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BOROPUKURIA FLY ASH - A PROSPECTIVE GREEN MATERIAL FOR COASTAL CONCRETE

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ABSTRACT

Coastal concrete i.e. structural concrete exposed to sea environment needs special care regarding its durability. Fly ash, coal burnt waste products, is reported to be well effective as blending material with cement for its contribution in making impermeable concrete and also in reduction the CO_2 emission associated with the production of cement. Bangladesh government has made a mega plan to reach a capacity 40,000 MW of electricity by 2030, half of which will be generated from coal. Now in Bangladesh 250 MW coal based power plant is in running condition at Boropukuria. Additional 5250 MW coal based power plant is going to be installed. This paper investigates the performance of fly ash concrete exposed to artificially made sea water (SW). Fly ash concrete specimen of 100 mm cubical size made by cement fly ash mix ratio 100:0, 80:20, 70:30, 60:40 and 40:60 have been studied in PW, normal and accelerated SW environment (1T & 6T) and also in submerged (SUB) and alternate wetting drying (AWD) condition up to 12 months. After 12 months of curing, the loss in compressive strength as compared to PW cured specimens of similar age are reported to lie in the range of 12% to 28% for OPC and 4% to 17% for 70:30 fly ash concrete. Fly ash concrete of cement replacement level 30 to 40% showed relatively less negative half cell potential (HCP) value as compared to other concretes. The study reveals that fly ash concrete of cement fly ash mix 70:30 may be effective for concrete exposed to coastal environment form strength and durability point of view.

Keywords: Cement; compressive strength; fly ash; marine environment; half cell potential

INTRODUCTION

Reinforced concrete is one of the most widely used building materials all over the world due to abundance of materislas, speed and versatility in construction, strength, durability, economy and relatively long life spans. However, corrosion of the reinforcement in concrete structures is of utmost important to the life cycle of these structures especially to those areas exposed to marine environment. The expanded uses of concrete have increased the interest of scientists / researchers for its use in aggressive environments although a well designed concrete structure is reported to survive up to its design life without any major repair/maintenance work in adverse environment. SW is a complex solution of many salts containing living matter, suspended silt, dissolved gases and decaying organic material. The average salt concentration of SW is about 3.5%. Compound of chloride present in SW is around 89%; whereas the presence of sulphate compounds is around 10%. Reinforced Concrete structures in SW environments are often found to be deteriorated. So prior to the construction of any concrete structure in such location, proper steps should be taken to overcome the risk of deterioration of concrete due to chloride and sulfate attack. Depending on the tidal range, nature, extent and mechanism of deterioration process, a reinforced concrete structure exposed to SW environment can be divide into different zones like Atmospheric zone, Splash zone, Tidal zone and Submerged zone. The tidal zone experiences alternate wetting drying action in SW and is considered as corrosive area (Gowda, 1981). In coastal environment, chloride ion penetrating into the concrete from SW reacts with $Ca(OH)_2$ liberated from cement hydration and form calcium chloroaluminate (Friedels Salt). On the other hand, sulfate ions that penetrates inside concrete forms gypsum and a complex compound namely calcium sulphoaluminate (Ettringite). Both the products occupy a greater volume after crystallization in the pores of concrete than the compounds they replace. The formation of gypsum hydrate may cause an increase in volume of 17.7% in concrete (Islam et al., 2010).

The use of blended cement containing supplementary cementitious materials as a replacement of certain percentage of Portland cement is more effective than ordinary Portland cement in reducing the rate of chloride diffusion when properly cured (Juenger, 2015). The four primary types of SCMs are slag, fly ash, silica fume, and metakaolin. Fly ash has been shown to drastically improve chloride ingress resistance (Basheer, et al. 2002, Thomas, 2004). Fly ash, a byproduct of burning pulverized coal at electric power generating plants, is a fine-grained material consisting of spherical, glassy particles comprised of silicate glass containing silica, alumina, iron and calcium. Due to its chemical composition, fly ash exhibits both pozzolanic and hydraulic activities (Plank et al., 2015). These properties allow it to be added to Portland cement as a mineral additive at the time of batching, or it can be interground with the cement clinker during the production of the cement. In the hardened state, the addition of fly ash greatly reduces the permeability of concrete which provides great resistance to chloride ion ingress (Scrivener et al., 2015). This is primarily due to higher fineness of fly ash compared to cement which leads to more compact concrete mix that reduces pore sizes in the cement paste and reduces the space available for chlorides to penetrate into the concrete (Erdogan et al., 2014). Some of the benefits of including fly ash admixtures in concrete include improved workability, reduced segregation, bleeding, heat evolution and permeability, inhibiting alkali-aggregate reaction and enhanced sulfate resistance (Federal Highway Administration 2011). Bangladesh has a long coastline along its southern border. Structural concrete in such location are always under the adverse effect of marine environment. Hence prior to construction of concrete structures at such locations care should be taken to mitigate the risk of chloride and sulfate attack. Relevant literature reveals that addition of fly ash as a partial replacement of cement in making structural concrete reduces the permeability of concrete, which in turns may resist the penetration of harmful salt ions within the concrete structure. Studies on the use of fly ash concrete in aggressive environments show that the percentage of cement replacement with fly ash and their relative proportion for making concrete in such environment is very important and still debatable as well. Bangladesh government has launched a mega plan to reach 40,000 MW capacity of electricity generation by 2030, half of which will be generated from coal. There already exist a 250 MW coal-based power plant at Barapukuria in Dinajpur utilizing coal from Barapukuria Coal Mining Company Limited. Adjacent to the Barapukuria Power Plant, another 250 MW plant is supposed to be set up. The 1200 MW coal based power plant will be built at Matabari, Cox's Bazar using ultra super critical technology with the funding from both GOB and JICA. In addition 1320 MW coal fired power plant, **"**Maitree Super Thermal Power Project" at Rampal, Khulna is going to be established as a joint venture between India and Bangladesh. Also a MOU between GOB and Huadian Hong Kong Co. Ltd has been signed for setting up a coal-fired power plant of Further Bangladesh government has planned to install one of the similar plants at Mawa of Munshiganj with a capacity of 522 MW, while two others with the total capacity of 566 MW in Khulna region, all of which are coal based. According to the EIA report, 28.1 million tons of coal will be burnt to produce the estimated 5500 MW of electricity at the proposed power plant. Considering 10% ash generation, it will produce around 2.8 million tons of fly ash. These ashes comprising of fly ash, bottom ash and liquid ash which are extremely hazardous contain hazardous and radioactive metals like arsenic, lead, mercury, nickel, vanadium, beryllium, barium, cadmium, chromium, selenium and radium. About managing the waste, the EIA report states that the fly ash "could" be used in cement factories and brickfields. Taking Barapukuria as an example, it produces more than 300 metric tons of fly ash in one day, none of which has ever been used in cement factories and brickfields. Rather, they are found dumped in surrounding locations including at the ponds, lagoons or landfills which is spirally affecting the environment. The unused fly ash and bottom ash disposed from coal combustion power plants, makes major negative environment effects such as air pollution and groundwater quality problem due to leaching of metals from the ashes, specially unused fly ash which has very small particle size. The aim of this research is to evaluate and explore the suitability of the use of Bangladeshi fly ash in structural concrete and its efficiency in enhancing concrete durability performance as well as strength characteristics through improvement of the concrete microstructure.

EXPERIMENTAL PROGRAMS

The experimental program was planned to study the effect of fly ash replacement with cement in concrete as per following steps:

Properties of materials used

(a) Cement: ASTM Type-I Portland Cement was used as binding material. Chemical compositions of ASTM Type-I (OPC) are given in **Table 1.**

(b) Fly ash: A low calcium ASTM Class F fly ash collected from Barapukuria Power Plant, Bangladesh was used. Chemical analysis of fly ash as conducted using XRF study is shown in **Table 1.**

(c) Aggregate: Locally available natural sand with fineness modulus 2.58, specific gravity 2.61, passing through 4.75 mm sieve and retained on 0.075 mm sieve was used as fine aggregate. The coarse aggregate was crushed stone with a maximum nominal size of 12.5 mm with fineness modulus 6.58 and specific gravity 2.70.

Table 1: Chemical composition of ordinary Portland cement and fly ash

Types	ASTM Type-I Cement	ASTM Class F Fly Ash
Chemical analysis (%)		
Calcium oxide, CaO	65.18	8.6
Silicon dioxide, SiO_2	20.80	59.3
Aluminum oxide, Al_2O_3	5.22	23.4
Ferric oxide, Fe_2O_3	3.15	4.8
Magnesium oxide, MgO	1.16	0.6
Sulfur trioxide, SO_3	2.19	0.1
Sodium Oxide, Na_2O	--	3.2
Loss on ignition	1.70	--
Insoluble residue	0.6	--

Table 2: Composition of Artificial Sea Water (Mayers, 1969)

Salt	Amount (gm/ liter)	% of total salt
Sodium chloride (NaCl)	27.21	77.74
Magnesium chloride ($MgCl_2$)	3.81	10.89
Magnesium sulfate ($MgSO_4$)	1.66	4.74
Calcium sulfate ($CaSO_4$)	1.26	3.60
Potassium sulfate (K_2SO_4)	0.86	2.46
Calcium carbonate ($CaCO_3$)	0.12	0.34
Magnesium bromide ($MgBr_2$)	0.08	0.23
Total	**35.00**	**100.00**

Variable Details

Different variables used in this experimental program are listed below:

(a) Five different mix proportions of cement fly ash (100:0, 80:20, 70:30, 60:40, 40:60) were used as cmentitious material.

(b) Artificial SW of two different concentrations (1T and 6T) was used as curing water. PW was also used for comparison. SW (1T) is simulated in laboratory by mixing tap water with exact amount and proportion of different chemical compounds found in natural SW **(Table 2).** 6T simulated SW is obtained by mixing 6 times chemical compounds respectively as that of 1T solution.

(c) Two different exposure states namely submerged (SUB) and alternate wetting drying (AWD) were used to simulate immersed and tidal zone condition.

Mix design

Sample description

A total of 400 no's of cubical specimen of size 100 mm were also cast from M38 concrete for different test as per program. The specimens were demoulded after 24 hours of casting and cured in PW at ambient temperature for 28 days. After that specimens were placed in SW of different concentration (1T, 6T) as well as PW for different exposure periods. Some of the specimens were subjected to AWD cycles (12 hours wetting followed by 12 hours drying) to simulate the tidal marine zone condition.Concrete specimens were designated as per grade of concrete and amount of fly ash as a percentage of total cementitious material. Thus M38FA40 concrete means grade of concrete is M38 and cement fly ash mix ratio is 60:40.

TEST CONDUCTED

(a) Strength tests

Compressive strength of concrete specimens was tested at the ages of 1, 3, 6 and 12 months in accordance with the BS EN 12390-3:2009. Reported strength is taken as the average of three tests results.

(b) Half Cell Potential measurement

Half-cell potential of the steel reinforcement placed at two depth level 15 and 25 mm in fly ash concrete specimens that were exposed to SW of different concentration under SUB and AWD state of exposure was measured at every month upto 12 months of curing in accordance with ASTM C 876.

RESULTS AND DISCUSSION

Fly ash concrete specimens that are exposed to PW and SW of different concentration for various exposure periods were tested after specific exposure periods. The test results are graphically presented and discussed in the following sections:

(a) Compressive strength

The compressive strengths of OPC and fly ash concretes exposed to different marine environment, have been graphically represented in **Fig.1** and **Fig.2.** Also for the ease of comparison, the relative compressive strengths are plotted in **Fig.3** and **Fig.4**.

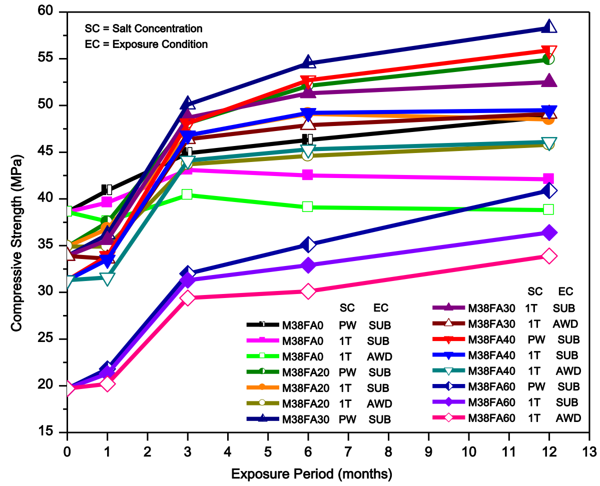

Fig.1: Compressive Strength - Exposure Period Relation for Concrete Exposed to 1T SW

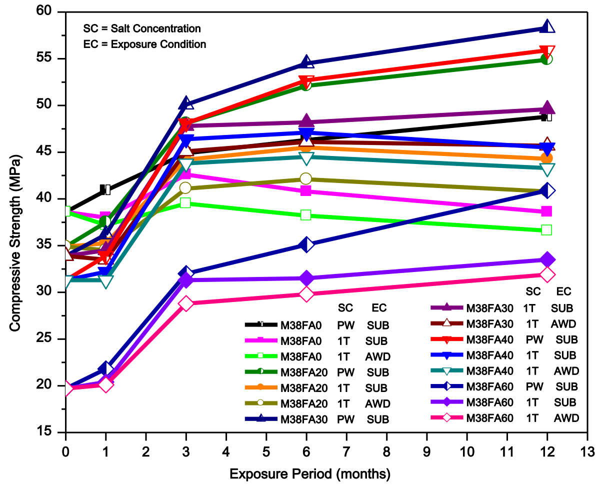

Fig.2: Compressive Strength - Exposure Period Relation for Concrete Exposed to 6T SW

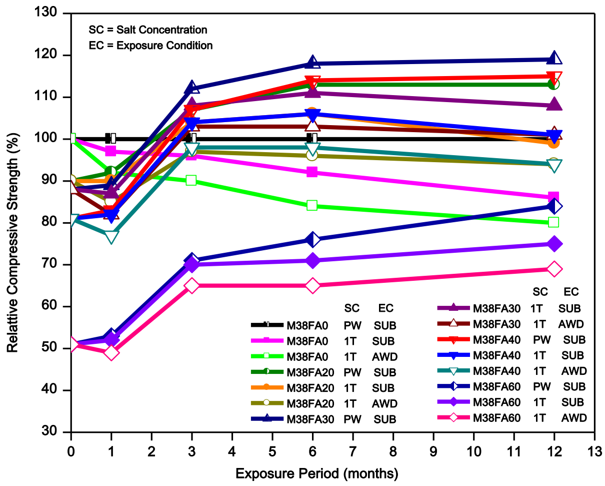

Fig.3: Relative Compressive Strength - Exposure Period Relation for Concrete (1TSW)

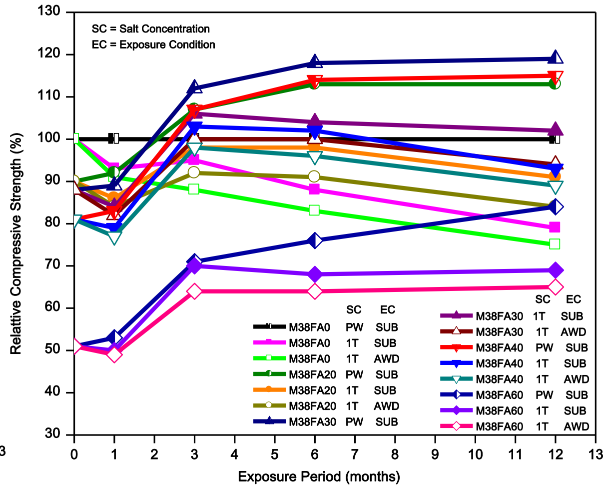

Fig.4: Relative Compressive Strength - Exposure Period Relation for Concrete (6T SW)

Compressive strengths corresponding to "O" month curing age represent the 28 days PW cured strength. In case of PW curing, the specimens for compressive strength were kept in SUB condition only and for SW curing, both SUB and AWD state of exposure conditions are used. In case of PW curing, OPC concrete shows higher strength at initial ages than that for fly ash concrete. But for relatively longer curing periods, the differences between the results are seen to be decreased. In case of PW curing, compressive strengths for 1 month exposure period is 38.6 MPa for OPC concrete, and 34.9, 33.9, 31.3, 19.7 MPa for fly ash concrete of cement fly ash mix ratio 80:20, 70:30, 60:40, 40:60 respectively; whereas the same values after 12 months curing, are 48.8 MPa for OPC concrete and 54.9, 58.3, 55.9, 40.9 MPa for fly ash concrete of similar replacement level. This is due to slow hydration rate of fly ash at early age of curing. Test results show that compressive strength of concrete cured in SW and under SUB condition show relatively higher values than those for AWD condition. In case of fly ash concrete with cement fly ash mix ratio 100:0, 80:20, 70:30, 60:40 and cured in SW of 6T concentration, compressive strength for SUB condition are 40.8, 45.5, 48.2, 47.1 and 38.6, 44.3, 49.6, 45.5 MPa for 6 and 12 months of curing; whereas the corresponding values are 38.2, 42.1, 46.1, 44.5 and 36.6, 40.8, 45.7, 43.3 MPa respectively for AWD condition of similar curing peirod. During wetting cycle, SW enters into the pore spaces of the concrete and during drying cycles the penetrated salt ions become dried up and react with the cement hydrates that result in the formation of expansive compound and leads to the strength deterioration. Also during drying cycle, moisture inside the concrete may come out from the specimens for which normal hydration process is disturbed. Rate of strength deterioration for different types of concrete is observed to vary with SW concentration as well as exposure condition.

The compressive strength data also provide important information regarding the gain in strength of concrete under SW curing. In case of AWD condition and for 12 months of curing under 1T SW shows a gain in strength of 17%, 27%, 19% for fly ash concrete of cement fly ash mix ratio of 80:20, 70:30, 60:40 respectively; whereas the same value for 6T SW curing under similar exposure condition are 6%, 18%, 12% respectively. Thus in aggressive environment, gain in strength for fly ash concrete of cement fly ash mix ratio 70:30 is observed to be higher than that for any other concrete studied. The loss in compressive strengths as compared to 12 months compressive strength of PW cured OPC concrete, are observed to lie in the range of 12% to 28% for OPC concrete, 8% to 22% for 80:20, 4% to 17% for 70:30, 7% to 20% for 60:40 and 18% to 40% for 40:60 fly ash concrete when exposed to SW of different concentration. Cause for strength reduction may be the formation of expansive compounds includes ettringite or frields salt when concrete specimens are cured in SW. Due to formation of these expansive materials, micro cracks are developed inside the concrete and their subsequent propagation with the progress of hydration weakens the bond between hydrated product and aggregate particles. Ultimate result is the deterioration of concrete and the loss in compressive strength. Fly ash concrete specially cement fly ash mix ratio 70:30 shows higher resistance to SW penetration as compared to OPC concrete at longer exposure periods. Gain in compressive strength after 12 months exposure period for fly ash concrete of cement fly ash mix ratio of 80:20, 70:30, 60:40 are in the range of 106% to 126%, 118% to 136%, 112% to 128% with respect to 28 days compressive strength of PW cured concrete, whereas this value is 95% to 105% for OPC concrete. For longer exposure periods with the progress of hydration, fly ash concrete offers better resistance against the penetration of SW due to its impermeable nature that results in higher gain in strength at later ages.

Overall observation reveals that fly ash concrete shows relatively lower rate of strength reduction as compared to OPC concrete. Fly ash concrete specially cement fly ash mix ratio 70:30 shows higher resistance to SW penetration as compared to OPC concrete over longer exposure periods as well as least reduction in compressive strength. Overall reduction of compressive strength was 22% for OPC concrete, 16% for 80:20 fly ash concrete, 12% for 70:30 fly ash concrete, 15% for 60:40 fly ash concrete and 27% for 40:60 fly ash concrete. From all the above discussion it is clear that fly ash concrete shows comparatively higher gain in compressive strength in SW and fly ash concrete of cement fly ash mix ratio 70:30 shows lowest strength deterioration at larger curing periods in any curing condition among all the concretes studied.

(b) Half Cell Potential

Half-cell potential (HCP) of the steel reinforcement placed at two depth level 15 and 25 mm in fly ash concrete specimens made from five different replacement level of fly ash which were exposed to SW of different concentration under SUB and AWD state of exposure are shown in **Fig.5** to **Fig.8.** Half cell potential was measured at an interval of one month for all the specimens. The reinforced concrete specimens were air dried for one hour before the half cell potential measurement. All potential values of concrete specimens become more negative with the increase of curing period. HCP value of M38FA0, M38FA20, M38FA30, M38FA40, M38FA60 concrete at a depth level of 15 mm were -122, -126, -119, -120, -125 mV respectively when exposed to SW of concentration 6T after 9 months of curing; whereas the same values for the same concretes after 12 months of curing in 6T SW were -274, -266, -255,

-262, -268 mV respectively. From the Figures, it is observed that there is a sudden drop of HCP values of all the concretes within the period of 10 to 11 months of exposure and this value drops from -100 to -200. This sudden drop can be attributed to the change in the condition of the potential of steel-concrete interface, possibly due to the ingress of sufficient amount of chloride at the rebar level. Therefore the chloride concentration at rebar level at the time of sudden drop can be considered as the critical chloride concentration responsible for depassivation of the steel reinforcement. Correspondingly the time at which this sudden drop had occurred was the corrosion initiation period under specific circumstances of the present investigation.

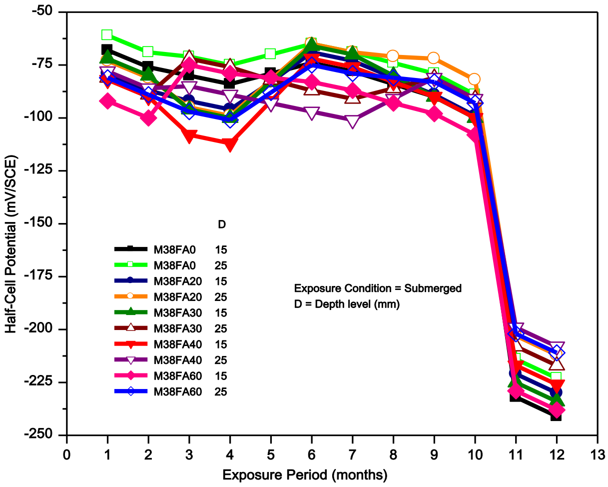

Fig.5: Half Cell Potential - Exposure Period Relation for Concrete Exposed to 1T SW (SUB)

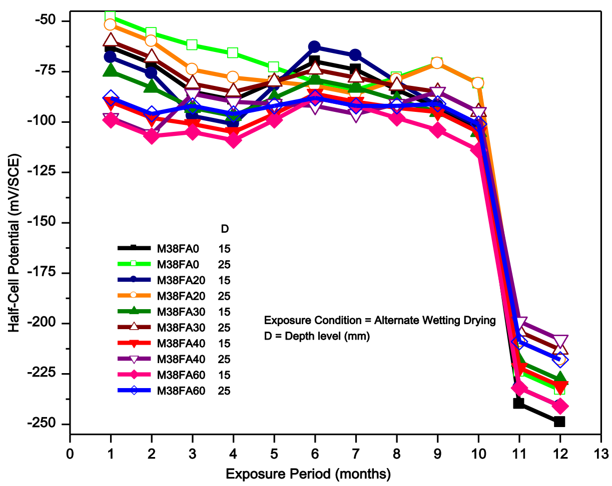

Fig.6: Half Cell Potential - Exposure Period Relation for Concrete Exposed to 1T SW (AWD)

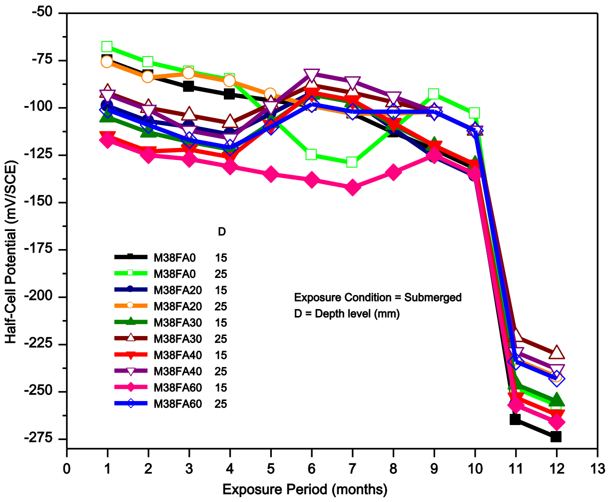

Fig.7: Half Cell Potential - Exposure Period Relation for Concrete Exposed to 6T SW (SUB)

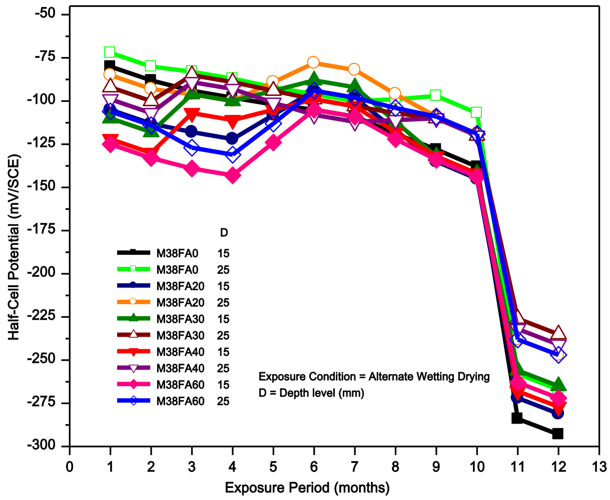

Fig.8: Half Cell Potential - Exposure Period Relation for Concrete Exposed to 6T SW (AWD)

It is also revealed form the HCP readings that fly ash concrete has better resistance against corrosion of steel as compared to OPC concrete for long exposure periods. In case of M38FA20, M38FA30, M38FA40, M38FA60 concretes, HCP values are -241, -228, -231, -240 mV for the steel at a depth level of 15 mm after 12 months of curing in SW of 1T concentration and in AWD condition; whereas the HCP values for same concretes are -281, -265, -277, -272 mV for 6T SW of similar condition. On the other side HCP values for OPC concrete are -249 and -293 mV respectively. From these HCP values, it is clear that fly ash blending can increase the resistance of concrete against rebar corrosion. Corrosion of reinforcement takes place due to ingress of chloride inside concrete. The passive oxide film surrounding the steel bar was destroyed due to presence of chloride ions. But in case of Fly ash concrete, ingress of chloride ion is observed to be reduced as compared to OPC concrete. Overall observation reveals that fly ash concrete of cement replacement level 30 to 40% shows relatively less negative HCP as compared to other concretes used in this study.

CONCLUDING REMARKS

Based on the test results of plain and reinforced concrete of five different replacement levels of cement by fly ash exposed to simulated SW of 1T and 6T concentrations under SUB and AWD state, the following conclusions may be drawn:

(1) Fly ash concrete shows relatively slower rate of strength gaining as compared to OPC concrete at early age of curing. But after 56 days of curing, compressive strength gaining rate increases for fly ash concretes as compared to OPC concrete.

(2) Compressive strength of concrete specimens cured in SW of different salt concentration and in different exposure show a decreasing trend with the increase of exposure periods. Also for concrete specimens exposed to AWD state exhibited higher loss in strength than that of SUB state of exposure.

(3) Effect of SW on strength reduction is lower for fly ash concrete as compared to OPC concrete. Upto 12 months of exposure in SW, overall losses in compressive strength lie in the range of 12 to 28% for OPC concrete, 8 to 22%, 4 to 17% and 7 to 20% for 20, 30 and 40% cement replaced fly ash concrete respectively. Concrete of cement: fly ash ratio 70:30 shows the least strength deterioration in all SW environments.

(4) At the initial stage of curing, HCP values were almost constant before the initiation of rebar corrosion. After the dipassivation of steel, HCP rapidly decreased to more negative values. Fly ash concrete showed relatively lower negative value of HCP values as compared to OPC concrete.

(5) The use of fly ash as partial replacement of cement clinker in cement production will reduce CO_2 emission to the environment and the problem of its disposal, saving the valuable fertile lands. Also it will save the national revenue by reducing the import of fly ash from foreign country.

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