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ADVANCEMENT OF HIGH PERFORMANCE CONCRETE UTILIZING NATURAL ADMIXTURE

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ABSTRACT

Today, the use of High Performance Concrete receives a focused attention and has a wide range of applications. It has been used due to the financial benefits that can be achieved from the earlier strength gain of HPC. It also reduces the permeability and increases wear or abrasion resistance of concrete. But for the production of HPC, it requires mineral admixtures as well as natural plant extracting admixtures in addition to pozzalonic materials. The mineral admixture increases the pozzolanic activity in the cement paste. In addition, the natural plant extracted admixtures improves the durability performance of the concrete. So, HPC contributes more towards the environmental friendly concrete .In this present research, the effect of control concrete with Natural Admixture and Natural Admixture added concrete with Partial replacements of cement by fly ash, silica fume; Metakaoline and Steel slag were studied. In the experimental study, the natural admixtures were added to control concrete by increments from 25 ppm to 125 ppm of P.juliflora based on the different trials for fresh and hardened properties, 100 ppm was found as optimum dosage for natural admixture. With this optimum % of natural admixture, the cement was replaced with Fly ash by 5% increment from 5% to 25%. Based on the fresh and hardened properties tests, the optimum percentage of fly ash was 10%. By adding optimum % of natural admixture, silica fume was added as partial replacement for cement from 5%, to 25%. Based on the fresh and hardened properties tests, it was found that 15% was optimum. By adding optimum % of natural admixture, Metakaoline were added as partial replacement for cement by 5% increment from 5% to 25%. Based on the fresh and hardened properties tests it was found that 15% was found to be optimum. At the same time Control concrete with optimum percentage of natural admixture and optimum percentage of 10% fly ash was partially replaced with steel slag for the fine aggregate by increasing from 5% to 40% and the test results revealed that 35% was optimum. By the above procedure the steel slag was partially replaced for fine aggregate with optimum % of natural admixture and optimum % of silica fume, was added 35% and with optimum % of Natural Admixture and optimum % of Metakaolin was found to be 35%.

The fresh, hardened and micro structural properties of the mix proportions for the following were compared in following three categorizes (i) control concrete with optimum % of Natural Admixtures, Fly Ash and Steel slag (ii) control concrete with optimum % of natural admixtures, Silica fume and Steel slag (iii) control concrete with optimum % of natural admixtures, metakaoline and steel slag. In addition, the electro chemical studies were also performed for the above mix proportions. The test results revealed that the addition of 100 ppm of natural admixtures with silica fume and Steel slag exhibits excellent performance in all aspects when compared to conventional concrete.

I. INTRODUCTION

Concrete has been comprehensively utilized as a construction material due to its advantageous characteristics. Many researchers were working in order to make concrete to withstand more strength and durable. Also researchers make an attempt to utilize industrial wastes as replacement for cement, fine and coarse aggregates for making concrete, which partially improves strength, durability and helps in protecting the environment. Thus, the production of normal concrete, high strength concrete and high performance concrete, etc., with partial replacement of industrial wastes, adding mineral admixtures and natural plant extracting admixtures are highly recommended.

1.1 HIGH PERFORMANCE CONCRETE

In many construction applications, concrete is used to meet a specific requirement besides high strength. For example in pre stressed concrete bridges, high rise buildings, off shore structures, highways, airport pavements and in machine foundations, concrete should possess high fatigue strength. In nuclear reactors exposed to huge temperatures, the concrete must have a high resistance to thermal cracking. The need for high strength and durability property requirements have made the researchers to develop concretes with high strength and durability through research, out of different grades of concrete. The M50 grade concrete provides several advantages such as high strength and better durability properties (ACI Committee 211.4R-93 1996). Over the past few decades, M50 grade concrete has been used for a wide range of applications. The M50 grade concrete is preferably used in Railway Bridge to eliminate vibration problems and minimize the maintenance cost.

1.2 ROLE OF MINERAL ADMIXTURES IN HPC

The need of high performance concrete explored the use of mineral admixtures and natural plant extracting materials to enhance the performance of concrete. For example mineral admixtures like as Fly ash, Silica fume and Metakaolin are used to overcome the adverse effect of calcium hydroxide produced during hydration of cement in concrete). These mineral admixture increases the pozzalonic activity in the cement paste, when compared to OPC. The pozzalonic reaction of these mineral admixtures influences the durability of cement paste by making it dense and impermeable. The natural plant extracting admixtures may also be used to enhance the durability performance of the concrete. The addition of mineral admixtures in optimum proportions exhibit development of concrete by reducing the heat of hydration, decreasing alkali aggregate reaction, improving chemical and corrosion resistance, etc.

1.3 ROLE OF FLY ASH IN HPC

Fly Ash commonly improves workability with decreased quantity of water. The reduction in water leads to increase in strength of concrete. FA added concrete is less vulnerable to the alkali-aggregate reaction due to its reduced permeability and less calcium oxide. Sulfate and other chemical attacks are decreased when FA is added in concrete as cement replacement material. The reduced permeability of fly ash added concrete decreases the chloride penetration.

1.4 ROLE OF SILICAFUME IN HPC

The use of SF in the concrete mix enhances workability and makes the mix more flexible with cohesiveness. This is the consequence of an enhanced dispersion of the cementitious materials and of the surface character of the silica fume particles, which are soft and absorb small water during mixing. The better workability of concrete, including SF is additional sensitive to variations in the water content of the mix than ordinary mix. The greater fineness of SF reduces bleeding of concrete. The mix containing silica fume has very small penetrability, excellent resistance to penetration by chloride ions and abridged freeze thaw effect.

II. LITERATURE REVIEW

1.Courard et al. (2003) investigated the effects of metakaolin additions on transport properties of mortars. Comparisons are made with ordinary Portland cement (OPC) to determine the influence of addition and replacement percentage. Cement is replaced from 5 % to 20% by metakaolin. A mixture with natural kaolin is also studied. The transport properties and chemical behaviors are analyzed by means of chloride diffusion tests and sulfate immersion. Observations after more than 100 days are used to check the rate of chloride diffusion and sulfate degradation. For metakaolin, the optimum seems to be between 10% and 15% with regard to inhibition effect on chloride diffusion and sulfate attack. For metakaolin admixtures, the optimum seems to be between 10% and 15% for mechanical properties and the inhibition effect on the chloride diffusion and sulfate attack.

2.Ravindra & Narasimhan (2003) have illustrated that, the replacement of 11.5% silica fume, in cement gained maximum compressive strength and after this percentage, the strength was decreased.

3.Ravindra & Narasimhan (2003) investigated the mechanical properties of high-strength concrete of grades M40 and M50, at 28 days characteristic strength with different replacement levels of cement with silica fume or micro standard cylinders (100 mm dia x 200 mm height) were used in the investigation. Specimens were cast with and without silica fume. The mechanical properties viz., compressive strength, concrete with various replacement of silica fume viz., 10%, 20% and 30% has been considered.

4.Sinan Caliskan (2003) has reported on micro structural investigations and chemical analyses by utilizing scanning electron microscopy and energy dispersive X-ray analyzer in the interfacial zone between three types

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of cylindrical aggregates (sandstone, limestone and granite) and two types of mortar matrices (plain mortar and 20% silica fume mortar). The strength of the interface was determined experimentally by means of aggregate push-out test. Interfacial strength was then related to the interfacial thickness and the amount of silica at the interface. It was found that higher the silica concentration in the interface, thinner the relative interfacial thickness and interfacial bond strength increased as a result of the densification role of silica fume.

III. EXPERIMENTAL INVESTIGATION

3.1 MATERIALS USED

3.1.1 Cement

OPC of 53 grade cement confirming to IS: 12269 – 1987 was used for this research work. The OPC was analyzed for physical properties and chemical compositions as per the procedure given in IS: 4031-1988.

3.1.2 Fly Ash:

Fly ash is the finely divided residue that results from the combustion of pulverized coal and is transported from the combustion chamber by exhaust gases. Fly ash is produced by coal-fired electric and steam generating plants. Typically, coal is pulverized and blown with air into the boiler's combustion chamber where it immediately ignites, generating heat and producing a molten mineral residue.

3.1.3 Silica Fume:

Silica fume is a byproduct of producing silicon metal or ferrosilicon alloys. One of the most beneficial uses for silica fume is in concrete. Because of its chemical and physical properties, it is a very reactive pozzolan. Concrete containing silica fume can have very high strength and can be very durable. Silica fume is available from suppliers of concrete admixtures and, when specified, is simply added during concrete production.

3.1.4 Metakaolin:

Metakaolin is a pozzolan, probably the most effective pozzolanic material for use in concrete. It is a product that is manufactured for use rather than a by-product and is formed when china clay, the mineral kaolin, is heated to a temperature between 600 and 800ºC. Its quality is controlled during manufacture, resulting in a much less variable material than industrial pozzolans that are by-products.

3.1.5 Fine Aggregate:

Fine aggregates are essentially any natural sand particles won from the land through the mining process. Fine aggregates consist of natural sand or any crushed stone particles that are ¼" or smaller.

3.1.6 Water:

Potable tap water obtained in the laboratory with a pH value of 7.0-8.5 and confirming to the requirements of IS: 456-2000 was utilized formixing of concrete and also for curing of the specimens.

3.1.7 Super Plasticizer:

In this research work, commercially available super plasticizer was used. It is based on sulphonated naphthalene formaldehyde and complies with IS 9103 -1999 and BS: 5075 Part 3.

3.1.8 Plant Extract:

The P. juliflora plant as shown in Figure 3.6 was powdered well and 600 g of the materials were refluxed with 10% methanol for 6 hours and the solution was filtered off. After the extraction, the solutions were filtered off. The solution was left out for overnight after the completion of refluxing to enable evaporation and comprehensive extraction. The powdered P. juliflora was dissolved in water in most wanted concentrations, which will be utilized to make different concrete mixes.

3.2 MIX PROPORTIONS AND TEST DETAILS

To achieve High Performance Concrete, M50 grade of concrete was used in this research. Trial mix ratio for M50 grade concrete was arrivedbased on recommendations of IS: 10262-1999.

By incorporating sulphonated naphthalene formaldehyde based super plasticizer the workability and cohesiveness of fresh concrete was improved. The identified mix ratio and the quantity of admixture materialsused for one meter cube of concrete mix are presented in Table 3.1.

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Table 3.1: Mix Proportion for M50 grade concrete

Cement(kg)	Fine Aggregate (kg)	Coarse Aggregate(kg)	Water(kg)	Super plasticizer(% of mass of binders)
545	516	1035	207	1.5

The control concrete C0 was cast without adding admixtures. The concrete mixtures C1 to C5 were made by adding varying percentages of plant extract from P. juliflora with 25 ppm to 125 of ppm at 25 ppm interval which is termed as PLEX concrete. The concrete mixtures with 5%, 10%, 15%, 20% and 25% replacement of cement by weight of mineral admixtures such as FA, SF and MK with optimum level of P. juliflora are designated from C6 to C10, C11 to C15 and C16 to C20, respectively.The mixtures with 10% FA, 15% SF and 15% MK in PLEX concrete with replacement of fine aggregate by weight using Steel Slag varrying from 0 to 40% with an interval of 5% are marked as C21 to C28, C29 to C36 and C37 to C44, respectively. Table 3.2 shows the mix proportions for different cementitious materials with natural admixture and steel slag as fine aggregate.

Table 3.2: Mix Identification and materials required per m3 of concrete

Sl. No.	Mix.ID	ement(kg)	Fine Agg. (kg)	CA (kg)	Water (kg)	FA (kg)	SF (kg)	MK (kg)	P. juliflora (ppm)	SP (%)	SS (kg)
1	C0	545.00	516.0	1035	207	-	-	-	0	1.5	-
2	C1	545.00	516.0	1035	207	-	-	-	25	1.5	-
3	C2	545.00	516.0	1035	207	-	-	-	50	1.5	-
4	C3	545.00	516.0	1035	207	-	-	-	75	1.5	-
5	C4	545.00	516.0	1035	207	-	-	-	100	1.5	-
6	C5	545.00	516.0	1035	207	-	-	-	125	1.5	-
7	C6	517.75	516.0	1035	207	27.25	-	-	100	1.5	-
8	C7	490.50	516.0	1035	207	54.50	-	-	100	1.5	-
9	C8	463.25	516.0	1035	207	81.75	-	-	100	1.5	-
10	C9	436.00	516.0	1035	207	109.00	-	-	100	1.5	-
11	C10	408.75	516.0	1035	207	136.25	-	-	100	1.5	-
12	C11	517.75	516.0	1035	207	-	27.25	-	100	1.5	
13	C12	490.5	516.0	1035	207	-	54.50	-	100	1.5	-
14	C13	463.25	516.0	1035	207	-	81.75	-	100	1.5	-
15	C14	436.00	516.0	1035	207	-	109.00	-	100	1.5	-
16	C15	408.75	516.0	1035	207	-	136.25	-	100	1.5	-
17	C16	517.75	516.0	1035	207	-	-	27.25	100	1.5	
18	C17	490.50	516.0	1035	207	-	-	54.50	100	1.5	-
19	C18	463.25	516.0	1035	207	-	-	81.75	100	1.5	-
20	C19	436.00	516.0	1035	207	-	-	109.00	100	1.5	-
21	C20	408.75	516.0	1035	207	-	-	136.25	100	1.5	-
22	C21	490.50	490.2	1035	207	54.50	-	-	100	1.5	25.8
23	C22	490.50	464.4	1035	207	54.50	-	-	100	1.5	51.6

24	C23	490.50	438.6	1035	207	54.50	-	-	100	1.5	77.4
25	C24	490.50	412.8	1035	207	54.50	-	-	100	1.5	103.2
26	C25	490.50	387.0	1035	207	54.50	-	-	100	1.5	129
27	C26	490.50	361.2	1035	207	54.50	-	-	100	1.5	154.8
28	C27	490.50	335.4	1035	207	54.50	-	-	100	1.5	180.6
29	C28	490.50	309.6	1035	207	54.50	-	-	100	1.5	206.4
30	C29	463.25	490.2	1035	207	-	81.75	-	100	1.5	25.8
31	C30	463.25	464.4	1035	207	-	81.75	-	100	1.5	51.6
32	C31	463.25	438.6	1035	207	-	81.75	-	100	1.5	77.4
33	C32	463.25	412.8	1035	207	-	81.75	-	100	1.5	103.2
34	C33	463.25	387.0	1035	207	-	81.75	-	100	1.5	129.0
35	C34	463.25	361.2	1035	207	-	81.75	-	100	1.5	154.8
36	C35	463.25	335.4	1035	207	-	81.75	-	100	1.5	180.6
37	C36	463.25	309.6	1035	207		81.75	-	100	1.5	206.4
38	C37	463.25	490.2	1035	207	-	-	81.75	100	1.5	25.8
39	C38	463.25	464.4	1035	207	-	-	81.75	100	1.5	51.6
40	C39	463.25	438.6	1035	207	-	-	81.75	100	1.5	77.4
41	C40	463.25	412.8	1035	207	-	-	81.75	100	1.5	103.2
42	C41	463.25	387	1035	207	-	-	81.75	100	1.5	129.0
43	C42	463.25	361.2	1035	207	-	-	81.75	100	1.5	154.8
44	C43	463.25	335.4	1035	207	-	-	81.75	100	1.5	180.6
45	C44	463.25	309.6	1035	207	-	-	81.75	100	1.5	206.4

FA – Fly Ash, SF – Silica Fume, MK – Metakaolin, SS – Steel Slag, Fine Agg. – Fine Aggregate, CA-Coarse Aggregate, PJ – P. juliflora , SP – Superplasticizer Table 3.3 presents the dimensions of the specimens and test detailscarried out for the present study.

Table 3.3: Specimen and test details

Sl. No.	Tests	Specimen	Size	No. of Specimens
MECHANICAL PARAMETER TEST				
1	**Compressive strength based on IS: 516-1959**			
	7 Days	Cube	150 X 150 X 150 mm	135
	14 Days	Cube	150 X 150 X 150 mm	135
	28 Days	Cube	150 X 150 X 150 mm	135
2	ensile strength based onIS: 5816-1999	Cylinder	mm diameter and300 mm height	135
3	strength based on IS:516-1959	Prism	100X100X500 mm	135
DURABILITY PARAMETER TEST				
	Saturated water absorption			

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4	based on ASTM C - 6420 - 81	Cube	150X150X150 mm	135
5	tivity based on ASTMC1585	Cube	150X150X150 mm	135
6	Rapid chloride ion Penetration Test (RCPT)based on ASTM C1202	Cylinder	m thick slices and102 mm dia	135
Total number of specimens				**1080**

IV. ANALYSIS AND DISCUSSION OF TEST RESULTS

4.1 Compressive strength of PRCM added concrete

All concrete specimens were cast and tested for 28 days of curing age and shown in Figure 4.1. The results indicated that all mixtures yielded comparable or higher compressive strength than the control concrete for all curing ages. The compressive strength of P. juliflora (C1 to C5) added concrete increases by 0.75%, 2.95%, 4.48%, 7.06% and 2.43% respectively at the age of 28 days when compared with control concrete and also found that P. juliflora with 100 ppm in M50 grade concrete reached optimum compressive strength is called PLEX concrete.In comparison, the percentage increase in PLEX concrete compressive strength, compared to control concrete at the age of 28 days, are 5%, 10%, 15%, 20% and 25% of FA, SF and MK. The evaluation is carried of the mixes C6 to C10 partial replacement of FA exhibits improve the compressive strength by 4.85%, 21.02%, 20.07%, 17.47% and 8.12%, respectively, at the age of 28 days as compared to control concrete. The compressive strength of the mixes C11, C12, C13, C14 and C15 partial replacement with SF showed an increase in compressive strength of 8.49%, 21.28%, 25.46%, 18.31% and 10.43%, respectively at the age of 28 days when compared to control concrete specimen. At the age of 28 days, the compressive strength of C16 to C20 mixes are improved by 8.18%, 11.89%, 20.05%, 16.93% and 4.72%, respectively, compared to control concrete.

The test result shows that at the age of 28 days, the C27, C35 and C43 mixes with 35% SS obtained the highest improvement in the development of compressive strength by 24.64%, 30.91% and 28.17%, respectively, compared to control concrete.

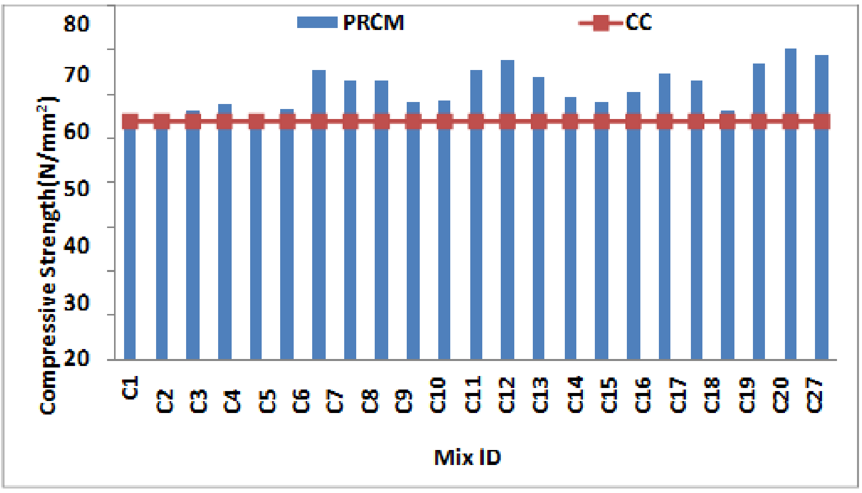

Figure 4.1: Compressive strength of control and PLEX concrete withPCRM added concrete Split tensile strength of PRCM added concrete

In comparison with control concrete, the split tensile strength of the PRCM mixes is increased, as shown in Figure 4.2. At the age of 28 days, the increase in split tensile strength was found to be 19.33%, 23.54% and 20.25% for partial cement replacement FA, 15% for SF and 15% for PLEX concrete, respectively, compared to control concrete. Compared to control concrete, the Mix Ids C27, C35 and C43 acquired a maximum split tensile strength of 16.39%, 35.11% and 22.68%, respectively, at the age of 28 days. The justification for strength improvement was that Steel slag had a higher value of specific gravity and aggregate effect value than the average aggregate but comparable values of aggregate crushing value and Los Angeles abrasive value for a coarse aggregate. In addition, the angular sharp edges of the steel slag particles have the ability to compensate to some extent for the detrimental effects of the aggregate and thereby help enhance the cohesion of the concrete. Consequently, this makes steel slag an effective replacement for coarse aggregate in concrete construction.

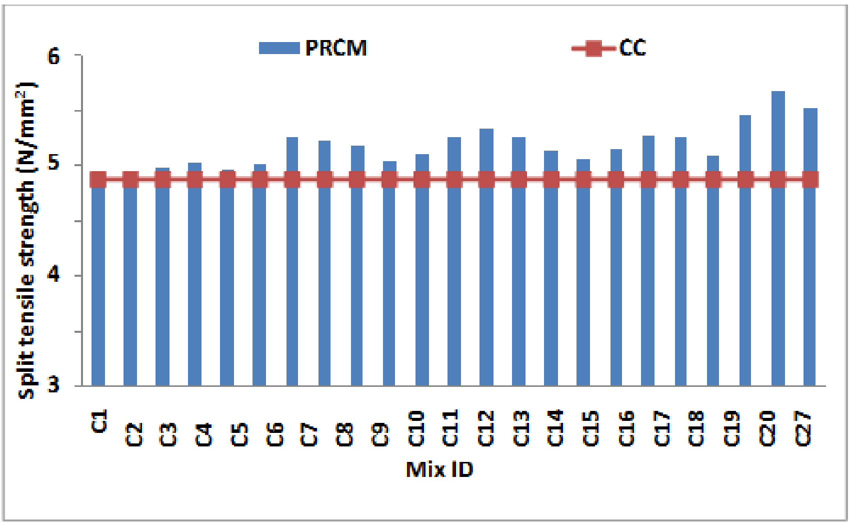

Figure 4.2: Split tensile strength of control and PLEX concrete withPRCM added concrete Flexural strength of PRCM added concrete

When compared with control concrete, P. juliflora added PRCM mixes has increased in flexural strength at the age of 28 days and shown in Figure 4.3. The flexural strength of the PLEX concrete with optimized mineral admixtures of 10% FA, 15% SF and 15% MK as a PRCM and with SS as partial replacement for FA from 0 to 40% with an interval of 5% at the age of 28 days is shown in Figure 5.3. Of all the 24 mixtures, C27, C35 and C43 achieved a maximum improvement flexural strength of 16.39%, 35.11% and 22.68%, respectively, compared to control concrete at the age of 28 days.

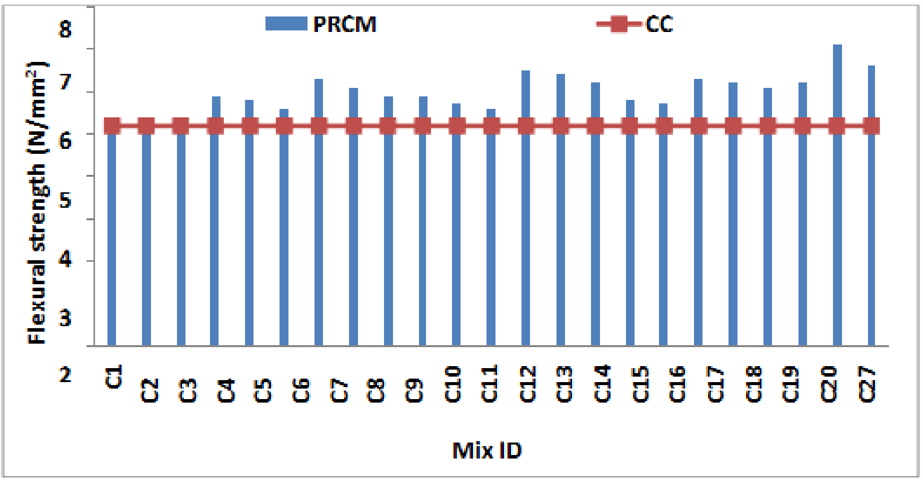

Figure 4.3: Flexural strength of control and PLEX concrete with PRCM added Concrete Water absorption of PRCM added concrete

The saturated water absorption of the PRCM concrete and control concrete mixes has tested at the age of 28 days and is shown in Figure 4.4. From the observation it was noticed that saturated water absorption was decreased for PRCM added concrete, at the age of 28 days, when compared to control concrete. The saturated water absorption of the mixes C27, C35 and C43 and 35% SS obtained the maximum reduction in saturated water absorption of 48.26%, 50.58% and 49.42%, respectively, when compared to control, at the age of 28 days.

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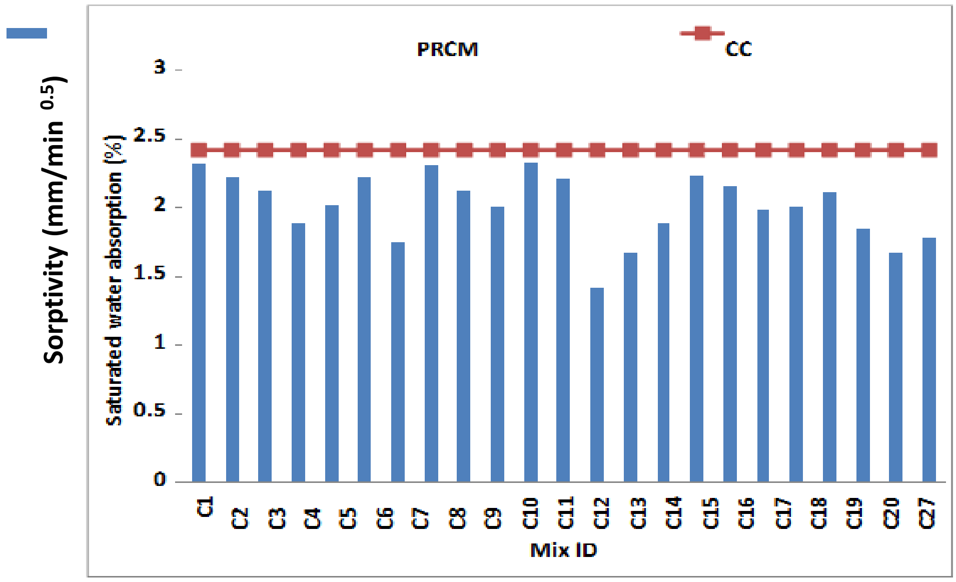

Figure 4.4: Saturated water absorption of control concrete and PLEX concrete with PCRM added concrete

Sorptivity of PRCM added concrete

When compared to control concrete, the sorptivity value of PLEX concrete with PRCM added concrete was reduced at the age of 28 days and shown in Figure 4.5. The sorptivity and relative sorptivity values of concrete mixes of PLEX concrete with PRCM added 10% FA, 15% SF and 15% MK and SS varying from 5% to 40% at 5% increment at the age of 28 days curing. The PRCM added mixes of C27, C35 and C43 with 35% SS as partial replacement for FA obtained the maximum reduction in sorptivity by 53.52%, 63.38% and 56.34%, respectively, when compared to control concrete, at the age of 28 days.

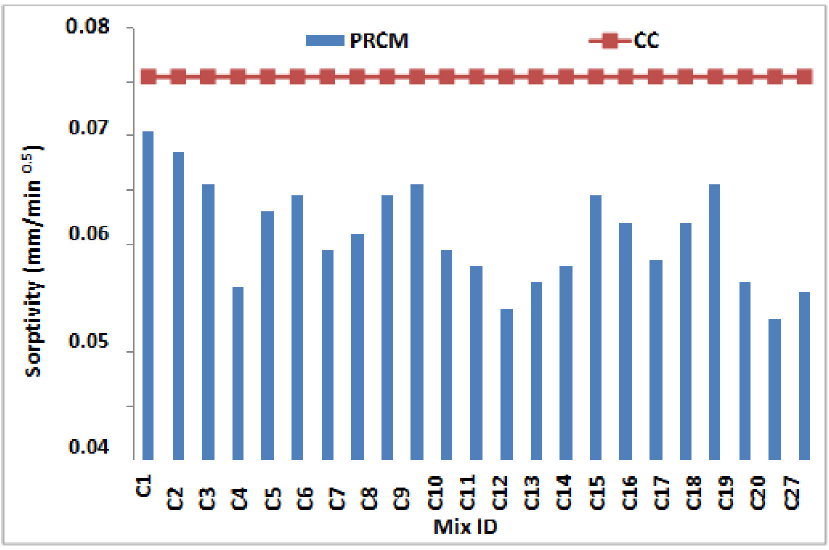

Figure 4.5: Sorptivity of control and PLEX concrete with PRCM addedconcrete

Rapid chloride ion penetration test

The Rapid chloride ion penetration test was carried out as per ASTM C1202. The value of total charge passed in Coulombs was carried out for PLEX concrete with PRCM added concrete and control concrete was represented in Figure 4.6, at the age of 28 days. The test values shows that there is an decreases in chloride ion penetration of PLEX concrete with PRCM, when compared to control concrete at age of 28 days. It shows that a total charge passed is comparatively very low permeability in all the mixes of samples FA, SF and MK with PLEX concrete. The Mix IDs C7, C13, and C15 with the partial replacement level of cement by 10% FA,

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15% SF and 15% MK resulted with lesser chloride ion penetration, when compared to control concrete. As per ASTM C1202, Charge passed (Coulombs) 1000-2000 is rated as low permeability. It shows that a total charge passed is comparatively

low permeability in all the mixes of PLEX concrete with mineral admixtures and steel slag. The mixes C27, C35, and C43 with 35% SS showed a lesser chloride ion penetration, when compared to control mix C0 in M50 grade concrete. Of all the 24 mixes C35 (15% of SF and 35% SS) obtained the maximum resistance to chloride ion penetration.

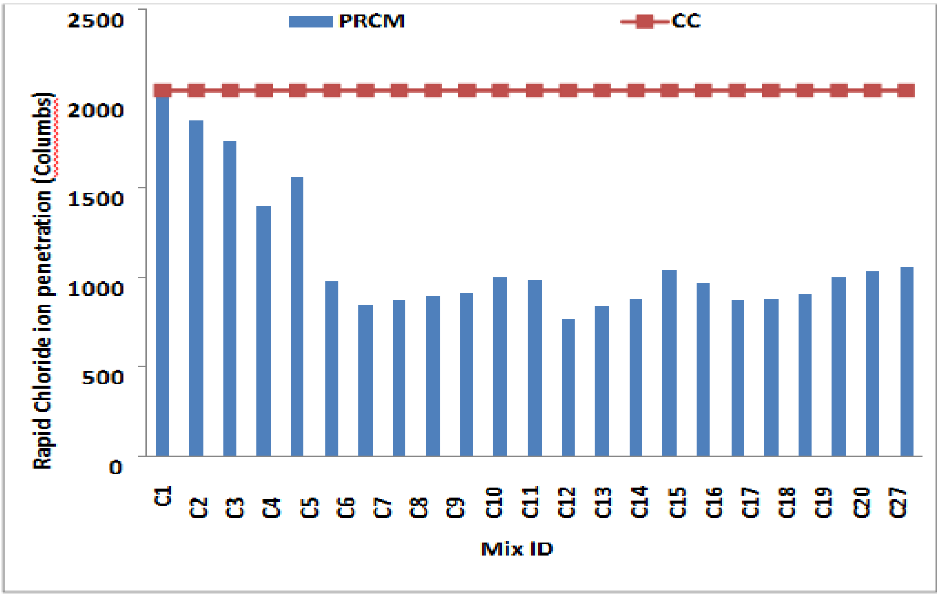

Figure 4.6: Rapid chloride ion penetrations of control and PLEX concrete with PRCM added concrete

V. CONCLUSION

GENERAL

The study reported in this research includes the following topics:

(a) Effect of P. juliflora and mineral admixtures with steel slag on the strength characteristics of M50 grade concrete

(b) Effect of P. juliflora and mineral admixtures with Steel Slag on the durability performance of M50 grade concrete

Experiments were conducted on natural corrosion inhibitor of P. juliflora and three mineral admixtures namely FA, SF and MK. The strength characteristics of PLEX concrete and mineral admixtures with different replacement levels of the above three mineral admixtures were studied at different ages. These three mineral admixtures with PLEX concrete were very effective in improving strength and durability of concrete. The conclusions from the different experimental studies such as strength and durability characteristics of the PLEX concrete with mineral admixtures and steel slag are presented in this chapter.

Conclusion

Based on the experimental study, the following conclusions were given:

- Concrete with 100 ppm P. juliflora gives better result at all ages with respect to strength and durability characteristics, when compared to control specimen.
- PLEX Concrete with 10% FA, 15% SF and 15% MK as a cement replacement material along with gives better performance compared to control mix.
- From the strength and durability study of concrete, it is revealed that the PLEX Concrete with 15% SF obtained better performance, compared to all other mixes.
- When compared to control, PLEX Concrete with15% SF as a partial cement replacement material shows

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increase in compressive strength, split tensile strength and flexural strength to 25.46 %, 23.54% and 25.24%, respectively,.

- The saturated water absorption, sorptivity and chloride ion penetration for the PLEX concrete with 15% SF is reduced to 41.32%, 60.56% and 64.18%, respectively, when compared to control specimen.
- Concrete with 10% FA, 15% SF and 15% MK as a cement replacement material and replacement of fine aggregate by 35% steel slag (SS) in PLEX Concrete obtained the maximum strength and durability performances, when compared to control mix.
- From the strength and durability characteristics, it was noted that, 15% SF as PCRM and 35% of SS as replacement offine aggregate, obtained the better performance, compared to all other mixes in PLEX concrete.
- The compressive strength, split tensile strength and flexural strength of the PLEX concrete with 15% SF and 35% of SS is obtaining the maximum strength of 30.91 %, 44.77% and 35.11%, respectively, when compared to control specimen,at the of 28 days.
- The EIS results and AFM images of steel embedded in NaCl solution revealed that the plant extract formed the surface protective layer over embedded steel.
- The PDS analysis indicated the alteration of the reactions of cathodic and anodic sites of steel and,

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