Carbonation Depth and Chloride-ion Concentration

In the tidal region and dry condition, carbonation depths in the specimens were negligible irrespective of the types of cement.

In the tidal region condition, for all concrete mixtures, concentration of more chloride-ion was observed at the surface, however it is reduced to a negligible value at deeper depth (see Fig. 15). Due to this high concentration of chlorides, especially for concrete with slag cement, steel bars with 3.5 cm of cover concrete, showed a high possibility of corrosion generally. Relatively more chloride-ions penetrated to a greater depth in concrete with ASTM Type V cement compared with Type II, trass, Type II with silica fume, and slag cement.

Compressive Strength and Permeability

Compressive strength test results for concrete mixtures under standard curing conditions are shown in Figs. 16 and 17. It can be seen that the compressive strength of all concrete mixtures is over 60 MPa at 360 days, regardless of w/cm ratio. Higher compressive strengths are expected at later ages for concretes containing pozzolans. Relatively higher strength was observed in the case of ASTM Type V, Type II and Type II + silica fume concrete mixtures when compared with trass and slag cement mixtures. However, concrete mixtures containing ASTM Type V cement showed undesirable performance in terms of corrosion.

Permeability under water pressure for all concrete mixtures was low irrespective of the type of cement and water-cement ratios used in this investigation (see Figs. 18 and 19)

CONCLUSIONS

1- For specimens exposed to the tidal region, specimens made with ASTM Type V cement (with 3.5 and 5 cm cover) and specimens made with slag and silica fume (with 3.5 cm cover) showed undesirable performance. The best performances was obtained for concrete mixtures containing trass cement and ASTM Type II cement + silica fume.
2- In totally submerged specimens, although corrosion potential is high and concrete electrical resistance is low, current density is negligible after 360 days.

3- All concrete mixtures showed no activity and very low current densities after 12 months of exposure in air. These concretes had high electrical resistance. For this exposure condition, there was no significant difference in the performance of concrete mixtures made with different cements and for various cover thicknesses.
4- In general, exposure in the tidal region was the worst condition for concrete mixtures when compared with the submerged and dry conditions.

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Table 1- Chemical Composition(%) of Cements and Cement Replacement Materials

	Type II	*Type V*	*Slag*	*Trass*	*Silica fume*
SiO_2	20.96	21.47	23.08	24.24	95.1
Al_2O_3	4.2	3.95	5.5	4.25	0.6
Fe_2O_3	4.6	4.4	3.4	3.8	1.1
MgO	3.4	2.3	3.4	3.8	0.6
CaO	61.88	63.84	60.2	58.8	1.02
SO_3	1.79	2.17	2.64	3.82	1.2
Na_2O+0.658 K_2O	1.47	1.01	1.08	1.26	-
C_3S	52.74	57.72	-	-	-
C_2S	20.31	18.01	-	-	-
C_3A	3.35	3.02	-	-	-

Table 2- Aggregate Properties

	Relative Density	**Absorption (%)**	**Fineness Modulus**
Sand	2.53	2.6	2.7
Gravel	2.56	1.46	6.5

Table 3- Mixture Proportions (per cubic meter)

Mixture	**Cement type**	**CRM type**	**w/cm**	**Water (kg)**	**Cement (kg)**	**CRM (kg)**	**Sand (kg)**	**Gravel (kg)**
A1	Type II	-	0.40	160	400	-	760	1050
A2	Type II	-	0.35	140	400	-	760	1050
B1	TypeV	-	0.40	160	400	-	760	1050
B2	Type V	-	0.35	140	400	-	760	1050
C1	Type II	Silica fume	0.40	160	372	28	760	1050
C2	Type II	Silica fume	0.35	140	372	28	760	1050
D1	Trass	-	0.40	160	400	-	760	1050
D2	Trass	-	0.35	140	400	-	760	1050
E1	Slag	Silica fume	0.40	160	380	20	760	1050
E2	Slag	Silica fume	0.35	140	380	20	760	1050

Table 4- Current Density and Concrete Resistance at 90 days; in the Dry Condition

Mixture	w/cm	Current ($\mu A/cm^2$)			Resistance (kohm)		
		3.5 cm	5 cm	7 cm	3.5 cm	5 cm	7 cm
A1	0.40	1.12	0.77	0.80	2.2	2.7	3.9
A2	0.35	0.53	0.41	0.22	3.9	4.5	4.3
B1	0.40	1.20	0.80	0.60	2.7	3.1	2.8
B2	0.35	0.60	0.54	0.41	4.5	5.5	5.0
C1	0.40	1.10	0.70	0.42	3.5	3.5	4.5
C2	0.35	1.50	0.80	0.36	3.5	4.0	4.0
D1	0.40	1.30	0.55	0.55	3.5	4.1	5.5
D2	0.35	0.72	0.53	0.45	4.0	5.5	5.8
E1	0.40	1.02	0.60	0.45	3.0	5.0	4.6
E2	0.35	0.70	0.70	0.45	5.0	5.0	5.2

Table 5- Current Density and Concrete Resistance at 360 days; in the Dry Condition

Mixture	w/cm	Current ($\mu A/cm^2$)			Resistance (kohm)		
		3.5 cm	5 cm	7 cm	3.5 cm	5 cm	7 cm
A1	0.40	0.22	0.17	0.20	4.0	4.5	5.0
A2	0.35	0.16	0.09	0.12	5.0	5.1	6.1
B1	0.40	0.29	0.25	0.17	2.1	2.9	3.5
B2	0.35	0.28	0.15	0.14	3.2	3.7	3.8
C1	0.40	0.28	0.19	0.14	5.4	5.7	6.0
C2	0.35	0.22	0.18	0.11	6.4	6.8	6.7
D1	0.40	0.20	0.18	0.19	5.6	5.8	6.0
D2	0.35	0.26	0.19	0.14	5.9	5.9	5.9
E1	0.40	0.23	0.23	0.19	4.1	5.0	5.5
E2	0.35	0.19	0.13	0.14	6.0	6.0	6.1

Table 6- Current Density and Concrete Resistance at 90 days; in the Tidal Zone

Mixture	w/cm	Current ($\mu A/cm^2$)			Resistance (kohm)		
		3.5 cm	5 cm	7 cm	3.5 cm	5 cm	7 cm
A1	0.40	0.96	0.88	0.59	1.8	1.7	1.6
A2	0.35	0.92	0.77	0.53	2.1	2.6	2.2
B1	0.40	2.84	1.72	0.70	1.0	1.9	1.9
B2	0.35	1.32	1.28	0.38	0.5	2.5	2.6
C1	0.40	0.95	0.80	0.43	1.8	2.0	2.1
C2	0.35	0.92	0.71	0.37	1.6	1.8	1.8
D1	0.40	1.60	1.05	0.97	0.8	1.9	2.1
D2	0.35	0.72	0.88	0.62	1.8	2.3	2.2
E1	0.40	1.80	1.56	1.36	1.4	1.3	1.7
E2	0.35	0.90	0.60	0.56	1.2	2.0	2.0

Table 7- Current Density and Concrete Resistance at 360 days; in the Tidal Zone

Mixture	w/cm	Current ($\mu A/cm^2$)			Resistance (kohm)		
		3.5 cm	5 cm	7 cm	3.5 cm	5 cm	7 cm
A1	0.40	1.84	1.38	1.79	0.8	1.2	1.2
A2	0.35	1.60	0.95	0.80	0.8	1.5	1.7
B1	0.40	3.08	2.51	1.86	0.4	0.5	0.7
B2	0.35	2.85	1.96	1.53	0.5	1.3	1.4
C1	0.40	1.18	1.66	1.10	1.2	1.3	1.3
C2	0.35	1.14	1.39	1.15	1.8	2.1	2.8
D1	0.40	1.40	2.35	1.23	1.1	1.3	1.5
D2	0.35	1.23	1.41	1.11	1.3	1.4	1.8
E1	0.40	2.58	1.79	1.28	0.9	1.4	1.8
E2	0.35	2.27	1.66	0.97	1.0	1.7	2.4

Table 8- Current Density and Concrete Resistance; in the Submerged Condition

Mixture	w/cm	90 days		360 days	
		Current ($\mu A/cm^2$)	Resistance (kohm)	Current ($\mu A/cm^2$)	Resistance (kohm)
		7 cm		7 cm	
A1	0.40	1.52	1.2	1.17	2.4
A2	0.35	1.15	2.0	0.50	1.8
B1	0.40	1.87	1.1	1.09	0.9
B2	0.35	1.95	1.2	0.70	1.0
C1	0.40	0.75	1.5	0.62	1.4
C2	0.35	0.40	2.2	0.38	1.9
D1	0.40	0.90	1.3	1.20	1.1
D2	0.35	1.00	1.6	0.90	1.5
E1	0.40	1.25	1.9	0.78	1.8
E2	0.35	1.10	2.2	0.51	2.0

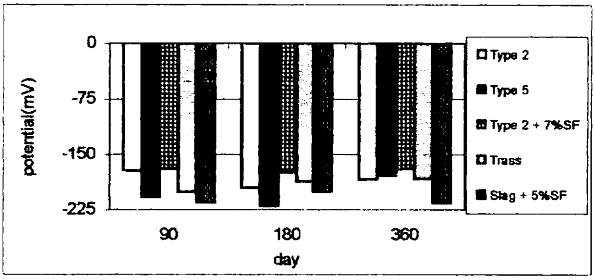

Fig. 1-Half-cell Potential versus Age; (w/cm)=0.35,cover=7 cm,submerged condition

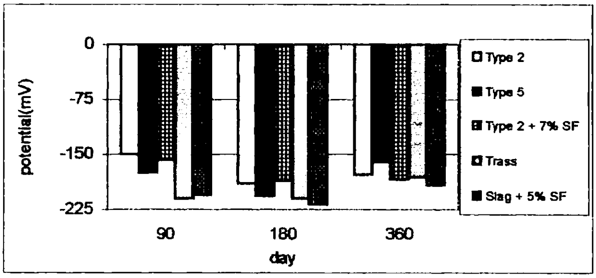

Fig. 2-Half-cell Potential versus Age; (w/cm)=0.4,cover=7 cm,submerged condition

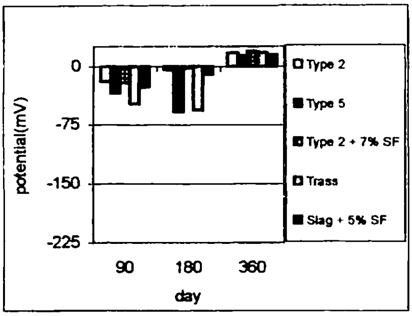

Fig. 3-Half-cell Potential versus Age; (w/cm)=0.4,cover=3.5 cm,dry condition

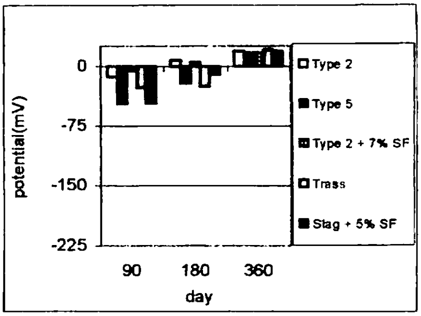

Fig. 4-Half-cell Potential versus Age; (w/cm)=0.35,cover=3.5 cm,dry condition

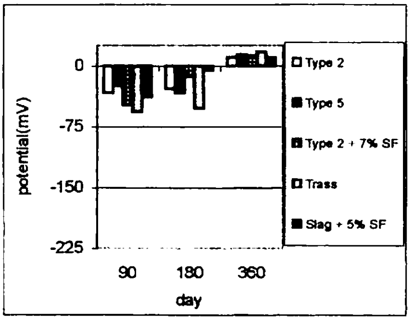

Fig. 5-Half-cell Potential versus Age; (w/cm)=0.4,cover=5 cm,dry condition

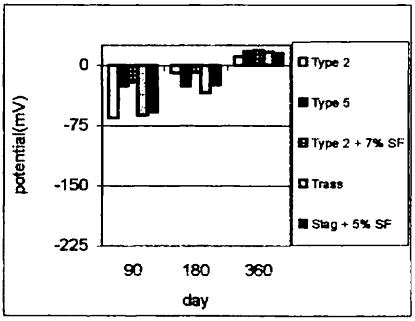

Fig. 6-Half-cell Potential versus Age; (w/cm)=0.35,cover=5 cm,dry condition

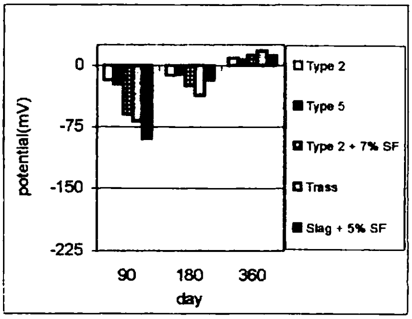

Fig. 7-Half-cell Potential versus Age; (w/cm)=0.4,cover=7 cm,dry condition

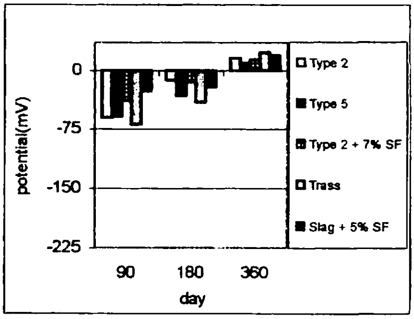

Fig. 8-Half-cell Potential versus Age; (w/cm)=0.35,cover=7 cm,dry condition

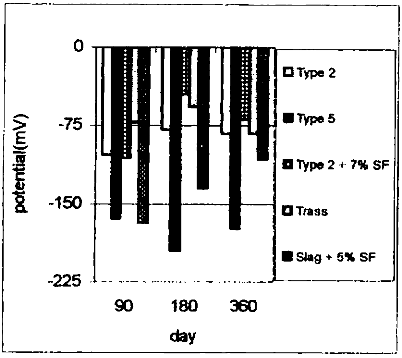

Fig. 9-Half-cell Potential versus Age; (w/cm)=0.4,cover=3.5 cm,tidal zone

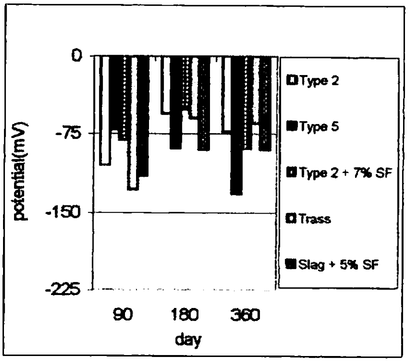

Fig. 10-Half-cell Potential versus Age; (w/cm)=0.35,cover=3.5 cm,tidal zone

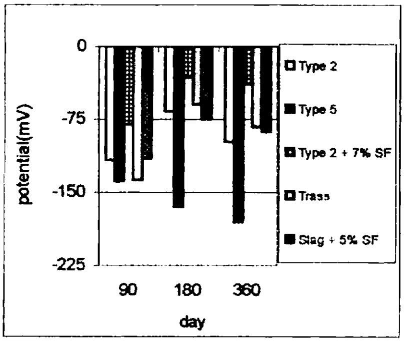

Fig. 11-Half-cell Potential versus Age; (w/cm)=0.4,cover=5 cm,tidal zone

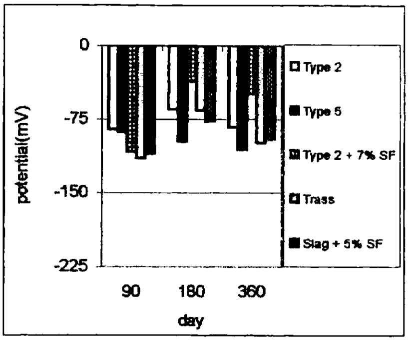

Fig. 12-Half-cell Potential versus Age; (w/cm)=0.35,cover=5 cm,tidal zone

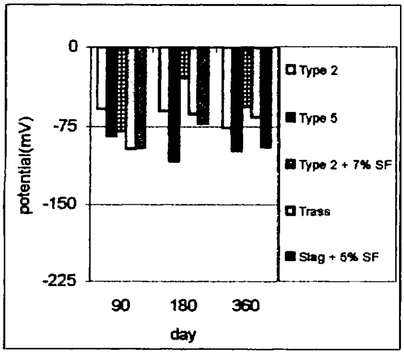

Fig. 13-Half-cell Potential versus Age; (w/cm)=0.4,cover=7 cm,tidal zone

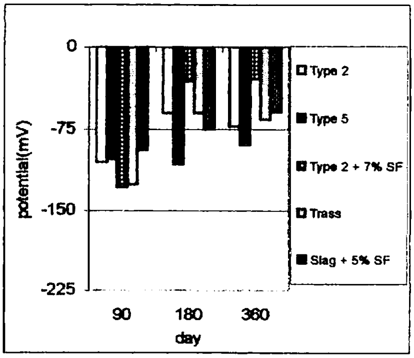

Fig. 14-Half-cell Potential versus Age; (w/cm)=0.35,cover=7 cm,tidal zone

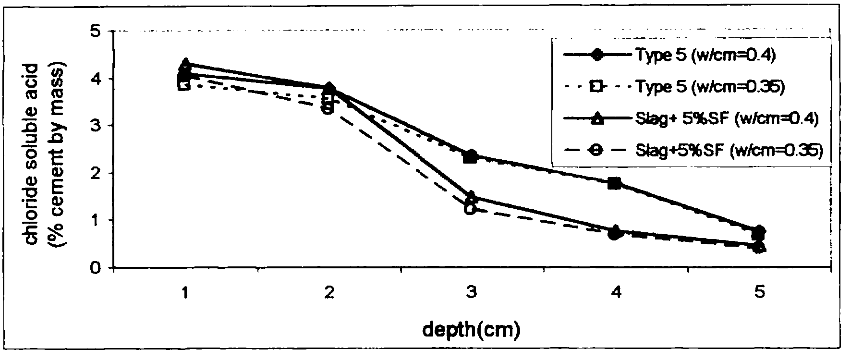

Fig. 15-Profile of Acid Soluble Chloride Ion Concentrations in Mortar; in the Tidal Region

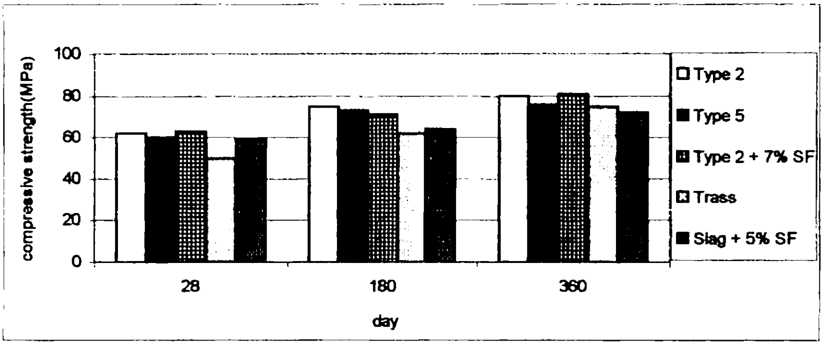

Fig. 16-Compressive Strength of Concrete versus Age; (w/cm=0.35)

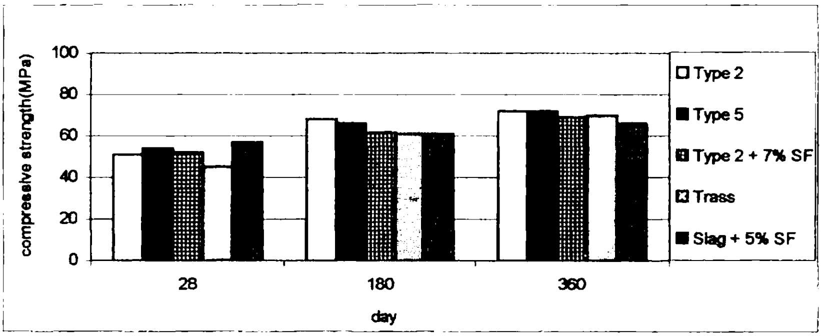

Fig. 17-Compressive Strength of Concrete versus Age; (w/cm=0.4)

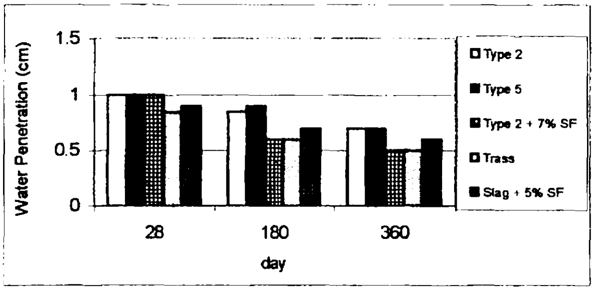

Fig. 18-Water Penetration in Concretes versus Age; (w/cm=0.35)

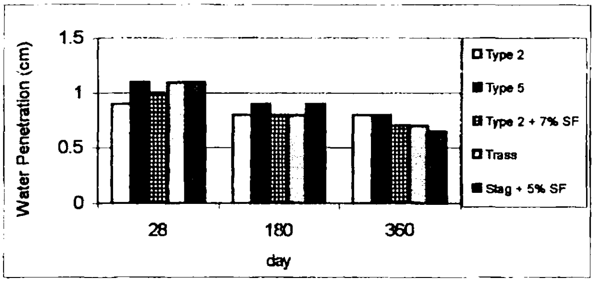

Fig. 19-Water Penetration in Concretes versus Age; (w/cm=0.4)