

# “TO STUDY THE CHLORIDE RESISTANCE OF FLY ASH CONCRETE WITH VARYING W/C RATIO”

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**Abstract-** A wide range of test methods has been used to measure the resistance of concrete to chloride penetration. Each method is purported to measure the property of concrete central to the chloride transport mechanism into concrete. They include water absorption, water permeability, chloride diffusion. In this paper, an assessment of commonly specified properties namely the water-cement ratio, 28-day diffusion coefficient was made in terms of its relation to the long-term chloride diffusion coefficient taking into consideration the precision of the test methods. The long-term chloride diffusion coefficient is derived from the chloride penetration profile into concrete after one-year immersion in sodium chloride solution. The resistance to chloride penetration of concrete containing fly ash of various fineness's was examined. Three different fly ash fineness's viz., original fly ash, 45% fine portion and 15% fine portion fly ashes were used for the study. Chloride resistance of concretes was evaluated using the measurement of the Coulomb charge as per ASTM C1202 and by determination of chloride ingress after different periods of exposure to 3% NaCl solution in full immersion and partial immersion modes. From the tests, it is found that the resistance to chloride penetration of concrete depends on the fineness of fly ash. The rapid chloride permeability test (ASTM C1202) clearly indicates that the Coulomb charge of concrete at the age of 28 days is significantly reduced with the incorporation of fly ash.

**Keywords-** Fly ash; Concrete; Chlorides; NaCl solution; Fly ash fineness

## 1. INTRODUCTION-

The concrete usage in the construction is started from the olden days of civilization. Concrete construction consumes a lot of materials like coarse aggregate and fine aggregate and the principal raw material of concrete i.e. cement clinker is responsible for greenhouse gas (GHG) effect accounting for 10% of global anthropogenic CO<sub>2</sub>. The fly ash is obtained as an unusable product from the coal burning power plants, to avoid the discarding problem of fly ash. It is used to replace the fly ash percentage by its cement content weight in concrete and the replacement is in between the 10% to 50% of fly ash in cement content. Fly ash is used as a pozzolanic mineral in concrete, the cement is partially replaced by mineral products such as

silica fume, including coal fly ash, and slag can reduce the CO<sub>2</sub> emission in manufacturing process of cement. A significant development in this direction has already been in the use and acceptance of Supplementary cementing materials (SCM). Use of SCM up to some extent will be fine and may not be adequate if the targets are different, for example maximum reduction of CO<sub>2</sub> emission and its sustainability. One type of fly ash is Class - C, it is having high calcium content which is having more than 20% Cao and other class F fly ash is also containing less amount of calcium which is less than class C.

Research on structural concrete incorporating high volumes of low-calcium (ASTM Class F) fly ash has been in progress at CANMET since 1985. In this type of concrete, the cement content is kept at about 150 kg/m<sup>3</sup>. The water-to-cementitious materials ratio is of the order of 0.30, and fly ash varies from 54 to 58% of the total cementitious material. A large dosage of a super plasticizer is used to achieve high workability.

This Project presents data on the durability of this new type of concrete. The durability aspects considered are: freezing and thawing cycling; resistance to chloride ion permeability; and the expansion of concrete specimens when highly reactive aggregates are used in the concrete. The investigations performed at CANMET indicate that concrete incorporating high volumes of low-calcium fly ash has excellent durability with regard to frost action, has very low permeability to chloride ions and shows no adverse expansion when highly reactive aggregates are incorporated into the concrete.

The majority of concrete deterioration cases is connected to corrosion of reinforcement due to carbonation- or chloride-induced passivation of steel bar.

## 2. CONCEPT OF RCPT :-

The RCPT has been used in recent years mainly to assess the ability of concrete to resist the penetration of chloride ions. In addition, the RCPT method has been used to investigate the mineral admixture effect on the resistance of chloride ion penetration, surface treatments, the aggregate fraction, the curing condition, and the cracking of concrete caused by the penetration of chloride ions. McCarter etc.

reported that the conductivity of the free pore fluid increases with increased temperature, and that the applied electrical potential of the RCPT heats the concrete specimen, thus affecting the flow speed. Pfeifer et al. mentioned that reliable correlations might not exist between the results of the RCPT and a 90-d salt ponding test. She observed that the transport of ions in concrete depends on the pore structure of the concrete, whereas RCPT results depend on both the pore structure characteristics and electrical conductivity of the pore solution.

Thus, it is inappropriate to use RCPT results to rank the chloride permeability of concrete containing supplementary cementing materials such as blast furnace slag, fly ash, and silica fumes.

In this study, Portland cement (OPC) concrete and fly ash concrete were carried out with the RCPT, and the chloride profile in the specimen was measured after the completion of the RCPT. A modified RCPT method based on the chloride penetration depth was used to assess the chloride permeability of OPC concrete and fly ash concrete.

ASTM C1202 measures the electrical conductivity of a 50 mm (2 in.) thick concrete disk over a 6-hour time period. The current readings taken are then integrated over the 6-hour period to obtain the final charge passed. Because it is the electrical conductivity (or resistance) that is measured, the test is really a long-duration resistivity test. It is assumed that the resistivity is directly related to the tortuosity of the pore network or concrete permeability, although the relation is not perfect. One problem with ASTM C1202 is that the current tends to increase during the test, especially with low quality/high-permeability concrete, because the specimens heat up, thus increasing the conductivity. Furthermore, chloride ions may migrate in while hydroxyl ions migrate out, changing the concrete conductivity. Another problem with ASTM C1202 is the amount of sample preparation needed. Sample cutting, vacuum saturation, and testing take at least 24 hours to complete. Additionally, sample cutting can introduce a significant amount of variation in the test method. Two samples both cut according to ASTM C1202 could have a difference in length between the two of 6 mm (1/4 in.) or over 12%. The samples may also not be reused because of concerns over leaching in a moist environment and the exposure to chlorides during the test, which may change the pore solution conductivity.

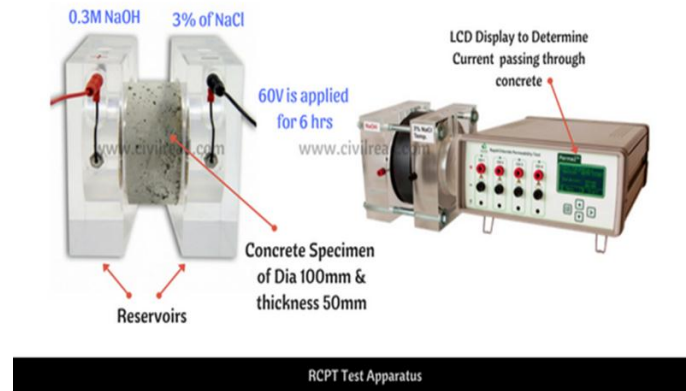


Fig. 2.1 RCPT Test Apparatus

### 2.1. ADVANTAGES OF RCPT :-

- 1) The RCPT can also be used to compare the effectiveness and performance of various systems, Such as sealers, membranes, and corrosion inhibitors, intended to reduce the ingress of chloride ions or reduce corrosion in concrete structures.
- 2) RCPT is Simple to conduct.
- 3) RCPT is fastest method to determine Chlorine resistivity.

### 2.2. DISADVANTAGES OF RCPT:-

- 1) The current that passes through the sample during the test indicates the movement of all ions in the pore solution (that is, the sample's electrical conductivity), not just chloride ions. Therefore, supplementary cementitious materials (such as fly ash, silica fume, or ground granulated blast-furnace slag) or chemical admixtures (such as water reducers, super plasticizers, or corrosion inhibitors) can create misleading results largely due to the chemical composition of the pore solution, rather than from the actual permeability. As a result, some researchers do not recommend the RCPT to evaluate the chloride permeability of concrete containing these materials
- 2) The conditions under which the measurements are taken may cause physical and chemical changes in the specimen, resulting in unrealistic values. For example, the high voltage applied during the test increases the temperature of the sample, which can accelerate hydration, particularly in younger concretes.
- 3) The precision statement in ASTM C1202-97 indicates that a single operator will have a coefficient of variation of 12.3%; thus the results from two properly conducted tests on the same material by the same operator could vary by as much as 42%. The multi-laboratory coefficient of variation has been found to be 18.0%; thus two properly conducted tests on the same material by different laboratories could vary by as much as 51%. For this reason, three tests are usually conducted and the test results averaged, which brings the multi-laboratory average down to 29%.

**2.3. PROCEDURE :-**

1) Remove specimen from water, blot off excess water, and transfer specimen to a sealed can or other container which will maintain the specimen in 95 % or higher relative humidity.

2) Specimen mounting (rubber gasket as sealant): Place a 100 mm outside diameter by 75 mm inside diameter by 6 mm thick circular vulcanized rubber gasket in each half of the test cell. Insert sample and clamp the two halves of the test cell together to seal.

3) Fill the side of the cell containing the top surface of the specimen with 3.0 % NaCl solution. (That side of the cell will be connected to the negative terminal of the power supply) Fill the other side of the cell (which will be connected to the positive terminal of the power supply) with 0.3 N NaOH solution.

4) Attach lead wires to cell banana posts. Make electrical connections to voltage application and data readout apparatus as appropriate; connect as shown in Fig. 5. Turn power supply on, set to  $60 \pm 0.1$  V, and record initial current reading. Temperatures of the specimen, applied voltage cell, and solutions shall be 20 to 25°C at the time the test is initiated, that is, when the power supply is turned on.

5) During the test, the air temperature around the specimens shall be maintained in the range of 20 to 25 °C.

6) Read and record current at least every 30 min. If a voltmeter is being used in combination with a shunt resistor for the current reading (see Fig. 5), use appropriate scale factors to convert voltage reading to amperes. Each half of the test cell must remain filled with the appropriate solution for the entire period of the test.

7) Terminate test after 6 h, except as discussed in Note 7.

8) Remove specimen. Rinse cell thoroughly in tap water; strip out and discard residual sealant.

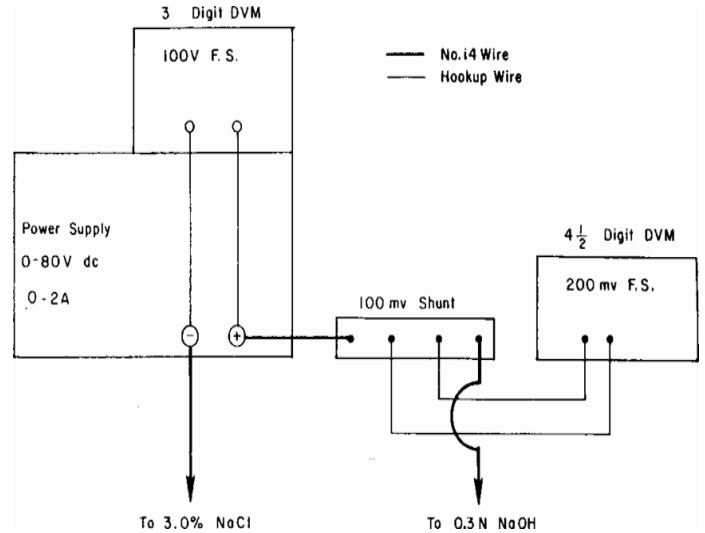


Fig. 2.4 Electrical Line diagram of connection

**2.4. CALCULATION :-**

Plot current (in amperes) versus time (in seconds). Draw a smooth curve through the data, and integrate the area underneath the curve in order to obtain the ampere-seconds, or coulombs, of charge passed during the 6-h test period.

Sample Calculation—If the current is recorded at 30 min intervals, the following formula, based on the trapezoidal rule, can be used with an electronic calculator to perform the integration:

$$Q = 900 ( I_0 + 2I_{30} + 2I_{60} + \dots + 2I_{300} + 2I_{330} + I_{360} )$$

where:

Q = charge passed (coulombs),

$I_0$  = current (amperes) immediately after voltage is applied, and

$I_t$  = current (amperes) at t min after voltage is applied.

OR

Alternatively, use automatic data processing equipment to perform the integration during or after the test and to display the coulomb value. The total charge passed is a measure of the electrical conductance of the concrete during the period of the test.

**3. MIX DESIGN**

**For M-40 grade of Concrete as per Control Mix Design**

**PROPERTIES OF MATERIALS**

Cement Ordinary Portland cement of M43 grade of Birla brand Conforming to IS 12269-1987  
 Fine Aggregate River Sand [Medium size], Specific Gravity=2.75.

Coarse Aggregate Size- 10mm+20mm mixed,  
 Specific Gravity=3.  
 Super Plasticizer Polycarboxylate Ether (PCE) based of  
 MYK Schomburg brand confirming to IS 9013.  
 Fly Ash. Pozzoplast (Drik India Pvt. Limited )  
 Water Drinking water From Bore well  
 Mixing & compaction Hand mixing & compaction without  
 any vibrator.  
 Curing In ordinary water tank only for 28 days

**1. TARGET MEAN STRENGTH**

$F_{ck}' = f_{ck} + 1.65 \times K$   
 $= [40 + 1.65 \times 5]$  [K=5 from table 1 of IS456]  
 $F_{ck}' = 48.25$  MPa.  
 i.e.  $F_{ck}' = 50$  Mpa

**2. WATER CEMENT RATIO (FROM GRAPH)**

From Table 5 of IS 456, maximum water-cement ratio (see Note under 4.1) = 0.45.

Based on experience, adopt water-cement ratio as 0.40.  
 $0.40 < 0.45$ , hence, O.K.

∴ Adopt W/C= 0.4

From Table 5 of IS 456, minimum cement content for 'severe'

exposure conditions = 320 kg/ m<sup>3</sup>

For better Early strength, adopt Cement content = 460 Kg/m<sup>3</sup>  
 $460 \text{ kg/m}^3 > 320 \text{ kg/m}^3$

Hence, O.K.

**3. SELECTION OF WATER CONTENT**

Adopted, W/C = 0.4

Max. Water content as per table 2 of IS 10262,

186 lit/m<sup>3</sup> water for 25 to 50 mm slump from table  
 Estimated Water content for 100 mm slump  
 $= 186 + [6/100 \times 186]$   
 $= 197$  lit /m<sup>3</sup>

As superplasticizer is used, the water content can be reduced up to 20 %

Using Super-plasticizer, we get,

$= (197 \times 0.80) = 157.6$  lit

Hence, the arrived water content is = 197.16 - 39.4 = 157.76 lit.

**CALCULATION OF CEMENT CONTENT**

W/ C Ratio = 0.40

Therefore Cementitious material ( cement + fly ash)  
 $= 157.6 / 0.40$

$= 394.4$  Kg/ m<sup>3</sup> > 320 Kg/m<sup>3</sup> (Min Cement Content)

But adopt Cement content = 460

Kg/m<sup>3</sup> .....

(460 Kg/ m<sup>3</sup> > 320 Kg/m<sup>3</sup> hence ok)

**4. PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE CONTENT**

volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for water-cement ratio of 0.50 =0.60.

In the present case water-cement ratio is 0.40. Therefore, volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water-cement ratio is lower by 0.10, the proportion of volume of coarse aggregate is increased by 0.02 (at the rate of +/- 0.01 for every ± 0.05 change in water-cement ratio).

Therefore, corrected proportion of volume of coarse aggregate for the water-cement ratio of 0.40 = 0.62.

Volume of coarse aggregate per unit total aggregate = 0.62 (for 0.4 W/C ratio)

Correction = 0.5-0.4=0.1

$= (0.1/0.05) \times 0.01 = 0.02\%$

Add 0.02%

∴ Coarse aggregate = 0.62 + 0.02 = 0.64%

∴ Fine aggregate = 1.00 - 0.64 = 0.36%

**5. MIX CALCULATIONS**

a) Volume of concrete = 1 m<sup>3</sup>

b) Volume of cement =

$$\frac{\text{Mass of Cement} \times 1}{\text{Specific Gravity of Cement} \times 1000}$$

$= [460 \times 1] / [3.15 \times 1000]$   
 $= 0.146$  m<sup>3</sup>

d) Volume of water = 157.6 x 1 / 1 x 1000  
 $= 0.157$  m<sup>3</sup>

e) Volume of plasticizer (@ 2.0 percent by mass of cementitious material)

$= (460 \times 2/100 = 9.2)$

$= 9.2 \times 1 / 1.20 \times 1000$

$= 0.0076$  m<sup>3</sup>

f) Volume of all in aggregate = 1 - (0.146+0.1576+0.0076)  
 $= 0.6894$  m<sup>3</sup>

g) Mass of coarse aggregate = f x Volume of coarse aggregate x Sp. Gravity coarse aggregate x 1000

$= 0.6894 \times 0.64 \times 3 \times 1000$

$= 1323.648$  kg / m<sup>3</sup>

h) Mass of fine aggregate = f x Volume of fine aggregate x Sp. Gravity of coarse aggregate x 1000

$= 0.6894 \times 0.36 \times 2.75 \times 1000$

$= 682.506$  kg / m<sup>3</sup>

**6. Total Material**

Cement = 460 kg / m<sup>3</sup>

Water = 157.6 litre

C.A. = 1323.648kg

F.A. = 682.506kg

Plasticizer = 9.2 kg / m<sup>3</sup>

4. RESULTS OF SAMPLE -

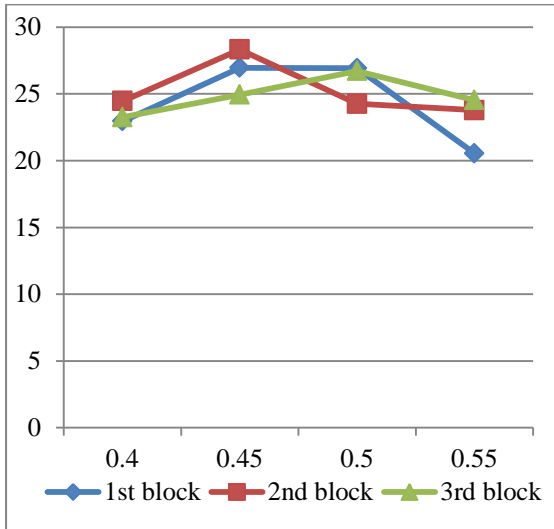
1 - Result for control mix

Grade of concrete	Type of Mix	Compressive strength in MPa (7 Days)	Average of 7 days In MPa	Compressive strength in MPa (28 Days)	Average of 28 days In MPa	RCPT Result (Coulomb)
M40	M. 0.40	22.95	23.55	39.15	40.66	3180.5
		24.46		40.09		
		23.26		42.76		
	M. 0.45	26.96	26.74	42.65	39.79	3008
		28.32		38.18		
		24.94		38.56		
	M. 0.50	26.92	25.82	37.99	36.37	3596.3
		24.26		34.36		
		26.73		36.78		
	M. 0.55	20.55	22.95	35.91	36.05	4270.9
		23.78		37.68		
		24.53		34.56		

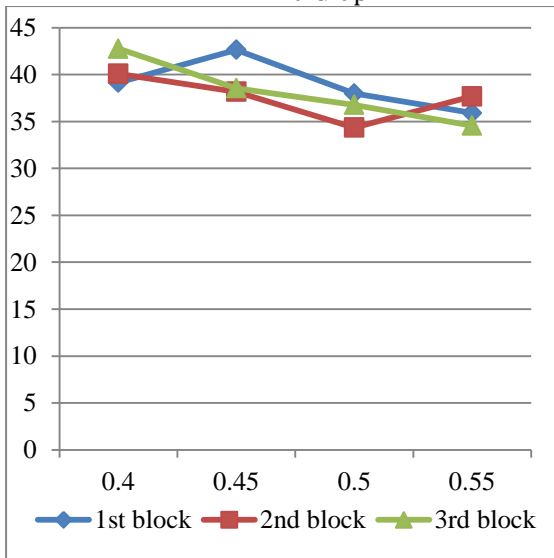
2- Result for fly ash mix

Grade of concrete	Type of Mix	Compressive strength in MPa (7 Days)	Average of 7 days In MPa	Compressive strength in MPa (28 Days)	Average of 28 days In MPa	RCPT Result (Coulomb)
M40	MF 15	18.61	22.56	35.44	34.90	3094.2
		22.67		32.36		
		26.40		36.89		
	MF 25	19.68	20.70	35.86	33.80	2921.7
		21.34		33.56		
		21.08		31.98		
	MF 35	18.17	19.56	34.86	33.55	3266.7
		20.82		32.81		
		19.68		32.98		
	MF 45	17.86	18.79	33.57	32.60	3768.8
		19.56		32.66		
		18.96		31.56		

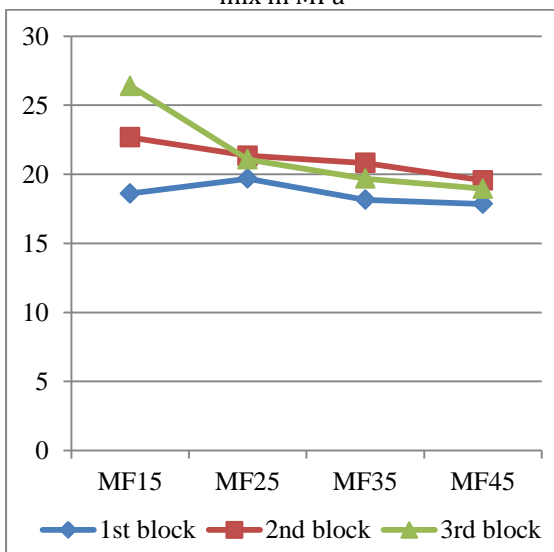




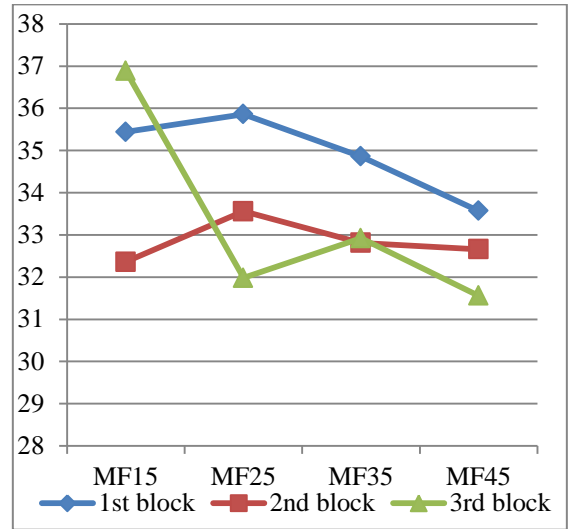
Graph 1: 7 day compressive strength results for control mix in MPa



Graph 2: 28 day compressive strength results for control mix in MPa



Graph 3: 7 day compressive strength results for fly ash mix in MPa



Graph 4: 28 days compressive strength results for fly ash mix in MPa

### 5. CONCLUSION :-

Concrete provides physical and chemical protection to the reinforcing steel against penetrating chlorides which may cause steel DE passivation, leading to increased risk of steel corrosion. The chloride resistance of concrete depends on the permeability properties of the concrete and the cover thickness to the reinforcement. The integrity of the concrete cover under service load, in terms of cracking and crack width, also influences the resistance to penetrating chlorides. The use of prescriptive specifications of cement type and w/c has been found to be extremely effective in specifying chloride resistance. The effect of the type of cement on chloride resistance of concrete is quite evident for concrete at higher w/c, but such distinctions diminish for concrete at low w/c below about 0.45. From the results, it is concluded that the resistance to chloride penetration of concrete is significantly increased with the incorporation of fly ash and the increase is enhanced with an increase in fly ash fineness. The increased results from the reduced average pore size of the paste and the improved interfacial zone. The incorporation of fly ash is especially enhanced for the fine fly ash, due to the spherical and smooth surface of the fine fly ash particles. The rapid chloride test clarifies the effect of fly ash and its fineness for all mixes. The effects of the fly ash replacement and the fly ash fineness on the resistance to chloride penetration are highly recognized for the low and normal strength concretes although they decrease with an increase in the strength of concrete.

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