in which 10% of the cement was replaced by diatomite. Finally, concrete mixtures S_1, S_2 and S_3 were prepared in which slag content was 20% of the total cementitious materials. All portland cement replacements were on weight basis.

Casting and Curing of Test Specimens

After casting, the molded specimens were covered with water-saturated burlap and left in the casting room at $20^{\circ}c \pm 1$ for 24h. They were then demolded and cured in fog room for 3 days. After moist curing the specimens were transferred to the control room and to the room prepared to simulate the hot climate conditions. Table3 shows the detail of curing conditions.

TESTING OF SPECIMENS

The $100 \times 100 \times 100$mm concrete cubes were tested in compression at 7,28,90 and 180 days. The water penetration test was carried out on $150 \times 150 \times 150$mm cubes at 3 and 6 months in accordance with DIN 1048 Standard.

The chloride and sulphate content tests were carried out on concrete cubes at different depths after 4 months. The carbonation depth was measured on $100 \times 100 \times 500$mm concrete prisms up to 9 months. The tests for the measurement of corrosion of reinforcement in concrete specimens were carried out on 75×150mm cylinders with a bar in the middle after 6 months using half cell potential ιechnique.

PROPERTIES OF FRESH CONCRETE

The properties of the freshly mixed concrete, i.e., slump and unit weight are given in Table2. By adjusting the amount of the superplasticizer, attempt was made to maintain the slump of all concrete mixtures between 50 to 100 mm.

TEST RESULTS AND DISCUSSION

Compressive Strength

The strength development characteristics of the various concrete mixtures under moist curing condition (curing condition 1) are shown in Figs 1,2 and 3. In Fig 1 for concrete mixtures containing 300 kg/m^3 cementitious materials, the highest strength of 50 MPa is obtained for the concrete incorporating 10% silica fume, and the lowest value of 32 MPa is for concrete with 20% trass at 180 days. The concrete mixtures containing Type 5 cement and 10% diatomite have the second highest strengths. Between 90 and 180 days, silica fume and trass concrete mixtures showed almost no strength gain.
Fig 2 presents the compressive strength of concrete mixtures containing 350 kg/m^3 cementitious materials. The compressive strength of all concrete mixtures has increased by increasing the amount of cement. Here again the highest strength value of 55 MPa at 180 days is reached by the silica fume whereas the trass concrete has shown the lowest strength with a value of 37 MPa. The same

trend observed for concrete mixtures where 400 kg/m^3 cementitious materials was used. As can be seen in Fig 3, the highest strength of 65 MPa is obtained for the concrete incorporating 10% silica fume, and the lowest value of 40 MPa is for concrete with 20% trass.

Depth of Carbonation

The depth of carbonation of all concrete mixtures under condition 4 (35°C and 65% RH) is shown in Fig 4,5 and 6. The results show the differences between the depth of carbonation of mixtures containing 300, 350 and 400 kg/m^3 cementitious materials at 9 months. It can be seen that the silica fume concrete has the lowest depth in all concrete mixtures. The second lowest depth is for concrete containing Type 2 portland cement and the slag concrete mixtures have shown the highest values. The increase of cement content from 300 kg/m^3 to 400 kg/m^3 has reduced the depth of carbonation in almost all concrete mixtures.

Chloride Penetration

The chloride content of the specimens at different depths has been measured by "Hach chloride test kit" method. In this technique powder samples are taken from the specimens at different depths and the amount of chloride is determined by chemical analysis. Test results for concretes containing different cement contents at 4 months and under curing conditions 2 and 3 are shown in

Fig7, 8 and 9. Irrespective of the curing conditions and regardless of the cement content, the concrete mixtures containing pozzolanic materials particularly for silica fume and diatomite mixtures, the chloride content is low at the depth of 10mm 1cm. This clearly shows the better performance of supplementary cementing material mixtures in the areas where both sulfate and chloride ions are present. Further results at later ages will demonstrate the longer term performance of the concrete mixtures.

Corrosion Test Results

The half cell potential measurement technique was carried out throuought the tests for specimens cured in conditions 3 and 4.
The results are shown in graphical form at 6 months in Fig 10,11 and 12. As expected, in curing condition 3 where specimens subjected to wetting and drying cycles in sea water, all concrete mixtures have shown high voltage values. This indicates that the oxide layer which protects the reinforcement against corrosion is in danger under this severe condition. However specimens maintained at curing condition 4, have shown greater resistance to corrosion. Concrete mixtures containing more cement (See Fig 12) have shown better performance when compared with mixtures containing 300 kg/m^3 cement. The use of supplementary cementing materials, specially silica fume and diatomite, has improved significantly the performance of the concrete mixtures and reduced the voltage values. This difference is more significant for silica fume and diatomite concrete mixtures under curing condition 4.

Water Penetration

The results of water penetration for all concrete mixtures containing three different cement contents at 6 months are presented in Fig 13, 14 and 15. Similar to other results obtained in chloride penetration tests and in carbonation tests, the addition of more cement has reduced the penetration of water into the concretes. At this stage the difference between the mixtures with and without supplementary cementing materials is not significant.

CONCLUDING REMARKS

For the concrete mixtures investigated and the curing conditions employed, the following conclusion may be drawn.

1- The wetting and drying cycles were found to be the worst curing conditions for all concrete mixtures when compared with three other curing conditions.

2- The compressive strength of concrete mixtures increased by increasing the amount of cement. The highest strength is obtained for the concrete containing 10% silica fume and the lowest is for the concrete with 20% trass at the age of 180 days.

3- The depth of carbonation in almost all concrete mixtures is reduced when cement content is increased. Concrete mixtures containing silica fume have the lowest depth of carbonation at the age of 270 days.

4- A lower depth of chloride ions into concretes was found less in mixtures prepared with supplementary cementing materials particularly for silica fume and diatomite concrete mixtures.

5- Concretes receiving wetting and drying cycles show the poorest performance in terms of the resistance to corrosion. However, concretes made with silica fume and diatomite show significant improvement in the resistance to the corrosion of reinforcement.

6- The beneficial effects of the use of supplementary cementing materials cannot be reflected in the 6 month results. This is due to the relatively slow rate of hydration reactions and pozzolanic reactions of these materials. Better performance is expected for these concrete mixtures when longer term results are obtained.

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TABLE 1—CHEMICAL ANALYSIS OF CEMENTITIOUS MATERIALS

Chemical Analysis	Type 2 portland cement	Type 5 portland cement	Trass	Silica fume	Slag	Diatomite
SiO_2	22.08	21.32	70.12	91.10	37.72	93.54
Al_2O_3	3.90	4.40	11.45	1.55	14.40	0.75
Fe_2O_3	5.00	3.80	2.20	2.00	1.20	0.10
CaO	63.56	64.40	4.20	2.24	40.60	1.68
MgO	2.20	0.80	0.80	0.60	5.80	0.00
SO_3	2.11	2.50	0.00	0.45	0.00	0.00
NaO	0.76	1.36	0.00	0.00	0.00	0.00
K_2O			0.00	0.00	0.00	0.00
LOI	0.54	1.28	8.69	0.00	0.00	3.46
C_3S	51.0	57.9				
C_2S	25.1	17.5				
C_3A	2.0	5.2				
C_4AF	15.2	11.5				

TABLE 2—PROPORTIONING OF CONCRETE MIXTURES

Mixture no.	W / C+SCM	Quantities (kg/m^3) Water	Cement Type 2	Cement Type 5	Silica fume	Trass	Diatomite	Slag	CA SSD	FA SSD	Sp*	Slump (mm)	Unit Weight (kg/m^3)
MP_1	0.4	120	300						953	953	2.40	50	2302
T_1	0.4	120	240			60			953	953	3.00	55	2259
M_1	0.4	120	270		30				953	953	3.30	70	2291
D_1	0.4	120	270				30		953	953	2.40	70	2335
S_1	0.4	120	240					60	953	953	1.50	70	2331
SR_1	0.4	120		300					953	953	1.50	70	2331
MP_2	0.4	140	350						953	953	2.80	80	2317
T_2	0.4	140	280			70			918	918	3.50	75	2285
M_2	0.4	140	315		35				918	918	3.85	65	2274
D_2	0.4	140	315				35		918	918	2.80	75	2340
S_2	0.4	140	280					70	918	918	1.75	75	2359
SR_2	0.4	140		350					918	918	1.75	100	2361
MP_3	0.4	160	400						883	883	3.27	85	2329
T_3	0.4	160	320			80			883	883	4.09	90	2307
M_3	0.4	160	360		40				883	883	4.49	60	2338
D_3	0.4	160	360				40		883	883	3.27	75	2305
S_3	0.4	160	320					80	883	883	2.04	70	2324
SR_3	0.4	160		400					883	883	2.04	90	2375

SP* = Melcrete superplasticizer

TABLE 3—CURING REGIMES FOR CONCRETE MIXTURES

NO	Curing regime
1	Standard moist curing
2	Curing in Gulf water at 35°C
3	Curing in Gulf water at 35°C under wetting-drying cycles
4	Curing at 35°C and 65% RH

Fig. 1—Compressive strength development of moist-cured concrete 300 kg/m[3] cementitious materials