and 20 chemical were adopted. Concrete specimens were prepared with 10, 20, 30 and 40% of activated fly ash replacement levels with cement. Compressive strength was determined at 7, 14, 28 and 90 days. They concluded that

(1) activation of fly ash improved the strength of concrete. However, the compressive strength of fly ash concrete was less than that of ordinary Portland cement (OPC) even after 90 days of curing; and

(2) among the activation systems, chemically activated coal fly ash (CFA) improved the compressive strength to a certain extent, only with 10 and 20% replacements. Since the CFA surface layer is etched by a strong alkali to facilitate more cement particles to join together and also the addition of CaO which is further promoting the growth of CSH gel and Ca(OH)_2 which is more advantageous to enhance the strength development.

2.3 USE OF GLASS GRANULATED BLAST FURNACE SLAG IN CONCRETE

Dubey et al. (2012) investigated the Ordinary Portland Cement (OPC) is one of the main ingredients used for the production of concrete. Unfortunately, production of cement involves emission of large amounts of carbon-dioxide gas into the atmosphere, a major contributor for greenhouse effect and the global warming, hence it is inevitable either to search for another material or partially replace it by some other material. The search for any such material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact. Concrete property can be maintained with advanced mineral admixtures such as blast furnace slag powder as partial replacement of cement 5% to 30%. Compressive strength of blast furnace slag concrete with different dosage of slag was studied as a partial replacement of cement. From the experimental investigations, it has been observed that, the optimum replacement of Ground Granulated Blast Furnace Slag Powder to cement without changing much the compressive strength is 15%.

Soutsos et al. studied the early age strength development of concretes containing ground granulated blast furnace slag (GGBS) at cement replacement levels of 20%, 35%, 50% and 70% have been investigated to give guidance for their use in fast track construction. 28-days target mean strengths for all concretes were 100 MPa. Although supplementary cementitious materials like GGBS are economical, their use has not gained popularity in fast track construction because of their slower strength development at early ages and at standard cube curing temperatures. There are however indications that supplementary cementitious materials are heavily penalised by the standard cube curing regimes. Measurements of temperature rise under adiabatic conditions have shown that high levels of cement replacement by GGBS, e.g. 70% are required to obtain a significant reduction in the peak temperature rise. However, despite that these temperature rises are lower than those of Portland cement mixtures they are still sufficient to provide the activation energy needed for the reaction of GGBS to “kick-in” earlier. The early-age strength under adiabatic conditions of GGBS mixtures can be as high as 250% of the strength of companion cubes cured at 20°C. The high early age temperatures are shown to be especially beneficial to GGBS concretes.

Khan et al. (2004) investigated the Portland cement, already being a very expensive material constitutes a substantial part of the total construction cost of any project and the situation has further been aggravated by the energy crisis, which has further increased the cost of production of Portland cement. Therefore, it is of current importance for the country to explore and develop cementing materials cheaper than Portland cement. In this research, GGBS (Ground Granulated Blast furnace Slag) was collected from Steel Mills Karachi (Pakistan) and pulverized to a very fine degree from a pulverized. Physical Chemical properties, such as, compressive strength, fineness, setting times, soundness and chemical composition of GGBS (Ground Granulated Blast furnace Slag) were investigated and comparison has been made with the relevant properties of cement Effect of replacement was seen on workability, compressive strength, tensile strength, modulus of rupture, equivalent cube strength by casting mixes of different ratios; 1:2:4, 1:1.5:3,

1:1.25:2.50, 1:1:2. w/b ratio for first two mixes was kept as 0.65 and for rest two mixes as 0.45. After cost comparison of GGBS and Ordinary Portland Cement it is concluded that price of GGBS is 25% to 50% less than that of Ordinary Portland Cement. This aspect of GGBS makes it economical.

Ravikumar et al. (2013) studied the effects of using different pozzolonic materials as a partial cement replacement material in mortar mixes. An experimental study of mortar made with Ordinary Portland cement (OPC) and 12% of OPC, replaced by different pozzolanic materials such as Fly Ash, Rice Husk ash, Silica Fume, Calcined Clay (Grog) and Slag (GGBS) were tested for the strength and durability properties, to determine the effect of these materials on mortar properties and was compared to control mortar mix. Mortar specimens were tested for compressive strength at age of 3, 7 and 28 days and flexural strength at age of 28 days. To investigate the mortar for its durability, the specimens after initial curing of 28 days were immersed in fresh water with solutions of 10% sodium sulfate (Na_2SO_4) and 10% magnesium sulfate (MgSO_4) for another period of 3 months. Through this period, the specimens were tested for compressive strength at 60, 90 and 120 days to evaluate its durability.

Awasure et al. carried out investigation that the Industrial wastes like Ground Granulated Blast Furnace Slag (GGBS) show chemical properties similar to cement. Use of GGBS as cement replacement will simultaneously reduce cost of concrete and help to reduce rate of cement consumption. This study report of strength analysis of GGBS concrete will give assurance to encourage people working in the construction industry for the beneficial use of it. This research work focuses on strength characteristics analysis of M20 grade concrete with replacement of cement by GGBS with 20%, 30%, 40% and 50% and compare with plain cement concrete. Now days crush sand is used to replace natural sand, so study area extends to find best percentage of replacement by using both crush and natural sand.

Kumar and Babu (2000) investigated that the utilisation of supplementary cementitious materials is well accepted because of the several improvements possible in the concrete composites and due to the overall economy. The present

paper is an effort to quantify the 28-day cementitious efficiency of ground granulated blast furnace slag (GGBS) in concrete at the various replacement levels. It was observed that this overall strength efficiency of GGBS concretes can also be defined through a procedure adopted earlier for other cementitious materials like fly ash and silica fume. The overall strength efficiency was found to be a combination of general efficiency factor, depending on the age and a percentage efficiency factor, depending upon the percentage of replacement as was the case with a few other cementitious materials like fly ash and silica fume reported earlier. This evaluation makes it possible to design GGBS concretes for a desired strength at any given percentage of replacement.

2.4 USE OF SUPERPLASTICIZERS IN CONCRETE

Manjrekar (1994) carried out the investigation that the super-plasticizers are in use in concrete for nearly one and a half decades, there are still some bad in certain quarters in using them. The researcher also tried to give answer some questions that arise in the minds of practicing engineers, consultants and others users.

Park and Seung (1999) studied that the properties of super-plasticized concrete have an appreciable fluidifying action in fresh concrete. They permitted a significant water reduction while maintaining the same workability. Bleeding of super-plasticized concrete was much lower than that of conventional concrete of the same consistency. Hence, they concluded that super-plasticizer did not affect the tendency of segregation of fresh concrete. The compressive, tensile and flexural strength of super-plasticized concrete were significantly higher than those of conventional concrete.

Kim et al. (2000) investigated the adsorption behaviour of a poly naphthalene sulfonate (PNS) super-plasticizer and its relation to the fluidity of cement paste for six cements at a given dosage of PNS super-plasticizer. The incompatible cements have a higher adsorption capacity of PNS super-plasticizer because of a lack of soluble alkali sulphates. There is an inverse relationship between the amount of PNS adsorbed and the mini-slump area value of the cement pastes at 30 min, i.e. the higher the amount of PNS adsorbed, the lower the initial slump value, and the higher

the slump loss. The addition of some Na_2SO_4 contributes to increase the slump area by reducing the amount of PNS adsorbed. Moreover, it has been found that additional calcium sulphate does not prevent the adsorption of PNS on cement particles as sodium sulphate does in cement pastes having $W/B = 0.35$. The contribution of alkali sulphate on dispersing mechanism of PNS super-plasticized cement pastes is explained in relation with initial slump and its loss.

Percheet al. (2003) concluded that the adsorption of super-plasticizers onto cement particles is a key factor in the rheology of cement and concrete. The adsorbed amount is generally measured as the difference between the amount of polymer present in the aqueous phase before and after contact with cement (depletion method). Adsorption isotherms of well characterized lignosulfonate and polycarboxylate admixtures have been measured on a model powder (MgO) using the depletion method and on an ultrafine cement by using an electroacoustic method. The method allowed us to follow the variation of zeta potential of the same suspensions as a function of increasing amounts of super-plasticizers. It was found that the influence of the adsorption of super-plasticizers on zeta potential measured by electroacoustic technique are significantly lower than those measured earlier with preceding instruments. The electroacoustic method is useful for studying the adsorption of super-plasticizers. It measures zeta potential values necessary for inter-particle force calculations. Differences in polymer structures and the effect of different ions on polymer adsorption can be observed.

3.1 GENERAL

The present chapter deals with the materials properties and the results obtained from the various test conducted on the materials used for designing Pavement Quality Concrete (PQC). In order to achieve the objective of the present study, an experiment program was devised to investigate the effect of fly ash and GGBS, as partial cement replacements, on the compressive and flexure strengths and durability of concrete.

3.2 MATERIALS USED

The properties of material used for making concrete mix are determined in laboratory under controlled conditions as per relevant IS codes of practice. The material characterization was carried out for all the major ingredients of concrete which include cement, coarse aggregates, fine aggregates, super-plasticizer and water, in addition to fly ash and GGBS. The purpose of the characterization is to check their acceptability as per relevant Indian standards so as to enable an engineer to design a concrete mix for a particular strength. The properties of the various materials, which were used in this study, are presented and discussed in the succeeding sub-sections:

3.2.1 Portland Cement

Cement is the most active component of concrete and usually has the greatest unit cost, thus, its selection and proper use are important in obtaining most economical balance of properties desired for any particular concrete mixture. It fills up voids existing in the fine aggregate and makes the concrete impermeable. It provides strength to concrete by binding the aggregate into a solid mass due to its setting and hardening properties when mixed with water. Although, it constitutes only about

20% of the total volume of concrete mix, its contribution to the compressive strength of concrete is the maximum. A good quality cement should satisfy all the requirements as per I.S. specifications. The amount of cement required for a given mix should be in a range of minimum and maximum amount for the given grade as per the IS code provision.

Portland cement, also referred to as Ordinary Portland Cement (OPC), is the most important type of cement and is a fine powder produced by grinding Portland cement clinker. OPC is classified into 3 grades namely 33 Grade, 43 Grade, 53 Grade depending upon the strength of 28 days. The specification for the cement of any grade is given by the various IS codes. IS 8112: 2013 provides the specification of the OPC 43 Grade.

Ordinary Portland Cement (OPC) of 43 Grade (Aditya Birla) from a single lot was used throughout the course of the investigation. It was fresh and without any lumps. The physical properties of the cement are determined from various method of physical test for cement (IS 4031) and the requirement, conforming to IS 8112:2013, are listed in Table 3.1. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture.

Table 3.1 Properties of OPC 43 Grade Cement

Characteristics	Values Obtained	Values specified by IS 8112:2013	Method of Test Ref.
Specific gravity	3.10	-	IS 4031 part 11
Standard Consistency (%)	27	-	IS 4031 part 4
Setting time (minutes)			
Initial	149	Min. 30	IS 4031 part 5
Final	257	Max. 600	IS 4031 part 5
Compressive strength (MPa)			
3 days	27.8	23	IS 4031 part 6
7 days	36.5	33	
28 days	48.6	43	

3.2.2 Aggregates

Aggregate occupy a large volume in concrete mixture and give dimensional stability to concrete. In the cement concrete, to provide good quality of concrete, aggregates are generally used in two size groups: coarse aggregates – Particle size more than 4.75mm and fine aggregate (sand) particle size less than 4.75mm. Coarse aggregates makes solid and hard mass of concrete with cement and sand and increase the crushing strength of concrete. It also reduce the cost of concrete, since it occupies major volume. Sand consists of small angular or rounded grains of silica and is commonly used as the fine aggregate in cement concrete. It fills the voids existing in the coarse aggregate and reduces shrinkage and cracking of concrete. It helps in hardening of cement by allowing the water through its voids. To form hard mass of silicates, as it is believed that, some chemical reaction takes place between silica of sand and constituents of cement. The fine aggregate assist the cement paste to hold the coarse particle in suspension this action promotes plasticity in the mixture and prevent the possible segregation of paste and coarse aggregate. The aggregates, which provide about 75% volume to concrete, should meet certain requirement if the concrete is to be workable, strong, durable and economical. The aggregate must be proper in shape, clean hard and well graded.

Coarse aggregates: The aggregates which are retained over IS sieve 4.75mm are termed as coarse aggregate. The coarse aggregate may be of following types: Crushed gravels or stone obtained by crushing of gravel or hard stone and partially crushed gravel or stone obtained as a product of blending of above two types.

The normal maximum size is 10mm to 20mm, however, particle sizes up to 40mm are also used in dry lean concrete. Regarding the characteristics of different type of aggregates, crushed aggregates tend to improve the strength because of interlocking of angular particles, whereas, rounded aggregates improve the workability due to the lower internal friction.

The coarse aggregate used were a mixture of two locally available crushed stone of 20 mm and 10 mm size in 70:30 proportion. The aggregates were washed to remove dirt, dust and then dried to surface dry condition.

Specific gravity and other physical properties of coarse aggregates are provided in Table 3.2. The sieve analysis of coarse aggregate was done in the laboratory and the values obtained are shown in the Table 3.3 for the 20mm aggregate and Table 3.4 for the 10mm aggregate.

Table 3.2 Properties of Coarse Aggregates

Characteristics	Value	
Colour	Grey	
Shape	Angular	
Maximum size	20mm	10mm
Specific Gravity	2.71	2.75
Water Absorption	0.2%	0.35%

Table 3.3 Sieve Analysis of Coarse Aggregates (20mm)

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

Table 3.4 Sieve Analysis of Coarse Aggregate (10mm)

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

Fine aggregates: The aggregates, most of which pass through 4.75mm IS sieve are termed as fine aggregates. The fine aggregates may be of following types: Natural sand, i.e. the fine aggregate resulting from natural disintegration of rocks, Crushed stone sand, i.e. the fine aggregate produced by crushing hard stone, Crushed gravel sand, i.e. the fine aggregate produced by crushing natural gravel. Depending upon the particle size distribution IS 383 has divided the fine aggregate into four grading zones (Grade I to IV). The grading zones become progressively finer from grading zone I to IV. In this experiment program fine aggregates were collected from the local supplier and were conforming to grading zone II. It was free from silt and clay particles. Sieve analysis and physical properties of fine aggregates are tested as per IS: 383 and result are shown in the Table 3.5 and 3.6. Specific gravity of fine aggregates was experimentally determined as 2.58.

Table 3.5 Physical Properties of fine aggregates

Sr. No.	Characteristics	Value
1	Specific Gravity	2.58
2	Fineness Modulus	2.55
3	Water Absorption	0.89%
4	Zone	II

Table 3.6 Sieve Analysis of Fine Aggregate

S. No.	IS-Sieve (mm)	Wt. Retained (gm)	%age Retained	%age passing	Cumulative % retained
1	4.75	5	0.5	99.5	0.5
2	2.36	59	5.9	93.6	6.4
3	1.18	136	13.6	80	20.0
4	600 μ	243	24.30	55.7	44.3
5	300 μ	415	41.5	14.2	85.8
6	150 μ	122	12.2	2	98.0
7	Pan	20	2	SUM	255.0
TOTAL		1000	Zone II		FM =2.55

3.2.3 Water

The potable water is generally considered satisfactory for mixing and curing of concrete. Accordingly potable water was used for making concrete available in material testing laboratory. It was free from any detrimental contaminants and was of good potable quality.

3.2.4 Fly Ash

Fly ash used in the study was obtained from Guru Nanak Dev Thermal Power Plant, Bathinda. Its physical and chemical properties are given in Table 3.7 and Table 3.8, respectively.

Table 3.7 Physical properties of fly ash

Physical Property	Value
Colour	Whitish grey
Specific Gravity	2.10
Bulk Density	1120 kg/m ³
Fineness	2840 cm ² /gm

Table 3.8 Chemical properties of fly ash

Constituent	Component in %
Silica (SiO ₂)	46.8
Alumina (Al ₂ O ₃)	23.7
Ferric Oxide (Fe ₂ O ₃)	13.2
Calcium Oxide (CaO)	1.2
Magnesia (MgO)	1.0
Loss of Ignition (LOI)	6.9

3.2.5 Ground Granulated Blast Furnace Slag

The blast furnace slag is a by-product of the iron manufacturing industry. Iron ore, coke and limestone are served into the furnace and the resultant molten slag floats above the molten iron at a temperature of about 1500°C to 1600°C. The molten slag comprises of about 30% to 40% SiO₂ and 40% CaO. After the molten iron is tapped off, the residual molten slag, which contains mainly siliceous and aluminous residue is then water-quenched rapidly, resulting in the creation of a glassy granulate. This glassy granulate is dried and ground to the essential size which is known as ground granulated blast furnace slag (GGBS). As compared to Portland cement, some additional energy is needed for the production of GGBS. This is an environmentally friendly construction material because in this emission of carbon dioxide is less.

GGBS (Grand Granulated Blast Furnace Slag)/Alccofine: Alccofine was used in the present study. Alccofine was obtained from Ambuja Cements Ltd. (ALCCOFINE MICRO MATERIALS RANGE), Mumbai. Alccofine 1101 has an average particle size of 4 to 5 microns; the top size d₉₀ is only 10 microns. The computed Blaine value is around 8000 cm²/gm. Alccofine 1101 should always be used with suitable water reducing admixture. Various physical and chemical properties of Alccofine material are given below:-

Setting Time:

Initial setting time > 2 to 3 hours

Final setting time < 6 hours

Technical data:

Fineness: 8000 cm²/gm (computed Blaine value)

Specific gravity: 3.10

Bulk density: 650-700 kg/ m³

Particle size distribution:

< 2.5 microns: 10 %

< 6 microns: 50 %

< 12 microns: 90 %

It is important to employ efficient mixing equipment while using Alccofine 1101. Colloidal mixers of high speed paddle mixers are recommended. Minimum speed of colloidal mixer should be 1500 rpm and over mixing should be avoided.

3.2.6 Super plasticizer

Conplast® SP430 procured from FOSROC Constructive Solutions was used in the present study. Conplast SP430 complies with IS: 9103:1999 and BS: 5075 Part 3. Conplast SP430 is based on Sulphonated Napthalene Polymers and supplied as a brown liquid instantly dispersible in water. Conplast SP430 has been specially formulated to give high water reductions up to 25% without loss of workability or to produce high quality concrete of reduced permeability. Table 3.9 shows the characteristics of Conplast SP430.

The dosage of super plasticizer recommended is 0.6% to 2% by weight of cementitious material. In this study, to attain medium workability of the control mix, super plasticizer amount of 0.6% of cement content was used, and for the other mixes the quantity of super plasticizers were found out depending upon the trials for achieving medium range of workability.

Table 3.9 Properties of superplasticizer

S. No.	Characteristics	Value
1	Type	Sulphonated Napthalene Polymers
2	Form	Liquid
3	Colour	Light brown
4	Specific gravity	1.220 to 1.225 at 30°C
5	Air Entrainment	Approx. 1% additional air is entrained

3.3 MIX DESIGN OF PAVEMENT QUALITY CONCRETE (PQC)

IRC 44: 2008 was followed for the mix design of pavement quality concrete, and the materials are conforming to the clause of MORTH specifications. The concrete pavements are designed on the basis of flexural strength of concrete. However, general practice is to design the mix on cube compressive strength and relationship between characteristic compressive strength and flexural strength as per IS: 456 are as follows:

Flexural strength, (N/mm²) = 0.7 × characteristic compressive cube strength of concrete, N/mm².

3.3.1 Design Parameters

Characteristic flexural strength required at 28d	5.5 N/mm ²
Maximum water cement ratio=	0.36
Maximum size of aggregate =	25mm
Degree of quality control=	Good
Minimum cement content =	350 kg/m ³
Maximum cement content=	425 kg/m ³

As per clause 602 of MORTH specification:

Cement	43 Grade OPC as per IS 8112
Coarse aggregate	20mm and 10mm as per 602.2.4
Fine aggregate	Sand as per IS 383 of zone II

3.3.2 Steps involved in the mix design as per IRC 44

1. The water-cement ratio was fixed as 0.36. The flexural strength was designed for water-cement ratio 0.36.
2. *Selection of water – cement ratio:* from the table 4 of IRC: 44-2008 approx. w/b ratio for M45 is 0.36.

Table 5 of IRC: 44 used for the suggestive water content for 20mm maximum size of aggregates and that is 186 kg/m³, reduction for water content up to 20% was done by use of super plasticizer and the water content used was 149 kg/m³.

3. *Calculation of cement content:* water cement ratio = .36 and water content = 149 kg/m³ thus cement content = 149/.36 = 414 kg/m³ which was in the minimum and maximum limits.
4. *Determination of the proportion of aggregates:* From the table 6 of IRC: 44 for w/b of .36 and 20mm maximum size the volume of coarse aggregate per unit volume of total aggregate for Zone II of fine sand is 0.62. For every decrease of .05 in w/b ratio, the given ratio will be increased approximately by 1 per cent. Thus for w/b ratio of .36 the ratio for coarse aggregate was calculated as .64 (coarse) and .36(fine).
5. *Combination of different coarse aggregate fractions:* In coarse aggregate 20mm and 10mm size of aggregate were used and for the suitable proportion so as to result in an overall grading conforming to table 1 of IRC: 44 they were used in 60 by 40 % i.e. 60% 20mm and 40%10mm. thus 20mm was used .382 and 10 mm was used .254 of total fraction of coarse aggregate.

For calculation of total quantity of various composition of the concrete in kg per unit volume the relation used was follow:

$$V = \left[W + \frac{C}{S_c} + \frac{1}{\phi} \times \frac{f_a}{S_{ca}} \right] \times \frac{1}{1000}$$

Where V = the absolute volume of the wet mix,

W = the mass of water in kg per cum of concrete,

C = mass of cement in kg per cum of concrete,

S_c = specific gravity of cement,

ϕ = proportion (in decimal fraction) of aggregate (20mm, 10mm, sand) and

S_{ca} = respective specific gravity of aggregates

f_a = mass of the aggregate in kg per cum of concrete.

Thus, the quantities of aggregates were calculated by simply putting the value of their fraction and specific gravity in the equation and the value of f_a was obtained.

Table 3.10 shows the quantity for the unit volume of the concrete assuming that there was 2% air in the 1 cum concrete. For the control mix superplasticizer content of 0.5% by weight of cement was used.

Table 3.10 Proportion for Pavement Quality Concrete Mixture (control mix)

Water		Cement	F.A. (sand)	C.A. (20mm)	C.A. (10mm)
Kg/m³	149	414	656.98	723.45	489.42
Proportion(by wt.)	0.36	1	1.586	1.747	1.18

Various concrete mixes were prepared with the varying percentage of fly ash and ground granulated blast furnace slag in the laboratory. Table 3.11 shows the quantity of material in kg/m³ for different mixes which were prepared in the laboratory.

Table 3.11 Quantity of materials in kg/m³ for different Mixes

Mix	Water	Cement	Fly Ash	GGBS	F.A.	C.A. (20mm)	C.A. (10mm)
FA00GG00	149	414	0	0	656.98	723.45	489.42
FA00GG50	149	207	0	207	656.98	723.45	489.42
FA00GG60	149	165.6	0	248.4	656.98	723.45	489.42
FA00GG70	149	124.2	0	289.8	656.98	723.45	489.42
FA00GG80	149	82.8	0	331.2	656.98	723.45	489.42
FA10GG40	149	207	41.4	165.6	656.98	723.45	489.42
FA10GG50	149	165.6	41.4	207	656.98	723.45	489.42
FA10GG60	149	124.2	41.4	248.4	656.98	723.45	489.42
FA10GG70	149	82.8	41.4	289.8	656.98	723.45	489.42
FA20GG30	149	207	82.8	124.2	656.98	723.45	489.42
FA20GG40	149	165.6	82.8	165.6	656.98	723.45	489.42
FA20GG50	149	124.2	82.8	207	656.98	723.45	489.42

FA20GG60	149	82.8	82.8	248.4	656.98	723.45	489.42
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3.4. CASTING OF SPECIMENS

In this section casting procedure for compressive strength test, and flexural strength test are discussed. The mixing of the material is done using a concrete mixer.

3.4.1 Specimens for compressive strength test

To study compressive strength, the cubes of 150mm ×150mm ×150 mm are casted for various mixes. The quantities of cement, coarse aggregate, fine aggregate, fly ash, GGBS and water for each batch replacement are weighed separately. The cement, GGBS and fly ash are mixed dry to a uniform colour separately. Fine aggregate are mixed to this mixture in dry form. The coarse aggregates are mixed to get uniform distribution throughout the batch. Then water is added to the mix. Firstly, 50 to 70% of water is added to the mix and then mixed thoroughly for 2 to 3 minutes.

Then admixture is diluted in water and then added to the mix. After this slump test was done for each mix. The slump for the mix is 50 to 75mm. The Cubes are filled with fresh concrete using vibrating table. Three cubes are casted for each parameter. The compressive strength test is carried out for 28 days and 56 days. Therefore, six identical specimens are casted for each concrete mix.

3.4.2 Specimens for flexural strength

The flexural strength of concrete is determined by casting beams of size 700 mm × 150 mm × 150mm. The quantities of cement, coarse aggregate, fine aggregate, GGBS, fly ash and water for each batch replacement is weighed separately. The cement, fly ash and GGBS are mixed dry to a uniform colour separately. Fine aggregate are mixed to this mixture in dry form. The coarse aggregates are mixed to get uniform distribution throughout the batch. Water added to the mix. Firstly, 50 to 70% of water is added to the mix and then mixed thoroughly for 2 to 3 minutes. Then

admixture is diluted in water and then added to the mix. The moulds are filled with fresh concrete and are vibrated properly. Four beams are casted for each mix. The tests are carried out after 28 days and 56 days of curing.

3.4.3 Specimens for Rapid Chloride Permeability Test

The resistance to Chloride Penetration of concrete is determined by casting cylinders of size 100 mm × 200mm. The quantities of cement, coarse aggregate, fine aggregate, GGBS, fly ash and water for each batch replacement are weighed separately. The cement, GGBS and fly ash are mixed dry to a uniform colour separately. Fine aggregate are mixed to this mixture in dry form. The coarse aggregates are mixed to get uniform distribution throughout the batch. Water added to the mix. Firstly, 50 to 70% of water is added to the mix and then mixed thoroughly for 2 to 3 minutes. The moulds are filled with fresh concrete and are vibrated properly. Two cylinders were casted for each mix. The test are carried out on 28 day.

3.5 TESTING OF SPECIMENS

In this section test setup for the tests (compressive strength test, flexural strength test and rapid chloride permeability test) is discussed.

3.5.1 Setup for Compressive Strength Test

Three identical specimens are crushed at 28days and three identical specimens are crushed at 56 days. The compressive strength is calculated by dividing the failure load by average cross sectional area. The compressive testing machine of capacity 5000 KN is used for determining the maximum compressive loads carried by concrete cubes. The compressive strength test machine used in all the tests is shown in Figure. At the test age the specimens are taken out of the curing tank and kept outside for 10 minutes. Then one specimen is placed on the steel plate of the machine such that the specimen is tested perpendicular to the casting position. Then the test is carried out at the loading rate of 5 KN/s specified IS: 516 - 1959.



Fig.3.1 Testing of concrete cubes for compressive strength

3.5.2 Setup for Flexural Strength Test

The beams are tested by placing them uniformly in the Universal Testing Machine of capacity 1000 KN. Specimen are taken out from curing tank at the age of 28 days and 56 days of standard curing and tested after surface water dipped down from specimens. This test is performed on Universal Testing Machine (UTM) as shown in Figure 3.2. The test is carried out at the loading rate of 70 KN/min. The magnitude of flexural stress acting uniformly to the line of action of applied loading is given by formula

$$f_b = \frac{p \times l}{b \times d^2}$$

f_b = flexural strength in N/mm²

p = maximum applied load to specimen in Newton

l = length of the span on which the specimen was supported (mm)

b = measured width of the specimen (mm)

d = measured depth of the specimen at point failure (mm)



Fig.3.2 Testing of concrete beams in flexure

3.5.3 Setup for Rapid Chloride Permeability Test

The test method (according to ASTM C 1202-97) covers the determination of the electrical conductance of concrete to deliver a rapid indication of its resistance to the penetration of chloride ions. According to Table 3.12 the Chloride Ion Penetrability is decided on the basis of charge passed. Specimens are placed in the vacuum desiccator's bowl as shown in Fig 3.3, which illustrates the setup of the vacuum pump, desiccator with stopcock, vacuum gauge and valve and the de-aerated water container after the water has filled the desiccators. The vacuum is maintained in the desiccators bowl for 3 hours. The de-aerated water is allowed to flow into the desiccator, so that it completely covers the specimens and no air is allowed to enter. The test method consist of monitoring the amount of electrical current passed through 50 mm thick slices of 100 mm nominal diameter cylinders for a 6-hours. A potential difference of 60 V dc is maintained across the ends of the specimen, one of which is immersed in a sodium chloride solution, the other in a

sodium hydroxide solution(3.0% NaCl and 0.3 N NaOH solutions) are filled in the two cells. The total charge passed, in coulombs, is related to the resistance of the specimen to chloride ion penetration. The complete setup is shown in Fig. 3.4

Table 3.12: Chloride Ion Penetrability Based on Charge Passed (ASTM 1202-97)

Charge Passed (Coulombs)	Chloride ion permeability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
<100	Negligible



Fig.3.3 Vacuum Desiccator's Bowl



Fig 3.4 Rapid Chloride Permeability Test

4.1 GENERAL

In this chapter the effect on compressive strength, flexural strength and chloride penetration resistance of PQC, due to partial replacement of cement with fly ash and ground granulated blast furnace slag in the concrete mix is discussed. Tests are performed at 28 and 56 days of curing of concrete. Super-plasticizer is used in all the mixes at 1% level by weight of cementitious material. Results are compared and checked for compressive strength, flexural strength and chloride penetration resistance of concrete.

4.2 COMPRESSIVE STRENGTH OF CONCRETE

4.2.1 General

In most structural applications, concrete is employed mainly to resist compressive stresses. When a plain concrete member is subjected to compression, the failure of the member takes place, in its vertical plane along the diagonal. The vertical crack arises due to lateral tensile strains. A flow in the concrete, which is in the form of micro crack along the vertical axis of the member will take place on the application of axial compression load and propagate further due to the lateral tensile strains.

4.2.2 Test procedure and results for compressive strength

Three identical specimens are crushed at 28 days and three identical specimens are crushed at 56 days. The compressive strength is calculated by dividing the failure load by average cross sectional area. The compressive testing machine of capacity 5000 KN is used for determining the maximum compressive loads carried by concrete cubes. Three specimens for each mix were tested and the corresponding values were observed and average values were taken for discussion. Test results of compressive strength test at the age of 28 and 56 days are given in the Table 4.1.

Table 4.1 Compressive Strength Test Results

Mix type	28 days (MPa)	56 days (MPa)
FA00GG50	48.0	51.9
FA00GG60	40.6	45.0
FA00GG70	38.0	40.3
FA00GG80	33.0	35.0
FA10GG40	46.2	49.5
FA10GG50	41.5	48.6
FA10GG60	31.5	33.1
FA10GG70	25.0	27.0
FA20GG30	39.2	43.7
FA20GG40	36.8	39.9
FA20GG50	31.5	36.0
FA20GG60	26.9	30.2

4.2.3 Discussion of compressive strength test results

(i) Effect of percentage replacement levels on compressive strength

Compressive strength for all the mixes are summarized in the Table 4.1 and the clustered columns are prepared for comparing the 28 and 56 days strength for mixes containing GGBS and fly ash as a replacement of cement. Fig 4.1 shows the 28 and 56 days compressive strength for all the mixes with and without the supplementary cementitious materials.

On observing the strength data provided in Table 4.1, it is found that a maximum compressive strength of 48.0 MPa is achieved at 28 days and 52 MPa is achieved at 56 days curing period.

From the Fig. 4.1, which shows the effect of replacement of cement only for all the mixes, it is observed that the maximum compressive strength of concrete is achieved when cement is replaced only with 50% GGBS for all ages. The strength is observed to slightly decrease to a value of 46 MPa at 28 days and 49.5 MPa at 56

days, when GGBS is replaced by 10% fly ash in the mix. For all other combinations there is a significant reduction in strength at both the ages.

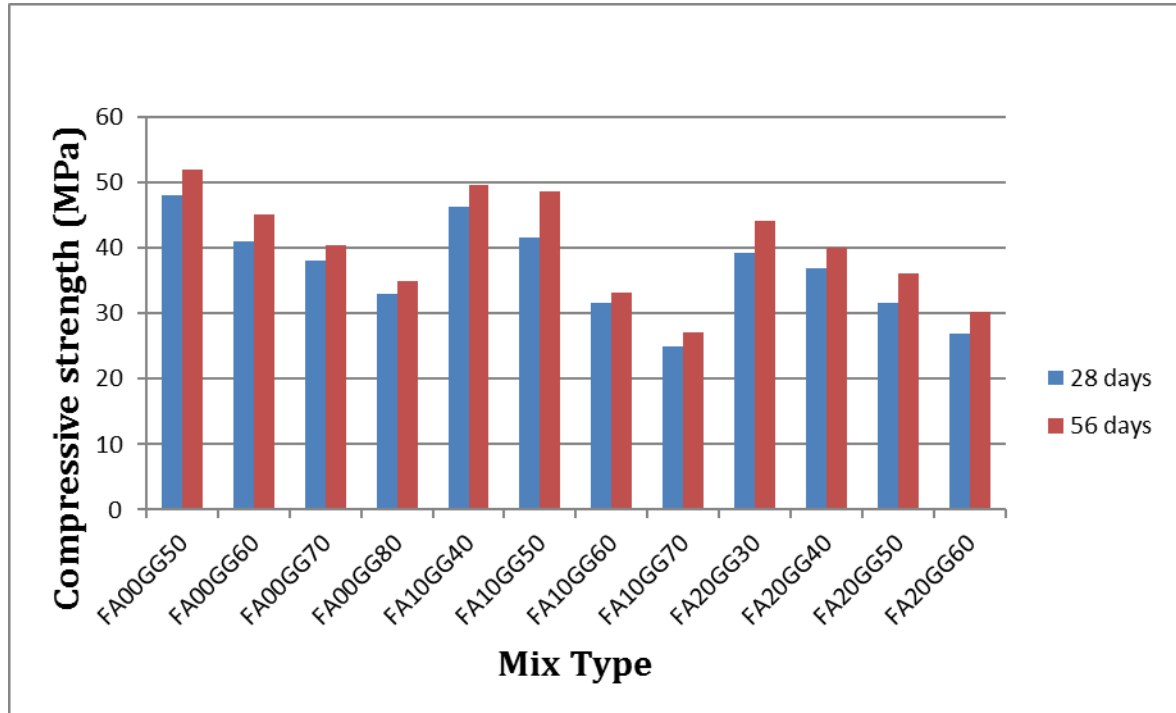


Fig 4.1 Compressive strength variation for different mixes

This indicates that the optimum percentage replacement of cement with GGBS only or GGBS with a small amount of fly ash is 50% from the mix combinations considered in the present study. This is true at both the curing ages of 28 and 56 days.

On further observation it can be seen that at least four mixes, out of the 12 combinations studied, satisfy the compressive strength requirements of 40MPa.

In order to further study the effect, the analysis of strength data is done for 50%, 60%, 70% and 80% replacements separately.

Figs. 4.2 to 4.5 show the effect of replacement of cement with GGBS and fly ash on the compressive strength behaviour of concrete.

Fig. 4.2 shows the effect of 50% replacement level on compressive strength. It is observed from the figure that for cement replacement up to 50% the highest strength is achieved for mix having only GGBS with the total 50% replacement. The compressive strength is lesser for the mix having a combination of 10% fly ash and 40% GGBS and this further decreases when fly ash content is increased to 20% and

GGBS content is reduced to 30% in the mix. This indicates that GGBS plays a much better role in strength development as compared to fly ash.

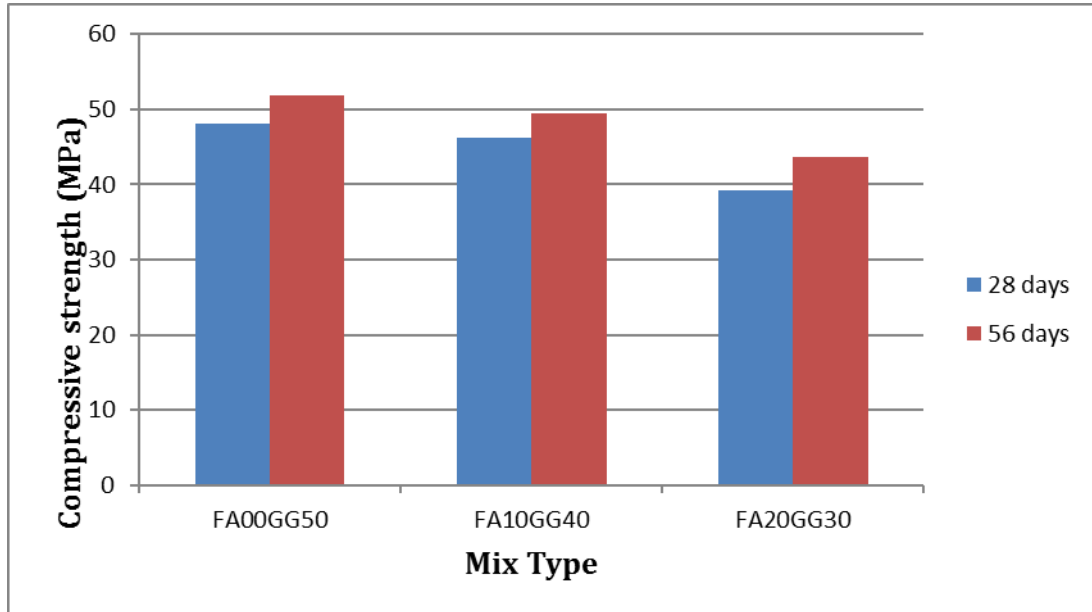


Fig. 4.2 Effect of 50% replacement on compressive strength of concrete

From Figure 4.3, which shows the effect of 60% replacement level on compressive strength, it is observed that the strength achieved for 60% replacement by GGBS alone is less than the mix having 50% GGBS and 10% fly ash. Both these mixes satisfy the minimum strength requirements of PQC mixes.

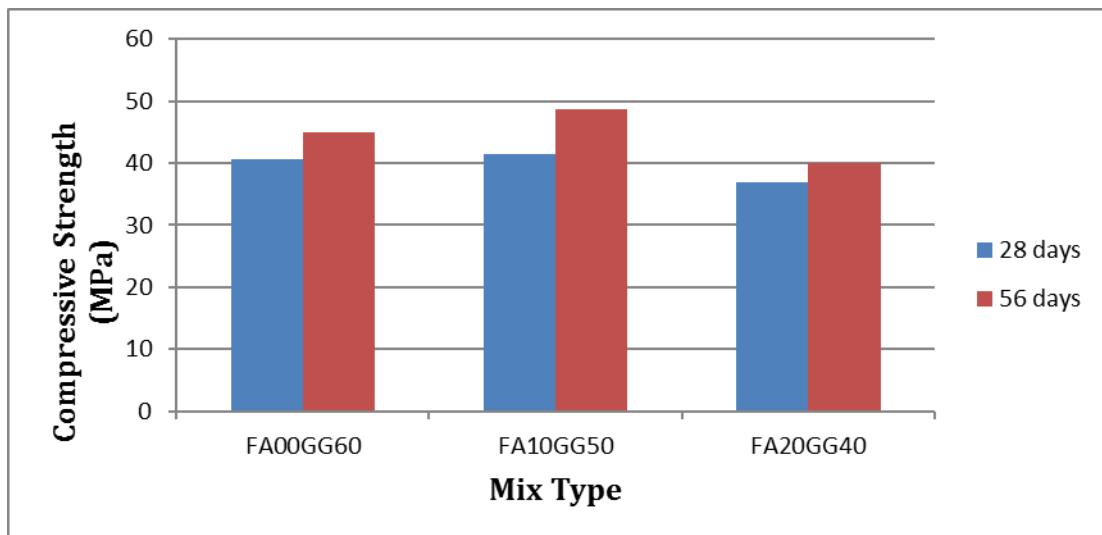


Fig. 4.3 Effect of 60% replacement on compressive strength of concrete

A further introduction of fly ash up to 20% and reduction of GGBS to 20% in the mix FA20GG40 led to a reduction in the compressive strength. This again reinforces the

point that the maximum replacement level of GGBS in the mix should be limited to 50% only. It can also be observed from the data that the strength gain from 28 to 56 days is higher for the mixes containing fly ash, which drives home the point that out of GGBS and fly ash, the pozzolanic effect of fly ash is much more. Fig. 4.4 shows the effect of 70% replacement level on compressive strength of PQC mixes.

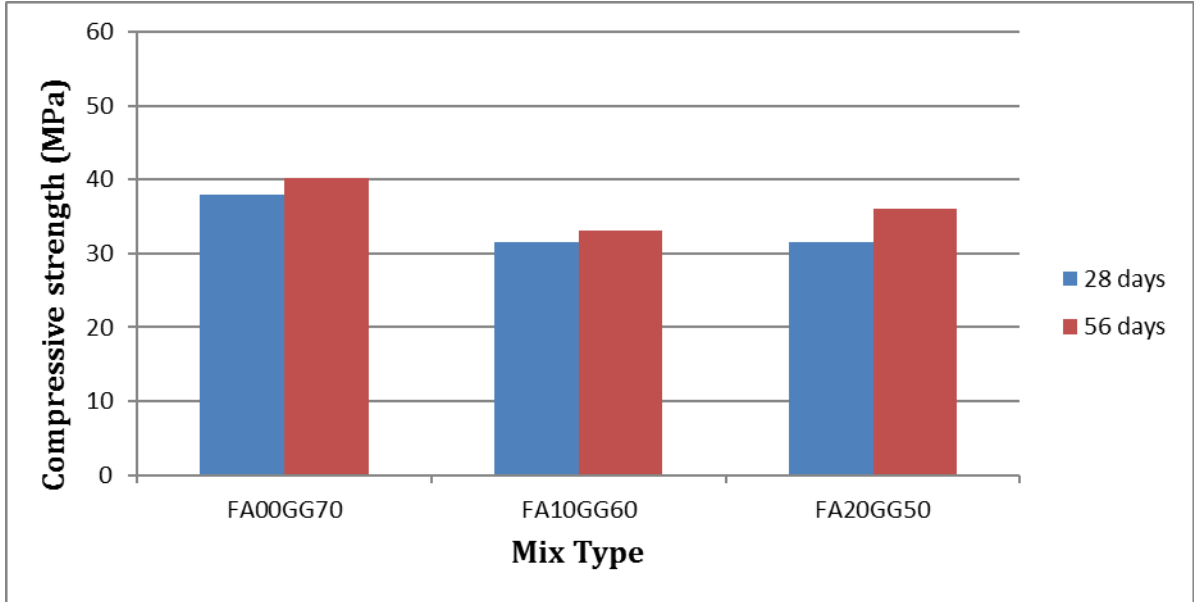


Fig. 4.4 Effect of 70% replacement on compressive strength of concrete

It can be observed from the fig. 4.4 that the mixes with GGBS alone have much higher strength as compared to mixes containing fly ash. Also the strength achieved for 70% replacement level is much less than that achieved for lower replacement levels. In fact, none of the mixes were able to satisfy the minimum strength requirements at this replacement level.

Fig. 4.5 shows the effect of 80% replacement level on compressive strength of PQC mixes. It can be observed from the fig. 4.5 that the mixes with GGBS alone have much higher strength as compared to mixes containing fly ash, on the same lines as for 70% replacement level. The strength achieved for 80% replacement level is again much less than that achieved for lower replacement levels. In fact, none of the mixes were able to satisfy the minimum strength requirements at this replacement level.

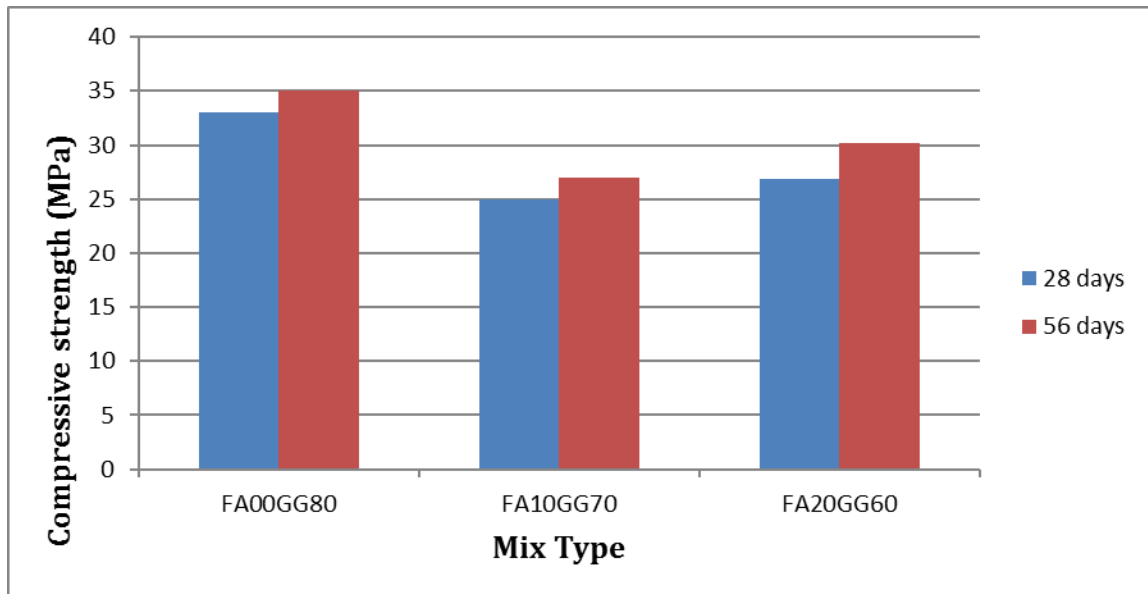


Fig. 4.5 Effect of 80% replacement on compressive strength of concrete

(ii) Effect of age on compressive strength of pavement quality concrete mixes

The Table 4.2 and Fig. 4.6 show the percentage variation in compressive strength of concrete mixes with age.

Table 4.2 – Effect of Age on Compressive Strength of PQC

Mix Type	28 days	56 days	% increase
FA00GG50	48.0	51.9	8.12
FA00GG60	40.6	45.0	10.84
FA00GG70	38.0	40.3	6.05
FA00GG80	33.0	35.0	6.06
FA10GG40	46.2	49.5	7.14
FA10GG50	41.5	48.6	17.11
FA10GG60	31.5	33.1	5.08
FA10GG70	25.0	27.0	8.0
FA20GG30	39.2	43.7	11.48
FA20GG40	36.8	39.9	8.42
FA20GG50	31.5	36.0	14.28
FA20GG60	26.9	30.2	12.27

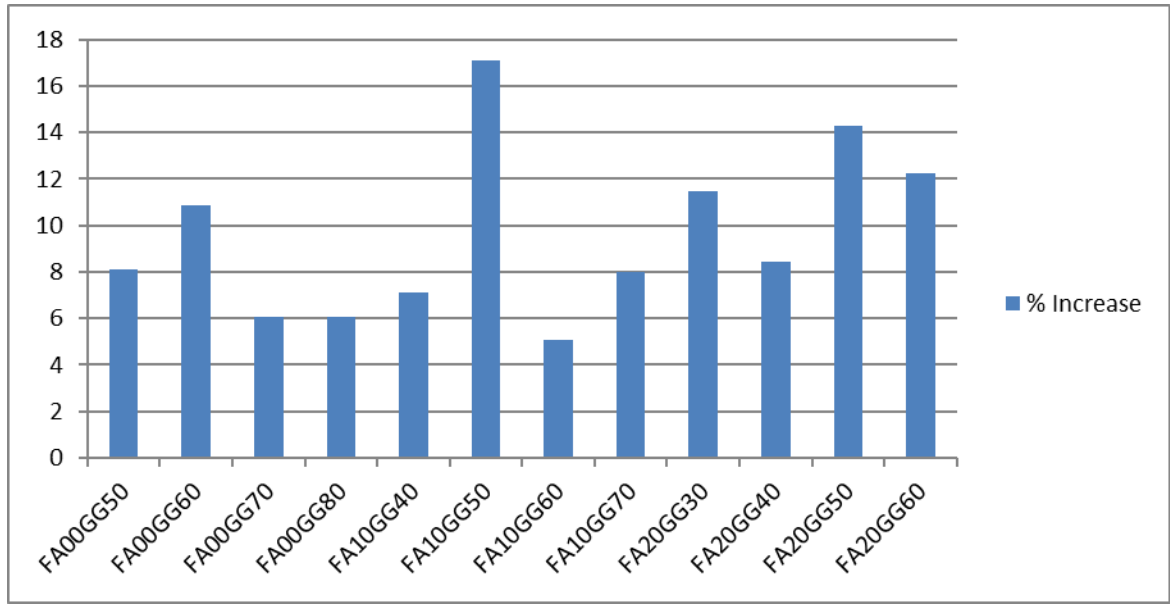


Fig. 4.6 Percentage variation in compressive strengths of 28days to 56 days w/b = 0.36

The percentage variation in the compressive strength of 28 days to 56 days is presented in the table and figure mentioned above.

From the data presented in the above-mentioned table and figure it is observed that the maximum gain in strength over the 28 days period is observed for mixes containing fly ash in addition to GGBS. For mixes containing only GGBS as a replacement material the strength gain is significantly less to the tune of 5 to 8% only. For the mixes having both ingredients the maximum strength gain is to the tune of more than 15%.

This again proves the point that fly ash provides the desired pozzolanic effect in the concrete mixes, when used in combination with GGBS as a cement replacement material.

4.3 FLEXURAL STRENGTH

4.3.1 General

The most common concrete structure subjected to flexure is a highway or airway pavement and strength of concrete for pavements is commonly calculated by means of bending tests. When concrete is subjected to bending, then tensile and compressive stresses and in many cases direct shear stresses are established.

4.3.2 Test Procedure and Results

Test specimens of beam size 150 mm × 150 mm × 700 mm are prepared for testing the flexural strength for various mixes. In these mixes, replacement of cement is done with fly ash and GGBS in different percentages. The beam moulds containing the test specimens are placed in moist air (at least 90% relative humidity) and a temperature of 27^o C for 24 hours from the time of addition of water to the dry ingredients. After 28 and 56 days of curing the specimens are tested in flexure on a Universal Testing machine of capacity 1000kN. Test results of flexural strength test at the age of 28 and 56 days are given in the Table 4.3.

Table 4.3 Flexural Strength at 28 & 56 days

Mix type	28 days	56 days
FA00GG50	4.03	6.15
FA00GG60	4.31	5.40
FA00GG70	3.70	4.35
FA00GG80	3.50	4.28
FA10GG40	5.59	5.70
FA10GG50	4.82	6.00
FA10GG60	4.62	4.80
FA10GG70	4.58	4.65
FA20GG30	4.37	4.60
FA20GG40	4.28	5.40
FA20GG50	4.12	5.44
FA20GG60	2.89	4.70

4.3.3 Discussion of flexural strength test results

(i) Effect of percentage replacement levels on flexural strength

Flexural strength for all the mixes are summarized in the Table 4.3 and the clustered columns are prepared for comparing the 28 and 56 days strength for mixes containing GGBS and fly ash as a replacement of cement. Fig 4.7 shows the 28 and

56 days flexural strength for all the mixes with and without the supplementary cementitious materials.

On observing the strength data provided in Table 4.3 it is found that a maximum flexural strength of 5.59 MPa is achieved at 28 days for the mix FA10GG40 and 6.15 MPa is achieved at 56 days curing period for the mix FA00GG50. Fig 4.7 shows the variation of flexural strength with different percentage variation of GGBS and fly ash for all ages.

The flexure strength is observed to slightly decrease to a value of 4.82 MPa at 28 days and 6 MPa at 56 days curing, when GGBS is replaced by 10% fly ash in the mix. For all other combinations there is a significant reduction in strength at both the ages.

The maximum flexural strength is obtained by the replacement of 60% of the cement with GGBS alone from the various mix combinations considered in the study for the 28 days curing but for the 56 days curing, 50% replacement of cement by GGBS gives the maximum flexural strength.

On further observations it has been observed that only four out of the twelve combinations satisfy the flexural strength requirements of 4.5 MPa for the PQC as per MORTH guidelines.

In order to further study the effect, the analysis of strength data is done for 50%, 60%, 70% and 80% replacements separately. Fig 4.8 to fig 4.11 shows the variation in the strength for mixes containing different percentage of cement replacement with GGBS and fly ash.

Fig. 4.8 shows the effect of 50% replacement level on flexural strength. It is observed from the figure that the highest flexural strength is achieved for mix having only GGBS with the total 50% replacement. The flexural strength is lesser for the mix having a combination of 10% fly ash and 40% GGBS and this further decreases when fly ash content is increased to 20% and GGBS content is reduced to 30% in the mix. This indicates that increase in the GGBS content increases the flexural strength more as compared to the increase in the fly ash content.

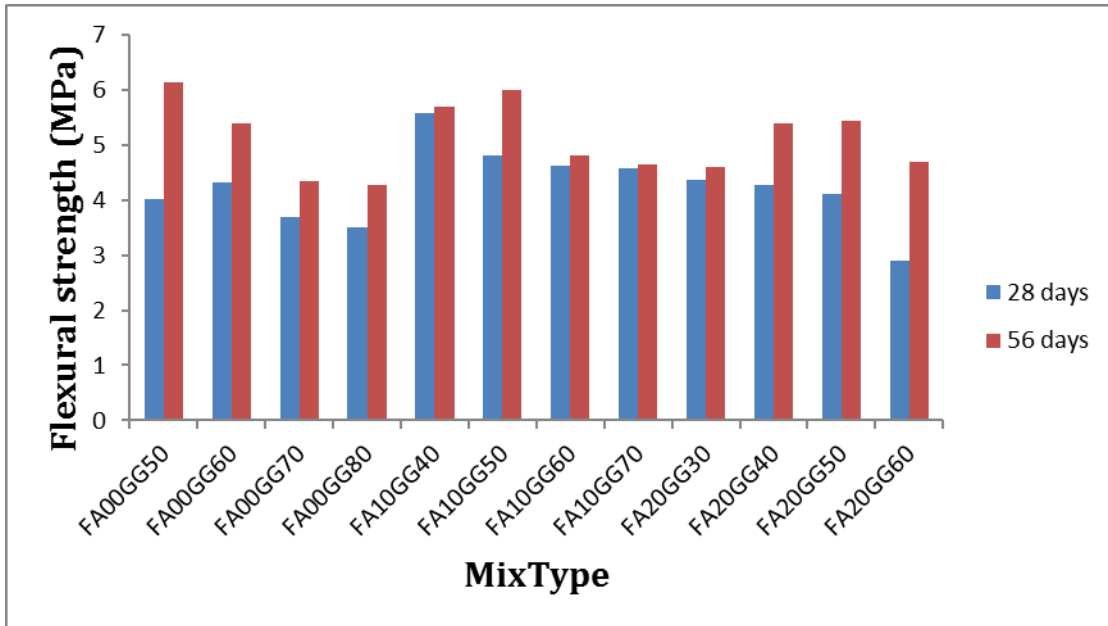


Fig. 4.7 flexural strength variation for different mixes

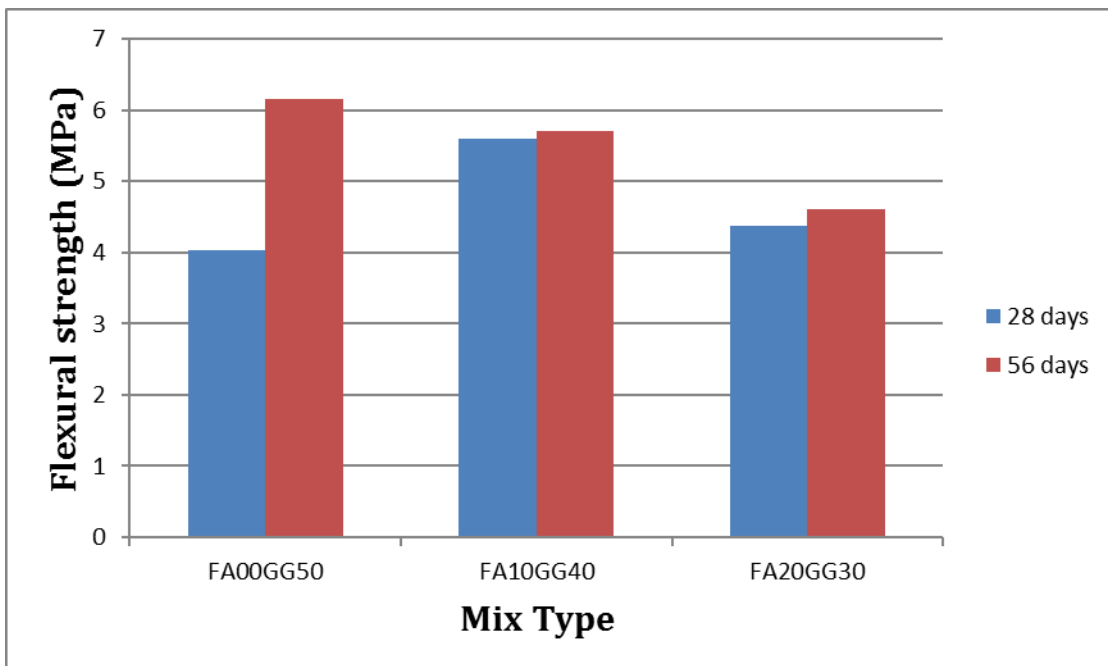


Fig. 4.8 Effect of 50% replacement on flexural strength of concrete

From Figure 4.9, which shows the effect of 60% replacement level on flexural strength, it is observed that the flexural strength achieved for 60% replacement by GGBS alone is less than the mix having 50% GGBS and 10% fly ash.

A further addition of fly ash up to 20% and reduction of GGBS to 40% in the mix FA20GG40 led to a reduction in the flexural strength. This again indicates the point that the maximum replacement level of GGBS in the mix should be limited to 50% only.

It can also be observed from the data that the strength gain from 28 to 56 days is higher for the mixes containing fly ash, which drives home the point that out of GGBS and fly ash, the pozzolanic effect of fly ash is much more.

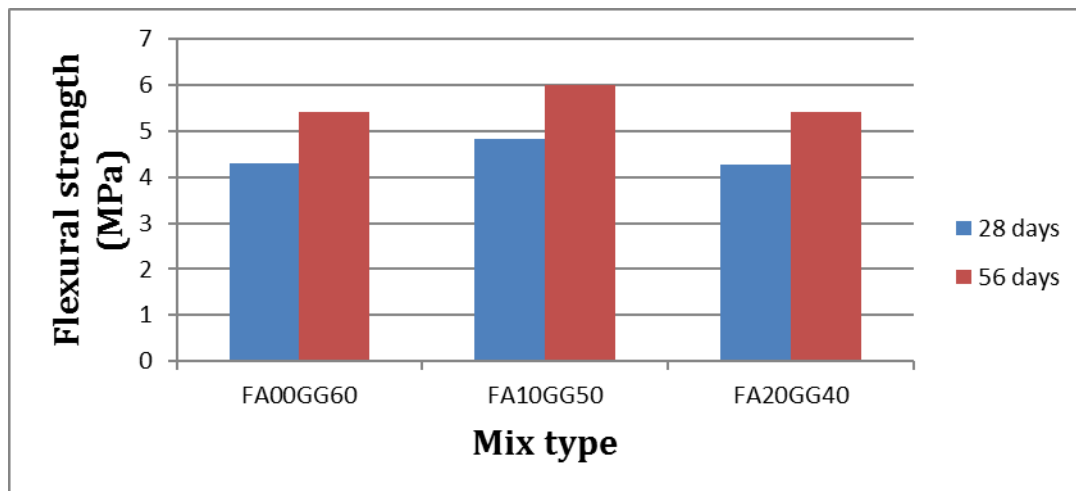


Fig. 4.9 Effect of 60% replacement on flexural strength of concrete

Fig. 4.10 shows the effect of 70% replacement level on flexural strength of PQC mixes. It can be observed from the fig. 4.10 that the mixes with GGBS alone have much lower flexural strength as compared to mixes containing fly ash. Also the strength achieved for 70% replacement level is much less than that achieved for lower replacement levels. The mix containing 10% fly ash has more flexural strength than the mix containing 20% fly ash.

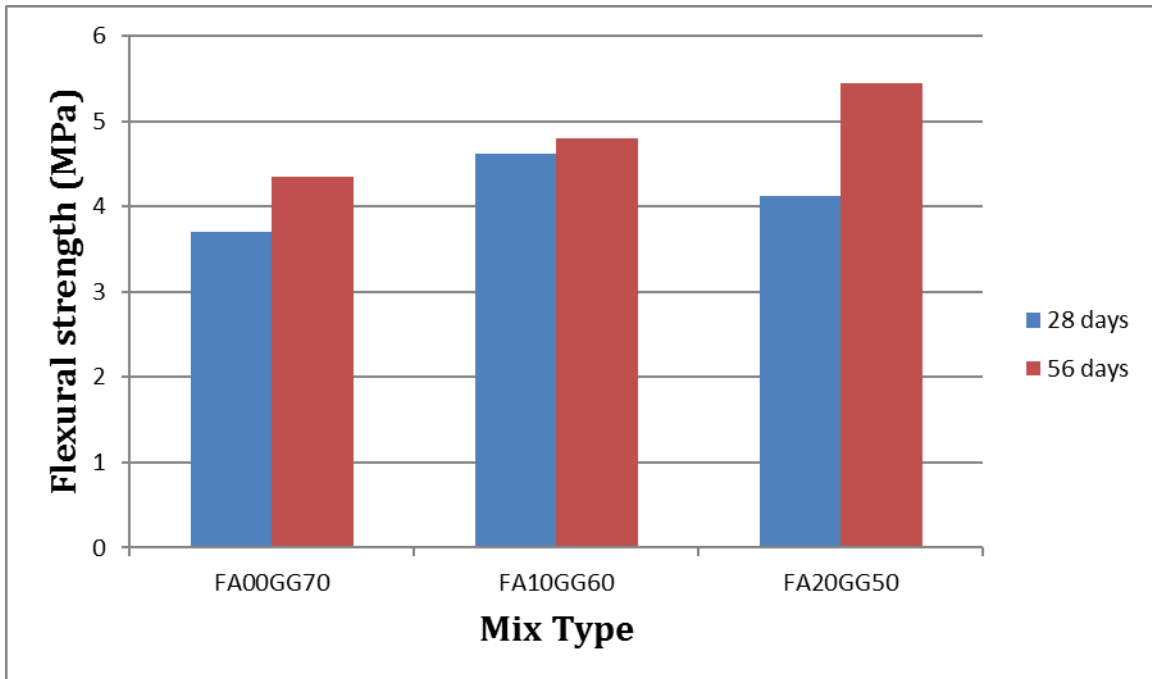


Fig. 4.10 Effect of 70% replacement on flexural strength of concrete

Fig. 4.11 shows the effect of 80% replacement level on flexural strength of PQC mixes. It can be observed from the fig. 4.11 that the mix with GGBS 70% and fly ash 10% has much higher flexural strength as compared to mixes containing fly ash 0% and 20%.

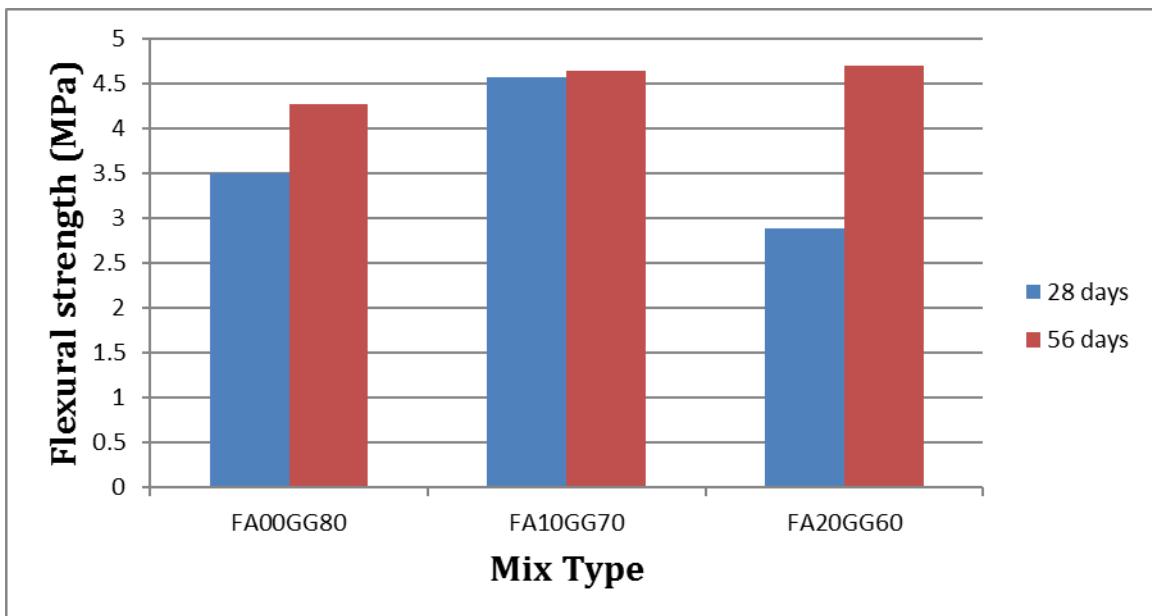


Fig. 4.11 Effect of 80% replacement on flexural strength of concrete

From the figures discussed above it is clear that the mixes which contains 10% fly ash and GGBS percentage satisfies the condition for the minimum strength for PQC.

ii) Effect of age on flexural strength of pavement quality concrete mixes

The Table 4.4 and Fig. 4.12 show the percentage variation in flexural strength of concrete mixes with age.

Table 4.4 – Effect of Age on Flexural Strength of PQC

Mix Type	28 days	56 days	% increase
FA00GG50	4.03	6.15	52.6
FA00GG60	4.31	5.4	25.29
FA00GG70	3.7	4.35	17.57
FA00GG80	3.5	4.28	22.28
FA10GG40	5.59	5.7	1.96
FA10GG50	4.82	6.0	24.48
FA10GG60	4.62	4.8	3.90
FA10GG70	4.58	4.65	1.53
FA20GG30	4.37	4.6	5.26
FA20GG40	4.28	5.4	26.17
FA20GG50	4.12	5.44	32.04
FA20GG60	2.89	4.70	62.63

From the data presented in the above mentioned table and figure it is observed that the maximum gain in strength over the 28 days period is observed for mixes containing fly ash in addition to GGBS. This again proves the point that fly ash provides the desired pozzolanic effect in the concrete mixes, when used in combination with GGBS as a cement replacement material.

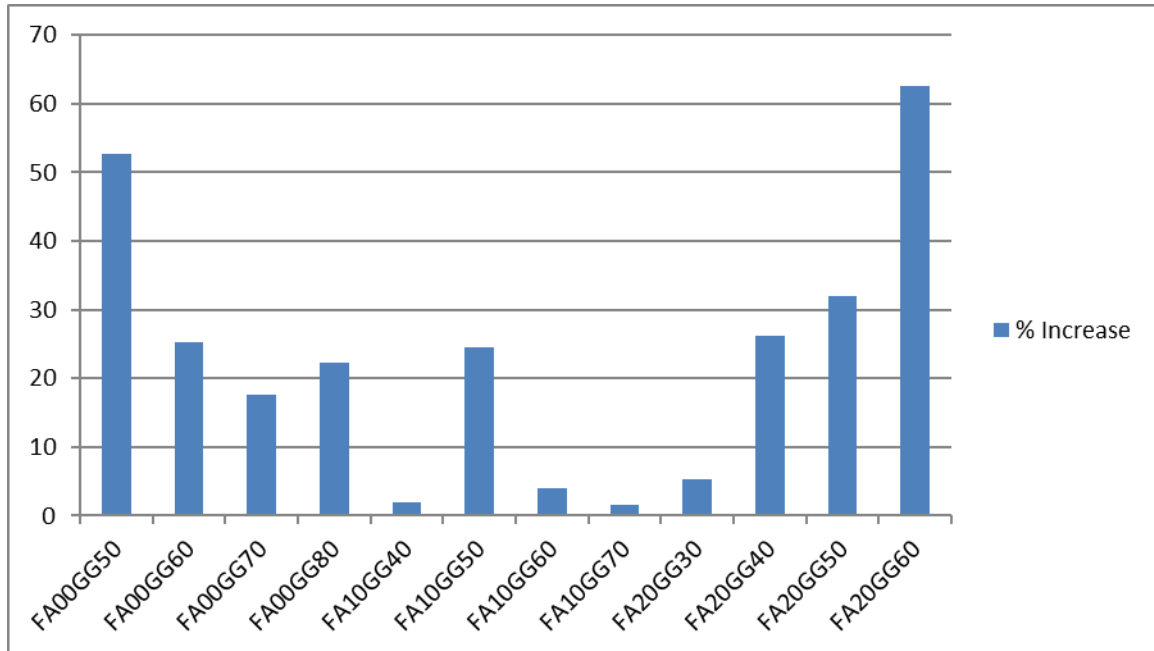


Fig. 4.12 Percentage variation in flexural strengths of 28 days to 56 days

4.4 RAPID CHLORIDE PERMEABILITY TEST

4.4.1 General

The resistance to Chloride Penetration of concrete is determined by casting cylinders of size 100 mm × 200mm. The quantities of cement, coarse aggregate, fine aggregate, GGBS, fly ash and water for each batch replacement are weighed separately. The cement, GGBS and fly ash are mixed dry to a uniform colour separately. Fine aggregate are mixed to this mixture in dry form. The coarse aggregates are mixed to get uniform distribution throughout the batch. Water added to the mix. Firstly, 50 to 70% of water is added to the mix and then mixed thoroughly for 2 to 3 minutes. The moulds are filled with fresh concrete and are vibrated properly. Two cylinders are casted for each mix. The test is carried out on 28 day.

4.4.2 Test Procedure and Results

The test method (according to ASTM C 1202-97) covers the determination of the electrical conductance of concrete to deliver a rapid indication of its resistance to the penetration of chloride ions. According to Table 3.11 the Chloride Ion

Penetrability is decided on the basis of charge passed. Specimens are placed in the vacuum desiccator's bowl as shown in Fig .3.3, which illustrates the setup of the vacuum pump, desiccator with stopcock, vacuum gauge and valve and the de-aerated water container after the water has filled the desiccators. The vacuum is maintained in the desiccators bowl for 3 hours. The de-aerated water is allowed to flow into the desiccator, so that it completely covers the specimens and no air is allowed to enter. The test method consist of monitoring the amount of electrical current passed through 50 mm thick slices of 100 mm nominal diameter cylinders for a 6-hours. A potential difference of 60 V dc is maintained across the ends of the specimen, one of which is immersed in a sodium chloride solution, the other in a sodium hydroxide solution (3.0% NaCl and 0.3 N NaOH solutions) are filled in the two cells. The total charge passed, in coulombs, is related to the resistance of the specimen to chloride ion penetration.

Test results of RCPT test at the age of 28 and 56 days are given in the Table 4.5.

Table 4.5: Rapid chloride permeability of samples at 28 days

Mix Type	Total charge passed (Coulombs) 28 days	Permeability
FA00GG50	363	Very Low
FA00GG60	284	Very Low
FA00GG70	207	Very Low
FA00GG80	212	Very Low
FA10GG40	313	Very Low
FA10GG50	250	Very Low
FA10GG60	187	Very Low
FA10GG70	188	Very Low
FA20GG30	324	Very Low
FA20GG40	238	Very Low
FA20GG50	248	Very Low
FA20GG60	166	Very Low

4.4.3 Effect of fly ash and ground granulated blast furnace slag replacement on rapid chloride permeability test of PQC

Table 4.5 shows the total charge passed in coulombs for various mixes of Pavement Quality Concrete (PQC) with the variation in the replacements levels of fly ash and ground granulated blast furnace slag, individually as well as in combinations, at the curing ages of 28 day. We can replace all the combinations with the cement because in all the cases the permeability is very low. Fig 4.13 shows the total charge passed in coulomb at 28 days.

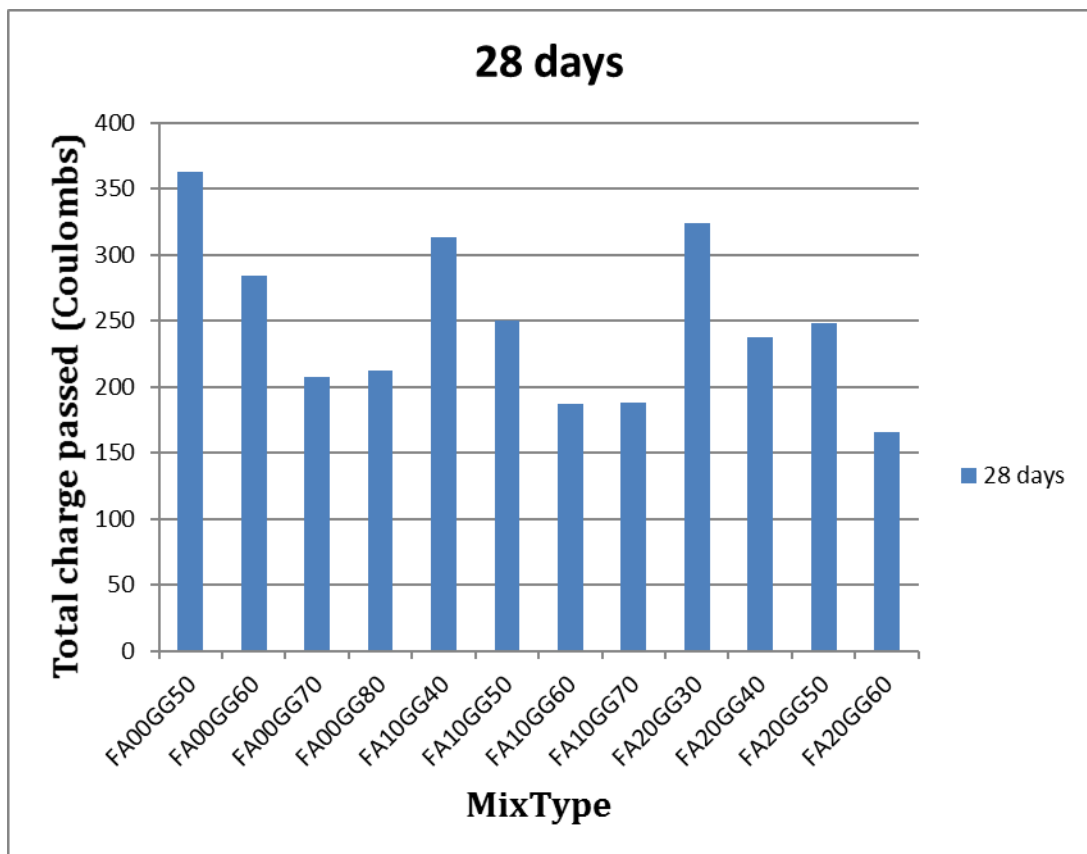


Fig. 4.13 Total charge passed in coulombs at 28 days

For all the mixes the total charge passed (coulombs) is below 1000 that indicates the permeability for all the mixes is very low. The least permeability is for the mix FA20GG60 where GGBS used is 60% and fly ash used is 20%.

5.1 GENERAL

An experimental program was devised to study the strength and durability characteristics of pavement quality concrete containing GGBS and fly ash. Tests were performed on hard concrete cured under standard laboratory conditions, and compressive and flexural strengths were observed at curing ages of 28 and 56 days. A discussion of results was carried out and the major conclusions drawn from the study are elaborated here in.

5.2 COMPRESSIVE STRENGTH OF PAVEMENT QUALITY CONCRETE

- The maximum compressive strength of concrete is achieved when cement is replaced only with 50% GGBS for all ages. The strength is observed to slightly decrease to a value of 46 MPa at 28 days and 49.5 MPa at 56 days, when GGBS is replaced by 10% fly ash in the mix. For all other combinations there is a significant reduction in strength at both the ages.
- It can be seen that at least four mixes, out of the 12 combinations studied, satisfy the compressive strength requirements of 40MPa. The mix containing 50 % and 60% GGBS without any content of fly ash and also the mix containing 10% fly ash with 40% and 50% GGBS respectively satisfies the requirement for the PQC
- The compressive strength is lesser for the mix having a combination of 10% fly ash and 40% GGBS and this further decreases when fly ash content is increased to 20% and GGBS content is reduced to 30% in the mix. This indicates that GGBS plays a much better role in strength development as compared to fly ash.
- The maximum replacement level of GGBS in the mix should be limited to 50% only. After 50% the strength gets reduced for other mixes.
- The strength gain from 28 to 56 days is higher for the mixes containing fly ash, which drives home the point that out of GGBS and fly ash, the pozzolanic effect of fly ash is much more.

5.3 FLEXURAL STRENGTH OF PAVEMENT QUALITY CONCRETE

- The maximum flexural strength of concrete is achieved when cement is replaced with 10% fly ash and 40% GGBS for 28 days and for 56 days the maximum strength is achieved for the mix when cement is replaced only with 50% GGBS.
- It is seen that four mixes, out of the 12 combinations studied, satisfy the flexural strength requirements for PQC. All the mixes which contains 10% fly ash with 40%, 50%, 60%, 70% GGBS satisfy the condition of PQC.
- For 28 days the minimum flexural strength is found for the mix which contains 20% fly ash and 60% GGBS replacement with cement.
- For the 56 days the maximum increase in flexural strength is when 80% of cement is replaced with 20% fly ash and 60% GGBS.

5.4 RAPID CHLORIDE PERMEABILITY TEST

- All the mixes containing fly ash and GGBS as a cement replacement shows very low permeability.
- The least amount of charge in coulombs is passed when 80% of the cement is replaced with 20% fly ash and 60% GGBS.

5.5 SCOPE FOR FURTHER WORK

In the present study experimental program was devised to study the strength and durability characteristics of mixes containing GGBS and flyash. The work can be extended further to study the performance of the pavement quality concrete slabs containing GGBS & flyash by constructing the trial stretches. The behaviour of these PQC slabs can be analysed under repetitive loading for the fatigue life consumed.

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