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Research Article

Impact of controlled permeable formwork liner against chloride penetration on the concrete structures

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Abstract

It has become a requirement to enhance the surface quality of concrete structures and their durability. A non-woven formwork called Controlled Permeable formwork (CPF) liner was developed. This CPF liner is permeable to air and water however prevents the getaway of cement and small particles. This paper investigates experimentally the impact of CPF liner on the concrete surface against chloride penetration. The concrete mix contained ordinary Portland cement (OPC) 53, pulverized fly ash (PFA), Micro silica, locally available aggregates, crushed sand, water and superplasticizer. The cylindrical and cubical concrete specimens were cast with impermeable steel formwork (SF) and CPF liner. The cubic and cylindrical specimens were tested at the age of 7 days and 28 days. Compressive strength and Rapid chloride penetration tests (RCPT) were conducted. The concrete cast with CPF liner gives excellent compressive strength 14% more than specimens cast with steel formwork and has acquired better resistance against Chloride penetration. The results show that the concrete sample cast with CPF liner shows 9.98% less charges passed than specimens cast with steel formwork.

1. Introduction

Reinforced concrete structures need to be durable. Their durability is a major subject on a global scale [1]. Corrosion of steel reinforcement depends upon the exposure conditions, ensuing in millions of expenses being spent on repair and maintenance. Durability of reinforced concrete structures depends on the quality of the cover zone. Cover region is a primary line of defence against either physical or chemical deterioration of the concrete structures [2]. Corrosion of the steel reinforcement in the concrete is due to chlorides and CO_2 from the surrounding environment [3]. Chloride diffusion coefficient of concrete relies upon the water/cement ratio and the cement type [4]. Impermeability of the surface of the concrete structures performs an essential role for attaining long term durability. And that can be achieved by increasing the cement content for the whole entire volume of concrete and decreasing the water/binder ratio [5]. And another method is to use Controlled Permeable formwork (CPF) liner.

CPF liner is a hydrophilic fiber texture, which removes excess quantities of water and decreases water/binder ratio and improves the concrete strength [6].

CPF liner consists of three different primary factors. 1) A filter that allows water and air from fresh concrete to pass through it and keeps cement and other small particles. 2) This water and air are transferred to outside the formwork through drainage system and

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creates denser and less porous concrete surface. 3) The filter and drainage system is supported by structural support that maintains formwork shape and concrete pressure. Figure -1 shows the overall factors of a CPF system.

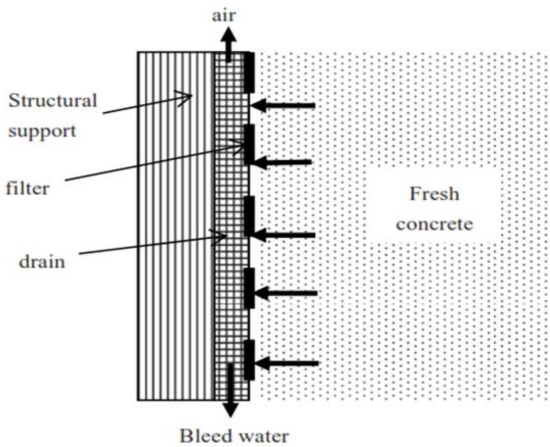

Fig. 1 Factors of a CPF System [8]

A range of research have shown the impact of CPF liner on concrete performance.

S Kothandarama et al. [2] have reported that CPF liner has extensively improved the tensile strength of concrete by almost 20% and abrasion resistance has been enhanced remarkably 50-80%.

S. Kumar et al. [4] have shown that the coefficient of chloride diffusion decreases as the strength of concrete increases, thus durability of the concrete structures increases.

Philip McKenna et al. [7] have reported that by using CPF liner, initial construction cost can be reduced, and improved surface strength, durability and overall appearance of the finished concrete can be achieved [7].

Suryawanshi AK et al. [8] have shown that improvement in impermeability can be achieved by using CPF liner. He used 350 kg/m3 cement as only cementitious material and kept cement/aggregate ratio 5.26.

Sahil Garg et al. [9] reported that CPF liners reduce w/c ratio and porosity of the concrete in the cover region and also found decreased chloride ion penetration depth. Sahil Garg et al. also found increased efficiency of permeable Formwork liner with increased water content in concrete mix.

L Basheer et. al. [10] used cement 450 kg/m3 and water/cement ratio was kept 0.45. The author have shown that by the use of CPF liner that resistance to the ingress of Chlorides and CO2 was increased and impermeability of concrete also increased.

The use of mineral admixture gives improved quality to the concrete. The use of micro silica improves quality of hardened concrete like compressive strength, hence flexural and tensile strength. The use Micro silica reduces the rate of carbonation permeability; therefore, it helps in protecting reinforcement steel from corrosion. The use of fly ash can help in decreasing porosity and can make concrete highly dense as it has very small particles.

Therefore, it is proposed to have look into to analyze the effect of the CPF liner against chloride penetration on concrete surface cast with two different formworks, with lower W/C ratio and use of mineral admixtures.

2. Objectives

- To analyze the impact on compressive strength of concrete with decreased W/C ratio by the application of CPF liner.
- To achieve the better concrete surface performance against Chloride penetration by application of CPF liner using fly ash and micro silica as replacement to the cement.

3. Method

3.1. Materials

In this test O.P.C. 53 grade cement having specific gravity 3.08 was used. Aggregates of size 10 mm, 20 mm and crushed sand, having specific gravity 2.85, 2.87 and 2.71 respectively, were used. Pulverized Fly Ash (PFA) and Micro silica were used as replacement materials. Fly ash is an industrial by-product from combustion process of coal used in power stations. The specific gravity of fly ash was 2.15. Micro silica is also a mineral admixture found as by-product in the industrial manufacture of ferrosilicon and metallic silicon. Microsilica is grey in colour and specific gravity of microsilica was 2.24. Additionally, a Super plasticizer, named Fosroc Auracast 270M, based on polycarboxylic ether polymer was used. The water which was accessible to the lab was used. In this experiment Type II CPF liner was used. It has two sides, one side acts as a drain and another side as a filter. Its average pore size is 30 μm and thickness is 1.5-2.0 mm. This CPF liner has water retaining capability of about 1L/m2 and drainage capacity about >3L/m2.

3.2. Specimen Preparation

Concrete mix of M55 was used to cast the samples. The w/c ratio was kept low 0.26. The details of the concrete mix proportion is shown in table 1. The mix proportion shown in the table 1 is surface saturated dry (SSD) before moisture correction. It is shown that different mineral admixtures were used to replace cement. The concrete mix was identified as CMD-1. The mix of M55 grade is with 21% fly ash and 3% micro silica as a replacement to cement by weight. The superplasticizer replaced 30% water content. The codes IS 456, IS 383, IS 10262:2009 and IRC 112:2011 were followed to conduct the experiment.

Table 1. Concrete Mix Proportion (Kg/m^3)

Ingredients	CMD-1
Cement	424
Fly Ash	118
Micro silica	17
20 mm	614
10 mm	606
Crushed sand	573
Water	171
Admixture	8.4 kg
W/C ratio	0.26

Conventional Steel moulds were used to prepare the concrete specimens. Concrete specimens of size 150 x 150 x 150 mm^3 and small cylinders of 100 mm Dia. and 200 mm height were cast for this study. Steel moulds were oiled before placing the concrete. The casted specimens in steel formwork serve as a reference for comparison purpose. Commercially produced CPF liner is used to paste on the inner side of the other moulds where oil is not used, only glue is used.

Figure- 2 shows the steel mould with CPF liner pasted inside. The specimens cast with CPF liner were recognized as 'CPF' and those cast without CPF liner in the steel moulds were recognized as 'SF'. Further to this, specimens were categorized as FlyAsh SF and FlyAsh CPF etc. to compare the results.

Fig. 2 Steel Mould with CPF Liner Pasted Inside

Before concrete mix, the concrete mix proportion is corrected as per water absorption and moisture content of the aggregates. The water absoption for 20mm, 10mm and crushed sand was 1.4%, 1.6% and 2.65% respectively. And moisture content for crushed sand was 1.5%. The concrete mixes were mixed in a pan of 0.037 m3 capacity. The moulds were filled with the fresh concrete. Then these moulds with concrete were compacted using a tamping rod. 12 cubic specimens and 2 small cylinders were cast. Half number of specimens were cast with steel mould and half with CPF liner. After 24 hr the moulds were removed and specimens cured in a water tank for 7 and 28 days.

3.3 Test Methods

3.3.1 Compressive Strength

The specimens cast with CPF liner were easy to demould. The cast specimens were cured and kept in curing tank for 7 and 28 days. The cubic specimens were taken out from the curing tank and kept outside to open air to dry for some time. IS 516 (1969) was followed for testing the specimens. The demoulded cubic specimens were measured for size, weighed and tested in Compression Testing Machine (CTM) to determine the compressive strength. 3 cubic specimens for each category were tested at age of 7 and 28 days. The cubic specimens were crushed by applying load and load was automatically recorded on digital screen and noted down.

3.3.2 Rapid Chloride Penetration Test (RCPT)

The RCPT test was conducted as per ASTM C1202-07. This test required a specimen of 100 dia. The 50 mm samples were cut from the cylindrical specimen.

Fig. 3 Core Sample From Specimen for RCPT

The side of the specimens were coated with sealer allowing it to dry and then specimens were vacuum saturated. The specimens were fixed in test apparatus and edges were sealed with sealant.

Fig. 4 RCPT Apparatus with Specimens

These two reservoirs were filled with 3% NaCl solution in – ve and 0.3n NaOH solution in + ve terminals as shown in figure – 3. Then terminals were connected to the unit and current was set to 60 V. Initial reading (I_0) was noted and continued to take reading in SI unit Ampere for 6 hrs at the interval of every 30 mins (I_{30}, I_{60}, I_{90}, …….., I_{360}).

4. Results and Discussion

4.1 Visual Observations

The specimens demoulded are observed visually. The Figures 5 and 6 shows surfaces of the demoulded specimens. The specimens cast with steel formwork were found with small pin holes and air bubbles on the surface. Air bubbles and pin holes create due to accumulation of air and mix-water on the interface of concrete and surface of the formwork. Specimens cast with CPF liner were found with clear texture and free from blow holes but with few pin holes.

Fig. 5 Surface of Demoulded Cubic Specimens

Fig. 6 Surface of Demoulded Cylindrical Specimens

Samples cast with CPF liner found dark in colour and the sample cast with steel form (SF) were lighter in colour. The dark colour of the samples can be due to CPF liner. The CPF liner has the capacity to hold the water, that provide humid environment for concrete curing before demoulding. So the samples cast with CPF liner were dark.

4.2 Compressive Strength Test Results

The Compressive strength test was conducted on cubic samples at the age of 7 and 28 days. The specimens cast with CPF liner were small in size with an average of 2 mm on each side due to thickness of CPF liner and accordingly test was conducted.

For concrete mix proportion CMD-I, it is observed that average compressive strength at 7 days for cubic specimens cast with steel formwork (SF) was 47.50 Mpa and 48.97 Mpa for specimens cast with CPF liner. And for 28 days it was 66.62 Mpa and 76.01 Mpa, respectively. The compressive strength test results are shown in Fig 7.

The cubic samples cast with CPF liner shows increased compressive strength than the specimens cast with steel formwork (SF), 3.09% and 14.09% at 7 and 28 days respectively.

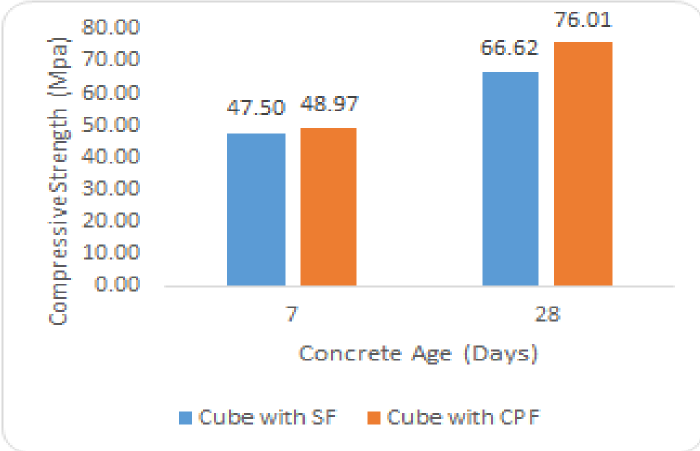

Fig. 7 Compressive Strength vs Age Test Results

It is found that the use of CPF liner contributed to increase the compressive strength of concrete mix CMD I with substitute of cement with fly ash and micro silica.

4.3 Rapid Chloride Penetration Test Results

RCPT was conducted after 28 days of curing. The table 2 shows that the lower is the charge passed, the greater is the resistance to the chloride penetration. The results are good for the concrete mix CMD I.

Table 2. Performance of Chloride Permeability Based Totally on Charge Passed. [8]

Chloride Permeability	Charges Passed (coulombs)
High	> 4000
Moderate	2000 - 4000
Low	1000 - 2000
Very low	100 - 1000
Negligible	< 100

For CMD-I, specimens cast with CPF liner shows 9.98% reduction in charge passed than specimens cast with steel formwork. That clearly shows the CPF liner is effective. That CPF liner reduces the permeability of the chlorides by creating strong, dense and impermeable structural surfaces. RCPT value of specimens was calculated using the formula;

$$R = 900 \times \{I_0 + 2 \times (I_{30} + I_{60} + I_{90} + I_{120} + \ldots\ldots\ldots + I_{330}) + I_{360}\} \quad (1)$$

Where,

R = Charge passed (Coulombs)

I_0= Current (Amperes) immediately after voltage is applied

I_t= Current (Amperes) at t min after voltage is applied

I_0 is the initial reading taken from RCPT apparatus and I_{30} is reading taken at 30 minutes and so on for I_{60}, I_{90},…,I_{360}.

The RCPT test results are shown in Fig. 8 and 9.

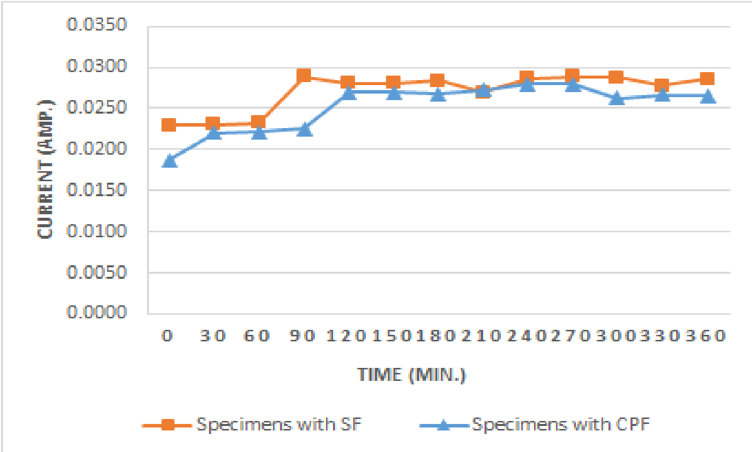

Fig. 8 Current Vs Time for RCPT Test

The concrete mix with micro silica and fly ash as a substitute to the cement is showing great reduction in chloride penetration with the use of CPF liner.

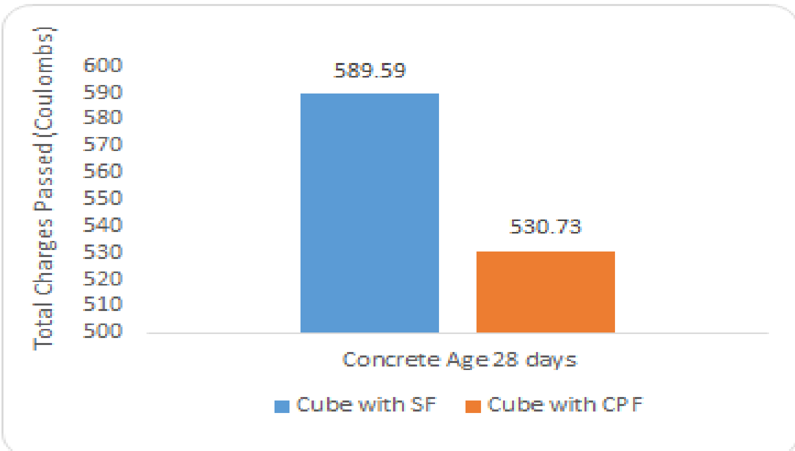

Fig. 9 RCPT Test Results - Coulombs Passed.

This shows that the CPF liner is helpful to reduce the chloride penetration.

5. Conclusions

The conventionally cast structures may result into opening of the pores and structure surface gets exposed to aggressive environments. This may lead to corrosion. This problem is addressed with applying surface treatments and coatings. This paper has demonstrated a different method. The experiment was carried out with replacement of cement with Fly Ash and micro silica and with lower W/C ratio in the concrete mix proportion. The steel moulds were used to cast the specimens. Half specimens were cast with steel mould formwork and half with Controlled Permeability Formwork liner pasted inside the steel mould. Concrete mix was prepared and samples were cast for testing and samples were kept in water for curing. After curing period the specimens were demoulded. The specimens cast with Controlled Permeability Formwork liner were easy to demould than the samples cast with steel formwork.

The Controlled Permeability Formwork liner helped to modify the properties of freshly placed concrete. The surface of the specimens cast with Controlled Permeability Formwork liner appeared better with less defects and blowholes. The dark colour of the surfaces shows the reduction in water/binder ratio in the cover zone. The use of mineral admixture makes the concrete mix cohesive and dense. The cubic specimens cast with CPF liner showed increased compressive strength than the specimens cast with conventional steel formwork.

The specimens cast with Controlled Permeability Formwork liner showed reduction in charges passed in Rapid Chloride Penetration test (RCPT). This shows reduction in chloride penetration through the surface. This shows Controlled Permeability Formwork increased the strength of concrete in cover zone. The Controlled Permeability Formwork liner has improved the durability, strength and overall appearance of the finished concrete surfaces.

This experiment shows that the performance of the concrete structures surfaces can be improved using Controlled Permeability Formwork liner as it is helpful to increase strength and impermeability.

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