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Evaluation of the effect of strength, duration, water pressure and casting direction on concrete permeability

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ABSTRACT: One of the major factors which controls the serviceability life of a concrete structure is its durability. Since the durability is dependent mainly on the permeability, some standards such as BS EN 12390-8 and DIN 1048-5 are aimed for water permeability assessment of concrete. Based on these standard test methods, a constant pressure is applied to the concrete surface, perpendicular to casting direction for a specific period of time. Since the applied water pressure, test duration and the direction of casting affect the concrete permeability, 150mm concrete cubes with water/cement ratios of 0.4, 0.5 and 0.6 were prepared and at the ages of 7, 28 and 91 days (after water curing) the permeability of the cubes was investigated, using "Cylindrical chamber" method. The results show that the penetration depth and volume in the casting direction are lower than the respective values, obtained in the direction, perpendicular to casting. It was also observed that, regarding the water/cement ratio, the exponent of the power function used to approximate the relation of penetration depth and volume with pressure, is approximately constant at a specific age and testing direction. This issue wasn't observed when approximating the relation of penetration depth and volume with test duration, using the power function. A linear relationship between the penetration depth and the penetration volume was also observed.

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1-INTRODUCTION

Water permeability of concrete, can be measured as a factor of its durability. Penetration of water containing harmful substances damages concrete through the freeze-thaw cycles, corrosion of reinforcement, chemical and physical changes. So, due to the importance of water permeability, researchers are attracted to evaluate the concrete permeability, using both laboratory and in-situ methods [1-5]. Some standard test methods exist for this purpose such as BS EN 12390-8 [6] and DIN 1048-5 [7]. Based on the instruction described in these standards, water under the pressure of 0.5 MPa is applied to the concrete surface, perpendicular to casting direction for 72 hours. As it is expected, the applied pressure, test duration and the direction of testing are important factors affecting the concrete permeability. So, the effects of the mentioned parameters on the permeability of the concrete samples with different water/cement ratios, and different curing periods are studied in this investigation, using the "Cylindrical chamber" method [8].

2-EXPERIMENTAL PROGRAMS

Cubic samples of 150×150×150 mm dimension with different water/cement ratios of 0.4, 0.5 and 0.6 were tested after 7, 28 and 91 days of curing. Water pressures of 0.1, 0.25, 0.5, 0.75 and 0.95 MPa with the test durations of 0.5, 1.5, 2.5 and 3.5 hours were used for this purpose. The "Cylindrical chamber" apparatus used for permeability measurements is shown in Figure 1. The apparatus is attached to the concrete surface using epoxy adhesive and the cylindrical chamber is filled with water. By turning the pressure handle, pressure is set to the desired value and the micrometer is read. During the testing process, the reduction in the height of the water inside the cylindrical chamber, the volume of the penetrated water is calculated. Having completed the test, the concrete sample is split into halves and the penetration depth is measured.

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3-RESULTS AND DISCUSSIONS

The ratio of the water volume, penetrated at the casting direction, to the respective values, obtained thorough the direction, perpendicular to casting, is shown in Figure 2. It is observed from this figure that the penetration volume ratios are smaller than 1. This means that the permeability in casting direction is lower than that of the direction perpendicular to casting. This can be due to the better compaction of the concrete layers due to their weights which results in less interconnected pores in casting direction. According to the results obtained during these experiments, the same trend tends to exist for the penetration depth ratio. The average penetration depth ratio is calculated 0.81.

The relation between the penetration volume (or depth) and the pressure at a specific test duration and direction is

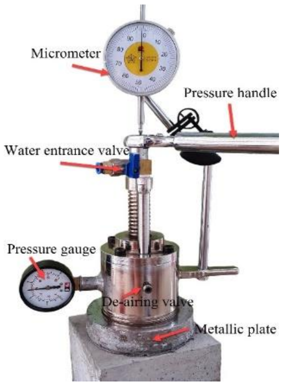

Fig. 1. "Cylindrical chamber" apparatus.

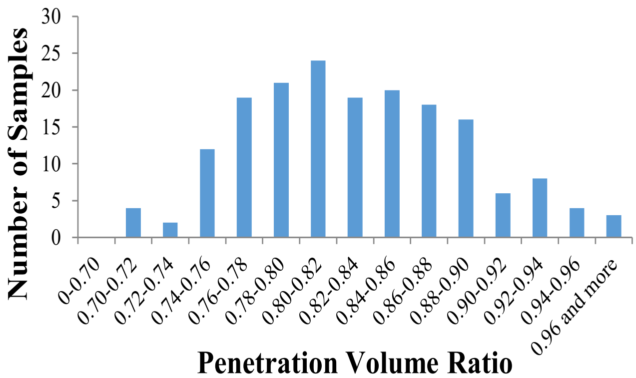

Fig. 2. Penetration volume ratio.

Table 1. The exponents n and m obtained from power function to predict the penetration volume-pressure ($V=a.P^n$) and penetration depth-pressure relation ($d=b.P^m$)

Casting direction		W/C=0.4				W/C=0.5				W/C=0.6			
Time (hours)		0.5	1.5	2.5	3.5	0.5	1.5	2.5	3.5	0.5	1.5	2.5	3.5
7 days	n	0.5064	0.5113	0.5103	0.4909	0.5034	0.5018	0.5087	0.4907	0.4954	0.5021	0.5056	0.4876
	m	0.4333	0.4244	0.4221	0.4247	0.4250	0.4285	0.4018	0.4006	0.4181	0.4125	0.3987	0.4247
28 days	n	0.4768	0.4732	0.4823	0.4795	0.4684	0.4748	0.4799	0.4728	0.4590	0.4572	0.4853	0.4631
	m	0.3848	0.3967	0.3774	0.3646	0.3577	0.3951	0.3996	0.3852	0.3557	0.3826	0.3624	0.3755
91 days	n	0.4271	0.4136	0.4206	0.4184	0.3979	0.4152	0.4126	0.4255	0.4246	0.4007	0.4162	0.4290
	m	0.3141	0.3386	0.3084	0.3130	0.3294	0.3278	0.3129	0.3080	0.3387	0.3306	0.3390	0.3187
Perpendicular to casting		**W/C=0.4**				**W/C=0.5**				**W/C=0.6**			
7 days	n	0.5531	0.5452	0.5646	0.5585	0.5420	0.5682	0.5648	0.5397	0.5630	0.5511	0.5292	0.5918
	m	0.4722	0.4602	0.4702	0.4654	0.4511	0.4638	0.4661	0.4712	0.4643	0.4542	0.4475	0.4217
28 days	n	0.5123	0.5246	0.5208	0.5145	0.5174	0.5228	0.5378	0.5274	0.5307	0.5369	0.5174	0.5283
	m	0.3812	0.4093	0.4088	0.3890	0.4118	0.4182	0.3998	0.4025	0.3804	0.4070	0.3874	0.3956
91 days	n	0.4544	0.4763	0.4559	0.4697	0.4424	0.4537	0.4449	0.4578	0.4661	0.4735	0.4692	0.4659
	m	0.3386	0.3033	0.3158	0.3056	0.2942	0.3107	0.3090	0.3131	0.3096	0.3179	0.3045	0.2941

evaluated using power function. The obtained exponents from the power function are summarized in Table 1.

From Table 1, it is observed that regarding the water/cement ratio, the exponent of the power function is approximately constant for the samples of a specific age and testing direction. It is seen that, the obtained exponent changes, when the testing direction or the age of the sample is different. It is also observed that the exponent obtained for casting direction at a specific age and older samples is lower than that of the direction perpendicular to casting and younger samples, due to the lower permeability. The same trend is seen for the penetration depth.

The same procedure was carried out to approximate the relation between penetration volume (or depth) and test duration at a specific pressure test and direction. For example, the relation between the penetration depth and test duration for the samples cured for 28 days and an applied water pressure of 0.15 MPa in casting direction is shown in Figure 3. From Fig.3, it is seen that although there is a strong relation between the penetration depth and the test duration using the power function, but the calculated exponent changes randomly. Factors such as connectivity of the pores, deformation of the pores due to the applied water pressure and the change of the water transport mechanism in the pores which are saturated compared to the dried pores which absorbs more water are the probable reasons for this issue.

The relation between the penetration depth and volume is evaluated using a regression approach and shown in Figure 4. From this figure, it is seen that there is a linear relation between the penetration volume and the water penetration depth. The calculated coefficient of determination (equal to 0.9651) shows a strong relation between the two parameters.

4-CONCLUSIONS

The "Cylindrical chamber" method was employed for measuring the water permeability of concrete samples with different water/cement ratios. The penetration of water in the direction of casting and in the direction of perpendicular

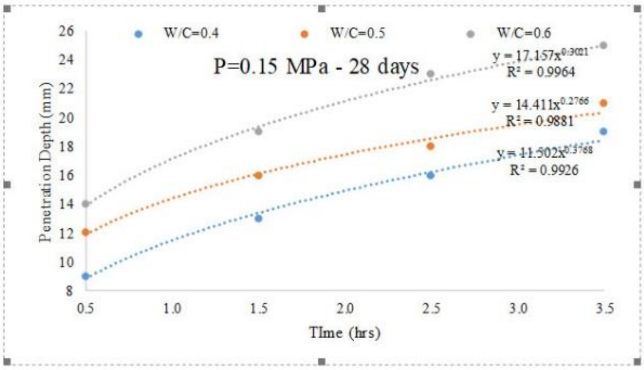

Fig. 3. The relation between penetration depth and test duration for an applied pressure of 0.15 MPa in casting direction after 28 days of curing.

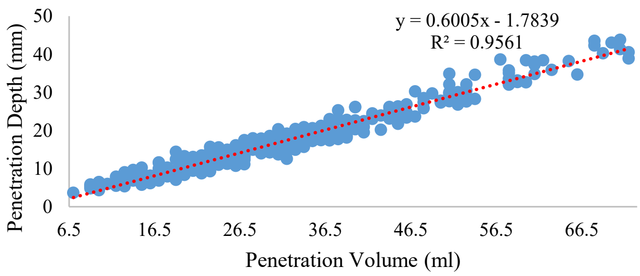

Fig. 4. The relation between penetration depth and penetration volume.

to the casting direction, under different water pressure and the testing duration were among the parameters that were studied during these investigations. It is concluded that the permeability in casting direction is lower than that of the direction perpendicular to casting. It was also observed that the relation between penetration volume (or depth) with the applied water pressure and the test duration can be estimated using power function. The exponent of the penetration volume (or depth)-pressure relation is approximately constant for a specific testing direction and age of the sample. The exponent obtained to estimate this relation in casting direction is lower than that of the perpendicular to casting direction. This issue wasn't seen for penetrated water volume (or depth)-test duration relation. It was also seen that the obtained exponent changed randomly depending on the testing direction, water pressure magnitude and the age of the sample. A linear relation between the penetration volume and the penetration depth was also seen to exist between relative measured values.

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