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PERFORMANCE OF CONCRETE UNDER DIFFERENT CURING CONDITIONS

Kefeng Tan* and Odd E. Gjorv**
*Southwest Institute of Technology, Mianyang, Sichuan, P.R.China
**The Norwegian Institute of Technology, Trondheim, Norway

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ABSTRACT

The effect of curing conditions on strength and permeability of concrete was studied. Test results showed that after 3 and 7 days moist curing only the concretes with w/c ratios equal to or less than 0.4 were accepted, while after 28 days of moist curing however, even the concrete with w/c of 0.6 could be accepted. Silica fume has a significant effect on the resistance to water penetration. For the concretes both with and without silica fume and with w/c + s of 0.5, the 28-day compressive strengths of 3 and 7 days moist curing were higher than those of 28 days moist curing, and the silica fume concrete seemed to be less sensitive to early drying. The curing temperatures did not affect the water penetration of concrete, but affected the chloride penetration and compressive strength of concrete significantly.

Introduction

Proper curing is one of essential means to get a durable concrete. It consists of the length of moist curing and the temperature of curing.

The hydration of cement can take place only when the vapour pressure in the capillaries is sufficiently high, about 0,8 of saturation pressure(1). Therefore early drying of concrete may stop the cement hydration before the pores are blocked by hydration products and thus a more continuous pore structures may be formed. The cover concrete is more sensitive to drying since it is more prone to lose water. The formation of a continuous pore structure in cover concrete may provide an easy passage for the intrusion of aggressive species and therefore the deteriorating of the concrete structures. Early drying can also lead to more shrinkage and cracking and this would aggravate the deterioration process of concrete. Usually the concretes with lower w/c are less sensitive to the curing.

It is well known that an elevated curing temperature will cause a low degree of hydration of cement at later ages and therefore a porous pore structure(2) of cement paste and lower strength(3) and higher permeability(4) of concrete. However not enough information is available for the curing conditions occurring in large scale concrete production, in which an elevated temperature could develop due to the release of the heat of cement hydration.

In this study, the permeability of concrete was tested based on the test methods of NS 3420 and ISO/DIS 7031, in which the maximum penetration depth of 25 mm was taken as a criterion for the acceptance/rejection of concretes. The objective of this study was to investigate which concrete at what curing conditions could be acceptable, to provide some guidance for the concreting practices in aggressive environments. Attention was paid to test the covercrete, since it is more prone to drying and attack by aggressive species. The designed variables included w/c ratios and silica fume.

Experimental

Materials. The composition of five mixes included in the test program is shown in Table 1. Norwegian P30 cement (type I) was used as binder, natural sand as fine aggregate, and crushed gravel as coarse aggregate. A naphthalene-based dispersing agent was used to get a workable fresh concrete.

Curing Conditions. Four moist curing regimes, as shown in Table 2 were chosen to study the influence of moist curing conditions on the compressive strength and permeability of concretes. The curing conditions of C2 and C3 conformed to that recommended by BS 8110 and ACI 308-81 for type I cement, while C4 is standard curing. The relative humility in the laboratory varied from 40 to 50% during the time of curing and testing.

To investigate the temperature effects on concrete at the semi-adiabatic conditions which occur in large scale concrete production, elevated curing conditions were applied. The temperature development in a semi-adiabatic condition was first monitored in a 14 liter box of 50 mm thick expanded polystyrene (Fig. 1). After a delay of 4 hours (induction period as shown in Fig. 1) , the same rate of temperature rise was used to heat up the water tank in which the specimens were sealed in plastic bags. After reaching the maximum temperatures of 50, 65 and

TABLE 1

Mix Proportions of Concrete

Mix No.	cement kg/m^3	Silica fume kg/m^3	Water kg/m^3	sand kg/m^3	gravel kg/m^3	dispers. agent kg/m^3	W/(C+S)	Slump (cm)
N1	435	0	148.0	783	1068	15.4	0.35	18
N2	400	0	160.0	809	1040	5.2	0.40	18
N3	350	0	175.0	837	1013	2.9	0.50	18
S3	314	31.4	172.7	837	1013	3.6	0.50	18
N4	312	0	187.2	860	990	0.8	0.60	17

TABLE 2

Curing Conditions

Codes	Days in mould	Days in water	Days in air
C1	1	0	48 - 66
C2	1	2	46 - 64
C3	1	6	42 - 60
C4	1	27	21 - 39

80°C the appropriate number of specimens were removed and put into another curing tank of the same temperature and slowly cooled down to room temperature during 48 hours.

Testing. Concrete permeability for different moist curing conditions was tested on the 100x100 mm cube specimens at an age of approximately 2 months for the specimens with different moist curing conditions. The test method was based on the NS 3420 and ISO/DIS 7031, water penetration method. After brushing the testing face (beside the casting face) with a steel brush, the cube specimens were kept in a container with RH of 100% for 6 days in order to minimize the capillary uptake effect. Then they were mounted in test cells as shown in Fig. 2. The applied pressure heads were 0.3, 0.5, 0.7 MPa for the 1st, 2nd, 3rd day respectively. Attention was paid to expel the air from the system by shaking the mounted cells before testing. After testing, the specimens were split and the penetrating fronts were determined.

Concrete permeability with different curing temperatures was tested on the Ø100x50 mm

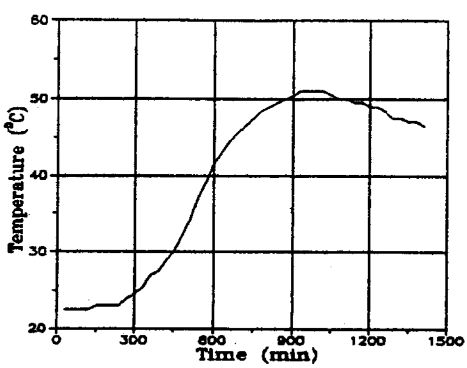

FIG. 1.
Rate of temperature development for semi-adiabatic curing conditions.

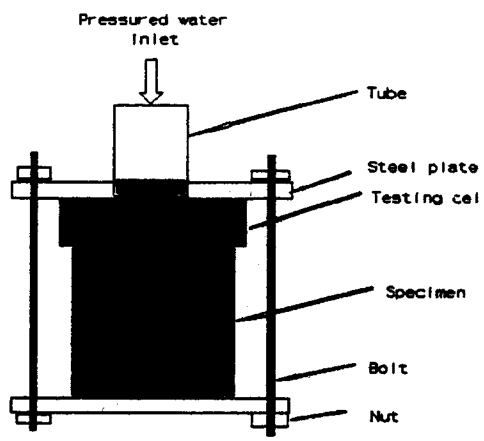

FIG. 2.
Test setup for water penetration test.

cylindrical specimens at an age of 2 months. The test procedures and set-ups were the same as that for cube specimens.

The compressive strength was tested on the 100x100 mm cubes at an age of 28 days.

For all tests, each value was the average of three specimens.

Results and Discussion

Compressive Strength. As had been expected, the compressive strength under standard curing condition (C4) decreased as the w/c increased (Fig. 3). The difference was approximately 15 MPa for the difference of w/c of 0.1. The incorporation of silica fume increased the compressive strength of concrete up to 30%.

The effect of moist curing conditions on the compressive strength of concrete is shown in Fig. 4. Apart from the curing condition of C1, the concrete specimens with curing conditions of C2 and C3 had higher strengths compared to those with the standard curing condition of C4, for concretes both with and without silica fume. This observation was consistent with the work of other researches(5). Theoretically, concrete with prolonged moist curing should have a higher strength. This discrepancy of strength may be due to the difference of relative humidity (RH) in concretes since the concretes with curing conditions of C2 and C3 were partly dried and had a lower RH. The removal of moisture from the interlayer of cement gel would reduce the disjoining pressure and increase the bonding forces between the particles of hydration products(6) and thus the compressive strength of concrete.

As can also be seen in Fig. 4, concrete with silica fume seems to be less sensitive to drying than that without, which implies a rapid pozzolanic reaction happening between the silica fume and calcium hydroxide released by C_3S and C_2S hydration(7).

The effect of elevated curing temperature on the compressive strength of concrete is shown in Fig.5. For comparison, test results(8) for a High-strength Lightweight Concrete (HSLWC, 28d 20°C water curing strength 102MPa) are also included. The compressive strengths decreased by 11%, 15%, 23% and 2%, 6%, 7% respectively for the two mixes when curing

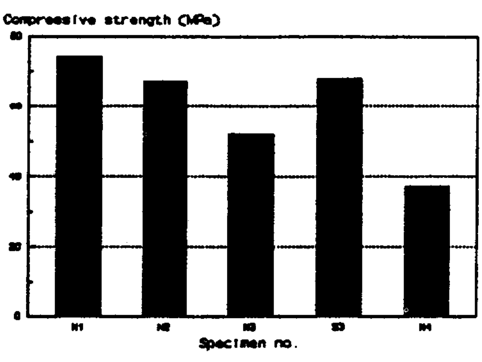

FIG. 3.
Compressive strength of concretes under standard curing condition (C4).

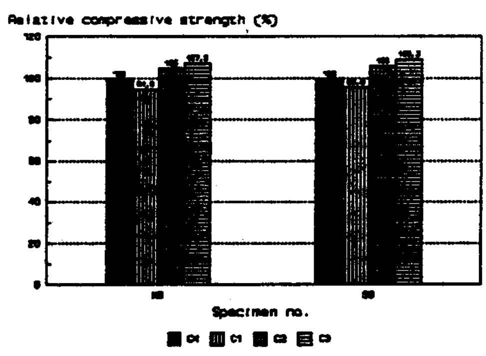

FIG. 4.
Relative compressive strength of concretes under different moist curing conditions.

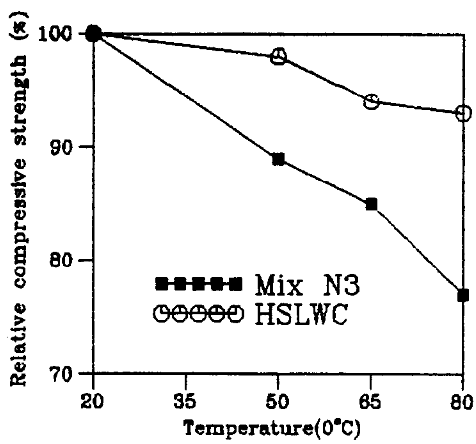

FIG. 5.
Effect of elevated curing temperature on compressive strength of concrete.

temperature increased from 20 to 50, 65, and 80°C. Thus, elevated curing temperature affect compressive strength of HSLWC to a much less significant level than that of normal strength concrete. This may be because the cement particles are closely packed in HSLWC and the hydration products from early hydration of cement are sufficient to fill the gaps between cement particles. Therefore the lower hydration rate at later ages caused by elevated curing temperature would not present any problem to HSLWC.

Water Penetration. The water penetration test was based on the test method of NS3420 AND ISO/DIS7031 and test results are shown in Fig. 6. It can be seen that the moist curing

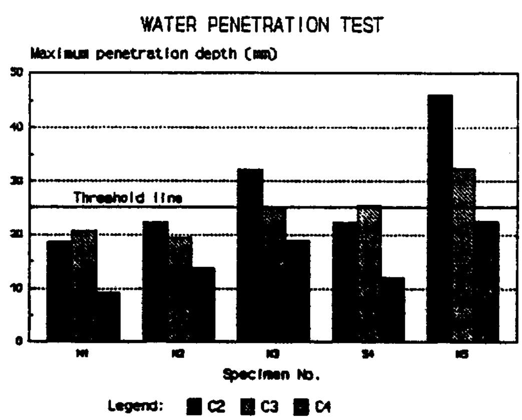

FIG. 6.
Maximum water penetration depths.

TABLE 3

Water and Chloride Penetration at Different Curing Temperature Levels

Temperature levels (°C)	Water penetratuion depth (mm)		t_0* (days)
	Maximum	Average	
20	17.4	14.0	10
50	15.6	13.4	8
65	19.4	15.5	6
80	15.6	13.2	3

*Time for the chloride ions start to penetrate through the specimen at an electrical potential of 12V.

conditions significantly affect the permeability of concretes. No big difference was found for the curing conditions of C2 and C3. which implies that even after 7 days of moist curing, the covercrete had not developed enough strength against drying shrinkage induced cracking. After 28 days of moist curing however, the water penetration depths of concrete were much smaller than that of concrete with the other curing conditions. In all cases, the silica fume concrete has a much higher resistance to water penetration. From Fig. 6 it also can be seen that after 3 and 7 days of moist curing only the concretes with w/c ratios less than 0.4 were accepted based on the test method described above. For the silica fume concrete with w/c+s of 0.5, it was uncertain, since a few specimens were unacceptable. For the curing condition of C4, all the concretes, including the concrete with w/c of 0.6 were accepted, indicating that the pores in cement had been blocked by the hydration products and sufficient strength of covercrete had been developed against the drying shrinkage induced cracking.

As shown in Table 3 no effect was found on the water penetration when concrete was cured at elevated curing temperature levels. However, the curing temperature affected the rate of chloride penetration significantly. The test setups for the chloride penetration test can be found in Ref.9. This may imply that the transport of water and chloride ions through the concrete under an external driving force may be through different mechanisms. The water has viscosity while the ion has not. Thus the change of pore structure caused by the different curing temperatures would affect the transport processes of the two media in different ways.

Conclusions

1. The compressive strength of concrete decreases as the w/c increases.
2. The incorporation of silica fume significantly increased the compressive strength up to 30%.
3. At the same age, concretes (with and without silica fume) with 3 and 7 days of moist curing have higher compressive strengths compared to those with 28 days of curing. This may be attributed to the removal of moisture from the interlayer of cement gel.
4. From the compressive strength point of view, the concrete with silica fume is less sensitive to early drying compared to that without.

5. The curing temperature significantly affected the strength of normal concrete, but not that of the high strength concrete.
6. For 3 and 7 days of moist curing, only the concretes with w/c ratios equal to or less than 0.4 can be accepted based on the water penetration test, while for 28 days moist curing, even the concrete with w/c as high as 0.6 can be accepted.
7. Concrete with silica fume has a higher resistance to the water penetration compared to that without.
8. Elevated curing temperature doesn't affect the resistance to water penetration of concrete but it decreases the resistance to chloride penetration.

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