IOP Conf. Series: Materials Science and Engineering **216** (2017) 012022 doi:10.1088/1757-899X/216/1/012022

Effect of Metakaolin and Slag blended Cement on Corrosion Behaviour of Concrete

Anita N Borade[1, 3] and B Kondraivendhan[2*, 3]
[1] Research Scholar, [2*] Assistant Professor,
[3] Applied Mechanics Department, Sardar Vallabhbhai National Institute of Technology, Surat-395007, Gujarat, India

[1]Email: boradeanita@yahoo.com; [2*] Email: kondraivendhan78@gmail.com;

Abstract. The present paper is aimed to investigate the influence of Metakaolin (MK) and Portland slag Cement (PSC) on corrosion behaviour of concrete. For this purpose, Ordinary Portland Cement (OPC) was replaced by 15% MK by weight and readymade available PSC were used. The standard concrete specimens were prepared for both compressive strength and half- cell potential measurement. For the aforesaid experiments, the specimens were cast with varying water to binder ratios (w/b) such as 0.45, 0.5 and 0.55 and exposed to 0%, 3%, 5% and 7.5% of sodium chloride (NaCl) solution. The specimens were tested at wide range of curing ages namely 7, 28, 56, 90 and 180 days. The effects of MK, w/b ratio, age, and NaCl exposure upon concrete were demonstrated in this investigation along with the comparison of results of both MK and PSC concrete were done. It was also observed that concrete with MK shows improved performance as compared to concrete with PSC.

1. Introduction

Concrete is the most widely used man-made construction material in the world today due to availability of raw materials, low cost of manufacturing and maintenance. It is also excellent in compression, durability and corrosion aspects. However, over the last few decades the durability of concrete becomes a serious problem which consumes major part of financial budget for inspections, repairs and maintenance of deteriorated structures [1]. Among the different factors affecting corrosion, chloride induced corrosion attract the more attention of the industry as well as researchers due to its severity. The sources of harmful chloride ions into the concrete are either internal (added through the ingredients of the concrete mix through chloride contaminated aggregate, contaminated water and through admixtures in fresh concrete) or externally in hardened concrete through de-icing salts, penetration of chloride ions from seawater in marine structures and from the soil and ground water contains chloride salts [2, 3]. The use of Supplementary Cementing Material (SCM) proves the influence on the hydration of cement compound either by physical or chemical effects [4, 5].

In addition to improving the durability, the use of these materials in construction reduces the waste deposits and the demand of cement. Hence helps in reduction in environmental pollution. The utilization of calcined clay in the form of metakaolin (MK) as a pozzolan for concrete has received considerable interest in recent years [6]. Thorough research has been carried out over the effect of different percentage replacement of cement with MK and many of them concluded that concrete incorporated with 15% MK exhibits premium level engineering properties comparable to silica fume concrete [7, 8]. From the literature it is also depicted that Portland slag cement is intensively studied and accepted as the reliable binder in corrosion resistance.

IOP Conf. Series: Materials Science and Engineering **216** (2017) 012022 doi:10.1088/1757-899X/216/1/012022

The present paper is aimed to investigate the influence of replacement of 15% of MK & PSC in concrete through compressive strength and half- cell potential measurements. For this purpose, six different concrete mixes with three water to binder ratio (w/b) of 0.45, 0.5 and 0.55 were designed and exposed to 0%, 3%, 5% and 7.5% of sodium chloride (NaCl) solution over varying curing ages such as 7, 28, 56, 90 and 180 days. The effects of MK replacement, w/b ratio, age, and curing procedure upon concrete properties were discussed and the results are compared with the concrete prepared with PSC.

2. Experimental Procedure

For the present investigation, Ordinary Portland cement (OPC) conforming to IS 12269-1999 was replaced with 15% MK confirming to IS 1489- 1991 and Portland slag Cement (PSC) confirming to IS 455-1995 were used. The chemical compositions of cements were evaluated from XRF (X-ray fluorescence) and the physical properties are shown in Table 1. The crushed gravels with maximum size 10mm and 20mm in 30:70 proportion were used as coarse aggregate (C.A). River sand confirming to zone-II of IS-383-2002 was used as fine aggregate (F.A). The specific gravity and water absorption of C.A were 2.88, and 1.10% respectively and the corresponding values for F. A. were 2.61, and 1.40%. Both the aggregates were confirming to (IS) 2386-2002 (Part I and III).

Table 1. Chemical and Physical Properties of Different Binders.

Bin-ders	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	Na_2O_3 (%)	K_2O (%)	LOI[a] (%)	Sp. Gra[b].	Sp. Sur.[c] (m^2/kg)
OPC	19.60	5.69	4.37	66.07	--	3.52	0.38	0.37	0.9	3.16	316.6
PSC	25.53	12.89	1.53	48.17	5.29	5.44	0.42	0.79	1.8	3.00	361.8
MK	56.73	41.66	0.89	0.19	0.14	0.17	--	0.23	3.3	2.64	1495.9
[a] Loss on Ignition,				[b] Specific Gravity,				[c] Specific Surface			

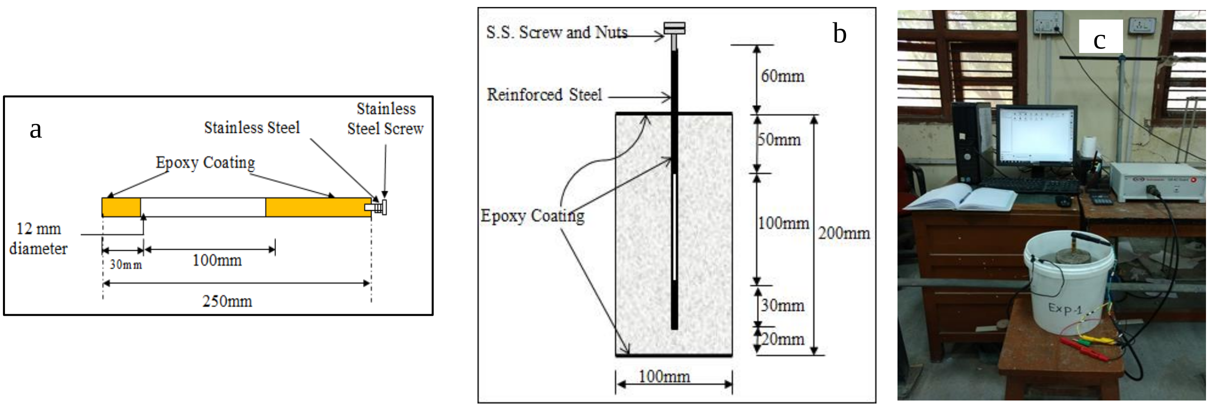


Figure 1. Line Diagram of a) Steel Preparation, b) Cylinder - G109- 2007, c) Lab Set-up for Potential Monitoring.

Concrete Cubes of 150mm size were prepared with PSC and OPC replaced with 15% MK Concrete mixture as per IS 10269-2009 with varying cement contents of 369 kg/m^3, 332 kg/m^3 and 302 kg/m^3 for 0.45, 0.5 and 0.55 w/b ratio respectively. The specimens were prepared for the aforesaid experiments were exposed to four different levels of Sodium Chloride (NaCl) solutions namely 0%, 3%, 5% and 7.5%. The compression strength testing was carried out at 7, 28, 56, 90 and 180 days of curing ages. The cylindrical specimens for half-cell potential measurement were prepared for the same concrete mix design with Thermo-Mechanically Treated (TMT) steel. The contents of carbon (C), phosphorus (P), Sulphur (S), Chromium (Cr) and Copper (Cu) were 0.23%, 0.018%, 0.016%, 0.006%

and 0%. The preparation of the steel was carried out as per the guidelines [9] as show in figure 1(a). Cylindrical samples of 100mm diameter and 200mm length with centrally embedded TMT steel bar of 12mm diameter were cast as show in figure 1(b).

3. Results and Discussions

The compression strength testing was carried out through Compression Testing Machine (CTM) at the rate of 140 kg/cm^2/min as per IS 519-2004 and results were plotted for compressive strength versus curing ages as shown in figure 2. It was observed from figure 2 that the early age strength was higher at higher w/b ratio compared to lower w/b ratio.

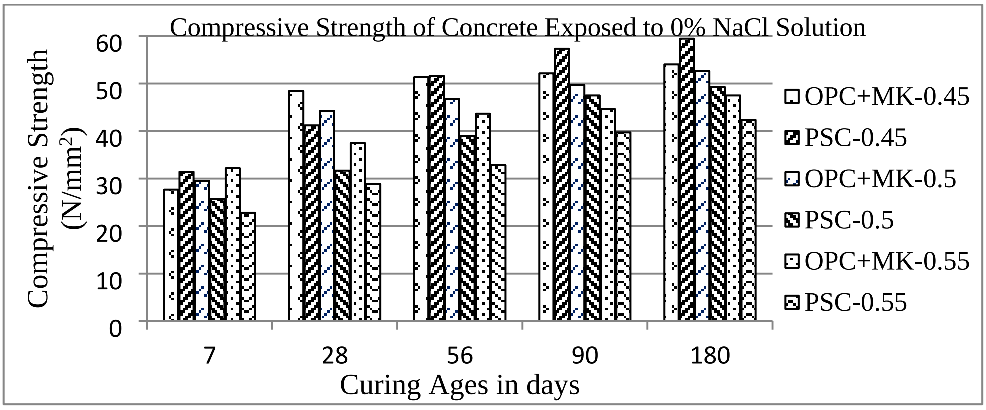
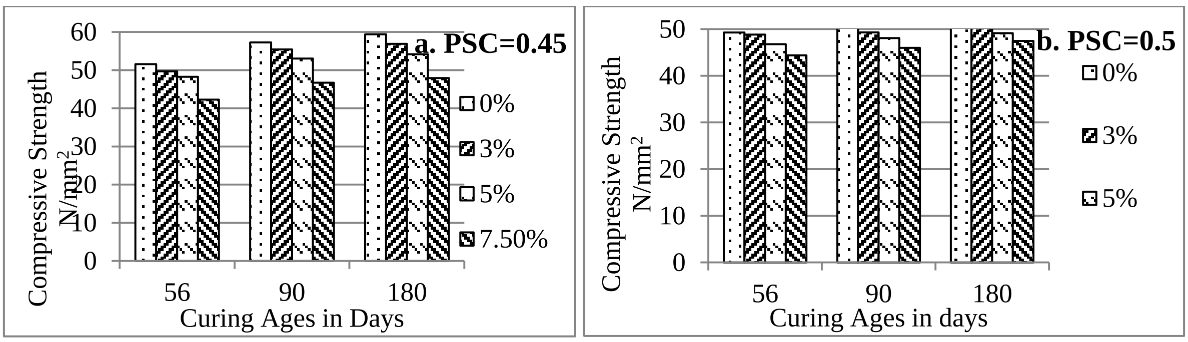


Figure 2. Compressive Strength for control concrete.

This may be due to large surface area of cementitious material demands more water for hydration process. MK is accelerating the early hydration of calcium silicate to produce extra polymeric silicate gel [5]. Strength of the concrete with MK was increased with increase in curing age and decrease with increase in w/b ratio. In the case PSC concrete, the hydration reaction is very slow at initial age, hence the rate of gain of compressive strength of PSC was lower at an early age and it was even less than concrete with MK but after 90 days, there was not much difference in strength of both concrete mixes. For all w/b ratios, compressive strengths were increased with increase in curing ages as expected.

3.1. Effect of NaCl Exposure on Compressive Strength

The results of effect of exposure condition on compressive strength over varied curing ages for PSC and MK are presented in figure 3 (a, b, c).



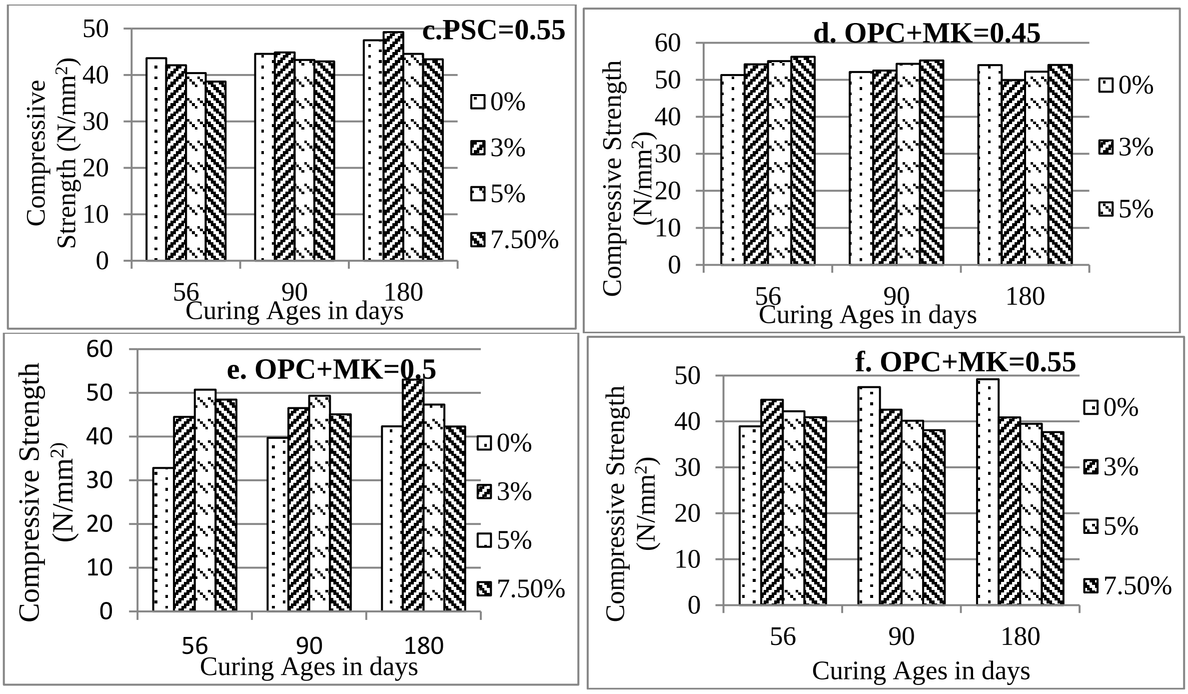
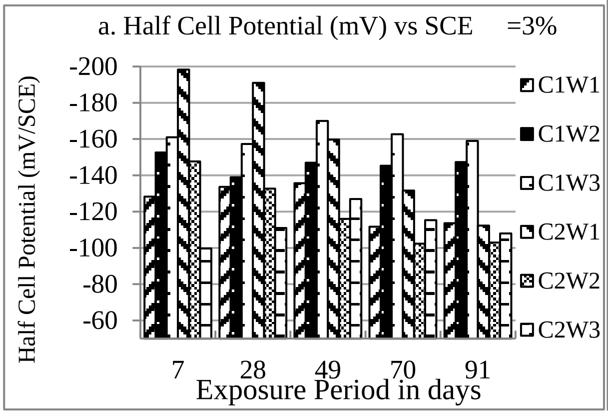


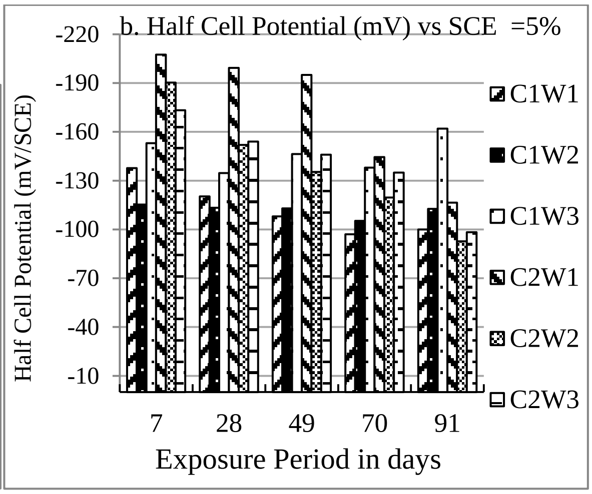
Figure 3. Compressive Strength versus Curing Ages.
(**Note:** The legend in the graph i e. 0%, 3%, 5% and 7.5% are percentage exposure of NaCl solution).

In the concrete with PSC, the compressive strengths were decreased with increased w/b ratio at all curing ages, whereas in case of concrete with MK showed reverse results at only lower w/b ratio. In addition, it was also observed that the compressive strength of MK mostly for various w/b ratios, were increased with increase in chloride exposure as compared to control concrete (0%) which was found reverse in case of PSC concrete. With increased chloride concentration, compressive strengths were decreased as shown in figure 3 (a, b, c) and figure 3 (d, e, f) depicted that compressive strength increase with age but decrease with chloride exposure for both the concrete as expected [10]. This may be because presence of higher percentage of alumina reacted with chlorides, forms friedel's salts and refines micro pores structure improves the strength [11]. In general the compressive strengths were increased for chloride exposure compared to control concrete for w/b ratio 0.45 and 0.5, which is lower for w/b ratio of 0.55.

3.2. Half Cell Potential Measurement:

The probability of corrosion of the reinforcing bars were monitored periodically with saturated calomel reference electrode (SCE) as shown in figure 1(c) over wetting (7 days) and drying (14 days) cycles in all types of the concrete specimens by the half-cell potential measurement [12] in and results were plotted for half-cell potential versus the curing ages in the NaCl solution environment as shown in figure 4 (a, b, c). The half- potential values of almost all specimens immersed in chloride environment were more negative at initial age which became stable over the time. This may be due to slow pozzolanic activity at initial age gives more negative potential. With the increase in the pozzolanic activity over the time refines the pore structure of concrete which may restrict the ingression of moisture and chloride up to rebar level improves the potential to positive. Concrete with MK gives more negative potential at lower w/b (0.45) ratio compared to higher w/b ratio (0.5 and 0.55). This phenomenon is attributed to the high fineness of metakaolin demands more water for hydration [13]. It was observed from the figures that the increase in w/b ratio increases the negative potential for PSC.





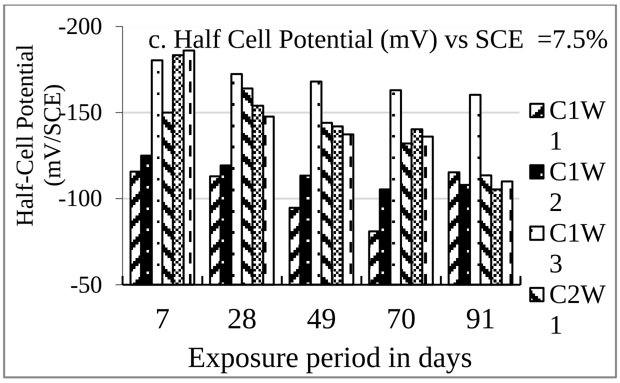


Figure 4. Potentials of Reinforced Concrete cylinder immersed in a.3%, b. 5%, c. 7.5% of NaCl.
Note: C1= PSC, C2=OPC+MK,
W1 (w/b) =0.45, W2 (w/b) =0. 5 and
W3 (w/b) =0.55.

Potential values were below (-126mV) up to 60 days which indicates corrosion risk is very less while the potential values were increased to the risk of intermediate corrosion (-126 to -256) [12].
From the observation, the concrete prepared with MK performs better than concrete with PSC in corrosion resistance. Potential values were exhibiting even at the end of 90 days less risk of corrosion. In general, it is also observed that the potential values of MK were negative at lower w/b ratio and positive at higher w/b ratio.

4. Conclusion
Based on the experimental studies on concrete with MK and PSC the following conclusions were drawn:
1. Concrete with MK shows high early-age compressive strength due to the higher rate of hydration contributed by MK.
2. At initial age the pozzolanic activity in case of concrete with PSC is sluggish and gives lower early age strength as compared to concrete with MK.
3. The Compressive strength of concrete with PSC reduced with the increase in sodium chloride exposure for all w/b ratios and all curing ages. Whereas, in concrete with MK, reverse nature was observed.
4. From half-cell potential measurements, it was observed that the concrete with MK at higher w/b ratio exhibited low negative potential values as compared to concrete with PSC.
5. Improved performance is exhibited in the case of concrete with MK specimens both the tests including compressive strength and half-cell potential. It is clear that for the concrete with MK performing better in corrosion resistance than that of the concrete with PSC.

5. References
[1] Trianaa V, Marriagaa J and Florezb J 2013 Mat. Research **16**, 1457-64.

[2] Andrade C, Alonso C and Molina F J 1993 Mat. Structures **26,** 453-64.
[3] Pradhan B and Bhattacharjee B 2011 *Const. and Build Materials*. **25**, 2565-75.
[4] Newman J and Seng B Advanced Concrete Technology, *Constituent Materials*, Elsevier, Great Britain, 2003.
[5] Martin S 1998, *Laboratory Report* **135**, RMC Readymix limited.
[6] Ramezanianpour A A and Jovein H B 2012 *Construction and Building Materials*, **30**, 470-79.
[7] Poon C S Kou S C and Lam L 2006 *J of Const and Build. Mat*. **20,** 858-65.
[8] Guneyisi E, Gesoglu M, Karaboga F and Mermerdaş K 2013 *Comp.Engg. Part B:*, **45**, 1288-95.
[9] ASTM G109 2005, Standard test method for determining the effects of chemical admixtures on the corrosion of embedded steel reinforcement in concrete exposed to chloride environments, (West Conshohocken, PA, ASTM).
[10] Batis G, Pantazopoulou P, Tsivilis S and Badogiannis E, 2005, *Cemt. & Con. Comp*. **27,** 125-30.
[11] Khatib J M and Hibbert J J, 2005 *Construction and Building Materials* **19**, 460-72
[12] ASTM C876 1999, Standard test method for half-cell potentials of uncoated reinforcing steel in concrete, (West Conshohocken PA, ASTM).
[13] Bai J, Wild S and Sabir BB. 2003, *Cement and Concrete Research* **33,** 353-62.