Pergamon

CEMENT AND CONCRETE RESEARCH

Cement and Concrete Research 29 (1999) 785–788

Communication

The influence of medium temperature environments on the water permeability of high performance mortar

M.F. Mohd Zain [a,*], K.M. Yusof [a], Yasunori Matsufuji [b]

[a]Department of Civil and Structural Engineering, Faculty of Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia
[b]Department of Architecture, Kyushu University, Fukuoka, Japan

Manuscript received 20 May 1998; accepted manuscript 18 February 1999

Abstract

In this study, the durability of normal portland cement mortar and silica fume mortar are characterized by measuring the water permeability under four different types of curing temperatures. It is observed that the water permeability of normal portland cement mortar increases as temperature increases up to 75°C. However, the water permeability of silica fume mortar decreases as the temperature increases. This indicates that the high pozzolanic reaction and microfiller effect of silica fume at medium temperature has modified the open channels at the transition zone of silica fume mortar, making it much denser and stronger and leading to a fine and discontinuous pore structure.

Keywords: Medium temperature; High performance mortar; Silica fume; Water permeability

In hot weather, where the temperature occasionally rises over 35°C, the durability of concrete or mortar decreases while its permeability increases due to cracking [1,2]. Long-term exposure to high temperatures such as in power plants and chemical plants can also increase the potential for reinforcing steel corrosion. This is due to the increased cracking of concrete, which possibly makes the ingress of corrosive solutions easier.

The use of silica fume in concrete or mortar to produce high strength, good chemical resistance, and low water and air permeability is the subject of many publications [3]. However, the influence of a medium temperature range of 20–75°C on the water permeability of high performance mortar is rarely determined.

Therefore, the intention of this study is to show that the water permeability of high performance concrete or mortar under medium temperature environments can be improved by using concrete incorporating silica fume together with sufficient curing method. In this study, the mortar was used instead of concrete to maximize the amount of paste in the mix and to avoid further complications by another variable involving different types of coarse aggregate.

1. Experimental procedure

1.1. Material

Normal portland cement was used in this study. For mineral admixture, silica fume (Elkem Microsilica grade 940-U; Elkem Materials and Carbon, Oslo, Norway) was used as 10% replacement of cement on mass to mass basis. The specific gravity of silica fume was 2.24. River sand was used as fine aggregate. Type "SP-8N" high range water-reducing agent was used with the air-entraining admixture to act as air content adjustment.

1.2. Mix proportions

The detailed mix proportions of the mortar paste are listed in Table 1. The control mixtures were proportioned to a slump flow of 200 ± 10 mm and air content of 3 ± 1% by using air-entraining admixtures and high range water reducer. In the temperature control room, the mixtures were mixed for 5–7 min, using a pan-type revolving paddle mixer of 0.05 m^3 capacity.

1.3. Specimen preparation and storage

After the properties of fresh mortar, such as temperature, slump flow, air content, and unit weight, had been measured (see Table 2) all cylindrical mortar specimens, 100 mm diameter × 200 mm long, were cast in cast iron molds. All specimens were cast in a standard manner. Cylinders from

* Corresponding author. Tel.: 603-829-6212; Fax: 603-829-6147; E-mail: fauzi@eng.ukm.my.

0008-8846/99/$–see front matter
PII: S0008-8846(99)00041-1

Table 1
Details of mix proportions

Type of mix	w/c (%)	Unit weight (kg/cm^3) Cement	Sand	Water	SP-8N (×C%)	AE Adm. (×C%)	Target flow	Target air content (%)
NPC 100	25	1	0.97	0.25	1.0	1.80	200 ± 10	3.0 ± 1.0
SF 100	25	1	0.97	0.25	0.8	3.00	200 ± 10	3.0 ± 1.0

Note: Silica fume was used on the basic weight of 10% replacement of cement.

each mix were prepared for the water permeability test. The specimens were exposed to the following curing conditions, namely;

1. Wrapped-dry air (WWD) curing. Immediately after casting, the specimens in their molds were covered with a plastic sheet and stored in the curing room at 20°C.
2. Dry air (DD) curing. Immediately after casting, the specimens in their molds were covered with a plastic sheet and stored in the curing room at 20°C.
3. Water-dry air (WD) curing. Immediately after casting, the specimens in their molds were covered with a plastic sheet and stored in the curing room at 20°C. At the age of 2 days, the specimens were demolded, marked, and immersed in water at temperature of 20°C.

At the age of 6 days after casting all surfaces of the specimens except the top and the bottom were treated with two coats of epoxy (Araldite AV 138; Ciba-Geigy, Tokyo, Japan). This allowed a unidirectional drying through two untreated faces. At the age of 7 days the specimens were transferred into four air-ventilated ovens, which controlled the temperature at 20, 35, 50, and 75°C. All specimens were cured in this manner for 7, 14, and 28 days. The total age after casting of the respective group of specimens prior testing are 14, 28, and 56 days. At the age of 14, 28, and 56 days, the mortar specimens were removed from the air-ventilated ovens and were cut into three slices using a 1.7-mm thick high speed water-cooled diamond grid blade. 25-mm thick slices from the top and bottom were then removed and the remaining three 50-mm thick slices were used as test specimens. Fig. 1 shows the coating and cutting method of mortar specimens. Immediately after the slices were obtained, they were marked and transferred into an air-ventilated oven, which controlled the temperature at 20°C to allow the surface moisture, absorbed during the cutting process, to dry out. On the following day, all the specimens were weighed and transferred into a temperature-controlled oven at 105°C until constant mass was reached (measured as a mass change, not exceeding 0.1% over the 24-h period).

1.4. Test procedure

The test rig illustrated in Fig. 2 was used to measure the water permeability. This test rig is similar in concept to the rig designed and used by Taywood Engineering Limited [4]. It comprises a top and bottom mild steel plate that bolts together onto an acrylic sleeve with O-ring seals at each end. A 2-mm diameter hole was drilled through the center of the base plate to form the water inlet. The specimens were placed in an acrylic mold and the annular space is then filled with silicone sealant. After the silicone sealant had been cured for 24 h, the specimen was removed from the mold and weighed before being installed in the test rig. Water was introduced into the test rig from the bottom. As the test rig was being filled with water, the quantity of absorbed water was measured at an interval of 10 min by reading the volume of flow rate through a calibrated glass tube. The increases in moisture content in the specimen during the test were determined by weighing the specimen again after the test was completed. The water permeability can be determined according to Darcy's law [5,6].

2. Results and discussion

2.1. Properties of fresh mortar

The properties of fresh mortar are given in Table 2. Mortar incorporating silica fume was called SF 100 and normal portland cement mortar was called NPC 100. The average slump flow for the NPC 100 and SF 100 were 212 and 190 mm and air content was observed to be 2.90 and 3.50%, respectively. The average 28-day compressive strength for the NPC 100 and SF 100 at 20°C were 84 and 94 MPa, respectively.

Table 2
The properties of fresh mortar

Type of specimen	w/c (%)	Type of curing	Flow	Air content (%)	Density (kg/m^3)	Mortar temperature (°C)
NPC 100	25	Water-dry air	212	2.9	2330	22
		Wrapped-dry air	212	2.9	2330	22
		Dry air	212	2.9	2330	22
SF 100	25	Water-dry air	181	3.5	2274	22
		Wrapped-dry air	203	3.4	2263	22
		Dry air	187	3.5	2273	23

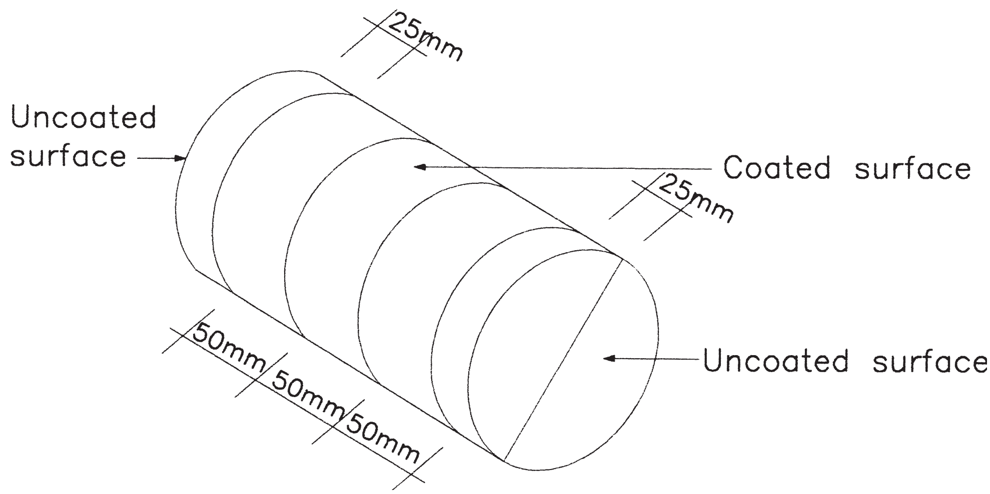

Fig. 1. Coating and cutting method of mortar specimens.

2.2. Water permeability

In order to study the influence of medium temperature environments on the durability of high performance mortar, the water permeability rates have been measured and are given in Table 3. The water permeability rates were practically decreased as the age increased except for NPC 100 under 50C and 75°C, subjected to DD curing. At this point, there are two possible reasons for the increase in water permeability of NPC 100. First, the rate and degree of hydration are affected by the loss of water at an early age, thereby increasing the water permeability. Also it is believed that when mortar specimens are exposed to medium temperature, the total pore volume increases, which affects the distribution of pore sizes and creates additional pore space in hardened cement paste [7,8]. The increase in porosity due to increased temperature leads to a decrease in the bulk mass density of cement paste. Although low water/cement ratio (25%) was used to minimize the volume of porosity, quick drying under 50–75°C of DD curing would lead to localized areas of high porosity in the hydrated cement paste and an increase in the water permeability of NPC 100 mortar. Second, it may be due to microcracks or shrinkage cracks re-

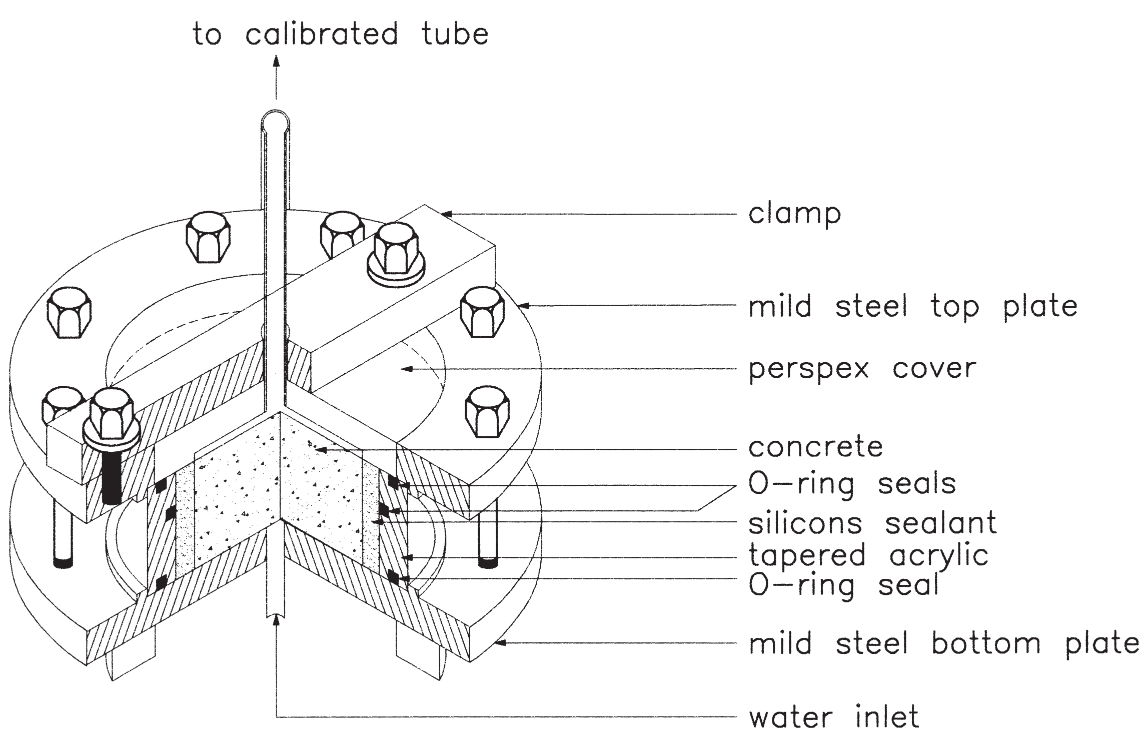

Fig. 2. Water permeability test rig.

Table 3
Water permeability coefficient

Type of specimens	Temperature (°C)	Water permeability coefficient ($\times 10^{-11}$m/s) 14 days	28 days	56 days
NPC, WD	20	7.1	6.5	5.7
	35	6.8	6.1	6.1
	50	7.1	6.2	5.1
	75	6.8	6.1	5.4
NPC, WWD	20	7.8	7.2	6.2
	35	7.2	6.9	5.8
	50	7.5	7.1	5.5
	75	7.6	7.2	5.6
NPC, DD	20	7.6	7.1	6.8
	35	7.5	7.3	6.4
	50	7.4	7.2	6.4
	75	7.3	7.7	6.8
SF, WD	20	5.4	5.7	4.8
	35	5.6	5.8	4.5
	50	5.5	5.2	4.2
	75	4.6	4.7	3.9
SF, WWD	20	6.0	6.2	5.9
	35	6.2	6.2	6.1
	50	5.3	5.2	5.4
	75	4.8	5.1	4.2
SF, DD	20	6.8	6.7	6.7
	35	7.0	6.4	6.5
	50	6.4	5.8	4.8
	75	7.1	5.3	4.4

sulting from thermal stresses occurred during drying at 105°C. Under these conditions, the presence of microcracks on the surface area and at the transition zone of the specimens could have a major influence on the results of the NPC 100 specimens.

As observed from Table 3, the silica fume mortar under WD curing showed the lowest water permeability. The difference between the results for WD curing and WWD curing is small, while the results of DD curing show that the mortar is more permeable for the specimens that are cured with DD method. The results indicate that the silica fume mortar under DD method suffers from poor curing and gives no protection against evaporation. According to the test results, the water permeability of NPC 100 practically increased as temperature increased. However, water permeability of silica fume mortar had a tendency to decrease as the temperature increased. The lowest water permeability of all specimens was observed at the age of 56 days under WD curing. This indicates that the high pozzolanic reactivity and microfiller effect of silica fume at medium temperature have modified the open channels at transition zone in silica fume mortar, making it denser and stronger and leading to a fine and discontinuous pore structure [9]. Similar to the results of compressive strength, the water permeability of silica fume mortar under medium temperature environments can be improved with a sufficient curing method, such as covering with sheet and spraying with water at the early age.

3. Conclusions

The silica fume mortar produced low water permeability rate under the temperatures of 50 and 75°C. It can be concluded that the high pozzolanic reactivity and microfiller effect of silica fume at medium temperature have modified the open channels at transition zone in SF mortar, making it much denser and stronger and led to a fine and discontinuous pore structure.

References

[1] ACI Committee 305 Report, Hot weather concreting, ACI Materials J 88 (1991) 417–436.
[2] ACI Committee 201 Report, Proposed revision of guide to durable concrete, ACI Materials J 88 (1991) 544–582.
[3] ACI Committee 226 Report, Silica fume in concrete, ACI Materials J 84 (1987) 158–166.
[4] P.B. Bamforth, The relationship between permeability coefficients for concrete obtained using liquid and gas, Magazine of Concrete Research 39 (138) (1987) 3–11.
[5] S. Freedman, Properties of Materials for Reinforced Concrete, in: Mark Fintel (Ed.), Handbook of Concrete Engineering, Van Nostrand Reinhold Company, New York, NY, USA, 1974, pp. 172–176.
[6] D. Perraton, P.C. Aitcin, Permeability, as seen by researcher, in: Yves Malier (Ed.), High Performance Concrete: From Material to Structure, E&FN Spon, Cambridge, Great Britain, 1992.
[7] F.S. Rostasy, R. Weiss, G. Wiederman, Changes of pore structure of cement mortars due to temperature, Cem Concr Res 10 (2) (1980) 157–164. (1980)
[8] Z.P. Bazant, M.F. Kaplan, Concrete at High Temperature. Material Properties and Mathematical Models, Longman Group Limited, Essex, England, 1996.
[9] M. Fauzi, Y. Matsufuji, T. Koyama, M. Nakatake, The influence of medium and high temperature environments on the physical properties of high strength concrete, Japan Concrete Institute 16 (1) (1994) 705–710.