Permeability of Concrete: A Study Intended for the "in situ" Valuation Using Portable Instruments and Traditional Techniques

Abdias Magalhães Gomes, Dr. Prof. Universidade Federal de Minas Gerais, Brazil.
Juliana Oliveira Costa, Universidade Federal de Minas Gerais, Brazil.
Horácio Albertini, Msc. Politécnico di Milano, Italy
José Eduardo Aguiar, Civil Engineer , Brazil

Abstract

Evaluate the permeability shown by an existing concrete in a structure is an essential and important step for the definition of its durability, performance and lifetime. Thus, such investigation presents a proposal of standards for concrete analysis trough permeability with under pressure water (defined as 0,40 BAR) using a "in situ" permeabilimeter equipment made by Germann Instruments. The considered standard signals for the classification of concrete in high, average and low permeability. From the presented results it was possible to present correlation curves with compressive strength, age and characteristic strength compression versus the passing water flow trough it.

Keywords:
permeability, ultrasound, concrete, durability

1. Introduction

Found on several ways, the water is the most important fluid on nature. Among its properties, is noticeable the capacity to penetrate in small pores or cracks, and the capacity of dissolve a large amount of substances.

Several researches refer and attest the great importance of the water molecule on the concrete structure, especially on the first ages, caused by the cement hydration and consequent hardness of the concrete. However, the presence of water after the hardness of the concrete and after the reduction, or the ceasing of the hydration reactions, may cause the deterioration of the concrete or of the steel bar present on the structure. The water take action as a direct agent (lixiviation) or transporting noxious substances, such as chloride ions, sulfate ions and acid, or components that can activate and propel many chemical reactions that speed up the degradation process of the matrix, proportioning this way a substantial reduction of the durability and the use life of the concrete and reinforced concrete structures.

Some authors emphasize that the permeability of the water is the most important factor to esteem the durability under the most diverse conditions of service of a structure. The permeability regulates the speed of aggressive water penetration for inside of the concrete besides controlling the movement of the water during the ice-thaw process. Therefore concrete must be projected and manufactured for the environment to which it goes to be displayed, because the permeability is related to the porosity that varies in accordance to the composition of the concrete, its factor water cement, its age and even though with its form of launching. In this paper, will be evaluated permeability and the compressive strength of the concrete with different compositions, water cement factor and ages, making possible to generate correlation curves, suggesting a standard of reference and analysis of the permeability in function of some variable of the concrete.

2. Equipments

The equipment used in this tests is named Germanns Water permeability Test (GWT) made by Germann Instruments A/S. According to the Instruction and Maintenance Manual, the GWT can be used for tasting of micro cracking and porosities of the concrete surface, the "skin-concrete", on-site. Also, the test system is applied for testing of joints and the integrity of waterproofing membrane by performing testing before and after membrane is applied. In Figure 1 is show the equipament GWT.

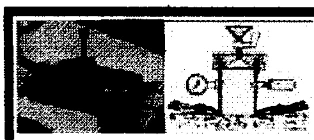


Fig 1: The equipment GWT.

With the GWT a sealed pressure chamber is attached to the concrete surface, water is filled into the pressure chamber and a specified water pressure is applied to the surface. The pressure may be kept constant using a micro-meter gauge with attached pin that reaches into the chamber. The testing may be made on vertical or horizontal faces. The result obtained, in most cases, represent a combination of the influence of three factors - surface porosity, water permeability and absorption. In each case, the test results are evaluated separately after planning of test conditions depending on the purpose of the testing.

The flux "q", may be calculed from the equation:

$$q = \frac{B.(g_1 - g_2)}{At} = \frac{78{,}6(g_1 - g_2)}{3018t} = \frac{0{,}026(g_1 - g_2)}{t} \quad \text{(mm/sec)}$$

Where "B" is the area of the micro-meter pin being pressed into the chamber water, 78.6 mm^2 for 10 mm pin diameter. "A" is the water pressure surface area, 3018 mm^2 (diameter 62 mm), g_1 and g_2 the micrometer gauge readings in mm before and after the test has been performed and "t" the time the test is performed over in seconds.

The surface permeability may be assessed by means of d'Arcys law:

$$K_{cp} = \frac{q}{(b.(\Delta P / L))} \quad \text{(mm/sec)}$$

In this case, "K_{cp}" is the concrete permeability coefficient, "q" is the flux, "b" is the percentage of the concrete cement matrix (assuming the aggregates are impermeable), "ΔP" is the pressure selected and "L" is the length the pressure is applied over (15 mm, equal to the thickness of the pressure gasket).

This calculation is based on the presumption that the water will flow parallel to the gasket, from the compression chamber to the outside. If the concrete is rather porous, this assumption may not be valid. In such cases, the water will flow into the concrete, primarily, building up a more and more stable pressure until the water flows below the pressure gasket as intended.

3. Laboratory tests and Results

For the accomplishment of the assays, was determined the mainly compositions of the concrete (pumped and ordinary) used by the Brazilian constructors, tables 1 and 2. These compositions use a cement, called CPII E 32, blast furnace slag and lime stone sand, lime stone aggregate and plasticizing admixture MBT Rheobuilt 320.

Pumped Concrete						
	9 MPa	**15 MPa**	**18 MPa**	**20 MPa**	**25 MPa**	**30 MPa**
Slag (kg)	45.0	82.0	89.0	88.0	99.0	119.0
Cement (kg)	133.0	151.0	166.0	179.0	200.0	243.0

Lime stone sand (kg)	324.0	307.0	300.0	295.0	285.0	266.0
Sand (kg)	603.0	570.0	556.0	549.0	530.0	494.0
Aggregate 1* (kg)	153.0	153.0	154.0	154.0	154.0	155.0
Aggregate 2* (kg)	866.0	870.0	871.0	873.0	875.0	876.0
Water/cement factor	1.0	0.8	0.7	0.68	0.6	0.7
Admixture (ml)	1068.0	1398.0	1530.0	1602.0	1794.0	2172.0

Table 1: Pumped concrete composition.

* Aggregate 1: lime stone diameter 9.5 mm. Aggregate 2: lime stone, diameter 19mm

Ordinary and traditional concrete						
	9 MPa	**15 MPa**	**18 MPa**	**20 MPa**	**25 MPa**	**30 MPa**
Slag (kg)	42.0	72.0	79.0	83.0	92.0	112.0
Cement (kg)	125.0	146.0	159.0	167.0	187.0	226.0
Lime stone sand (kg)	311.0	295.0	289.0	285.0	275.0	257.0
Sand (kg)	579.0	549.0	536.0	526.0	512.0	476.0
Aggregate 1* (kg)	276.0	277.0	277.0	278.0	278.0	279.0
Aggregate 2* (kg)	826.0	829.0	831.0	832.0	834.0	837.0
Water/cement factor	1.0	0.8	0.7	0.68	0.6	0.5
Admixture (ml)	1002.0	1398.0	1428.0	1500.0	1674.0	2028.0

Table 2: Ordinary concrete composition.

* Aggregate 1: lime stone diameter 9.5 mm. Aggregate 2: lime stone, diameter 19mm

The compressive strength and water flow tests were realized at the age of 3, 7 and 28 days. The results of the assays with permeabilimeter are presented in table 3. The number of readings is a function of the velocity of the water flow into the concrete, this way sometimes its impossible to achieve the standard pressure stability of 0.40 BAR.

Sample	**Reading number**	**Time Period (min)**	**Micrometer Reading (mm)**	**Flow "q" (mm/s)**
Pumped Concrete 15 MPa 28 days	0	0.00	0.00	-
	1	0.50	0.59	5.12×10^{-4}
	2	1.00	1.19	5.21×10^{-4}
	3	1.50	1.42	2.00×10^{-4}
	4	2.00	1.49	6.08×10^{-5}
	5	2.50	1.65	1.39×10^{-4}
	6	3.00	1.80	1.30×10^{-4}
	7	3.50	1.90	8.68×10^{-5}
	8	4.00	2.15	2.17×10^{-4}
	9	4.50	2.25	8.68×10^{-5}
	10	5.00	2.30	4.34×10^{-5}
	11	5.50	2.48	1.56×10^{-4}
	12	6	2.60	1.04×10^{-4}

	Flow average =	1.88×10^{-4}
	Standard deviation =	1.55×10^{-4}

Table 3: Example permeabilimeter test lab results equal the results of concrete 15 MPa in age 28 days.

The average values of compression resistance and water flow in the samples are summary present in tables 4 and 5.

Ordinary concrete						
	Compressive Strength (MPa)			**Water flow (mm/s)**		
Resist / Age	3 days	7 days	28 days	3 days	7 days	28 days
9 MPa	2.03	5.86	12.98	4.11×10^{-3}	3.61×10^{-3}	2.00×10^{-3}
15 MPa	6.11	10.18	16.55	7.42×10^{-4}	5.14×10^{-4}	1.20×10^{-4}
18 MPa	4.83	10.44	19.22	0.42×10^{-4}	0.20×10^{-4}	0.05×10^{-4}
20 MPa	6.74	11.16	22.86	0.20×10^{-4}	0.12×10^{-4}	0.021×10^{-4}
25 MPa	8.53	20.37	29.92	6.10×10^{-5}	0.43×10^{-5}	0.041×10^{-5}
30 MPa	9.24	15.28	32.94	4.01×10^{-5}	0.043×10^{-5}	0.004×10^{-5}

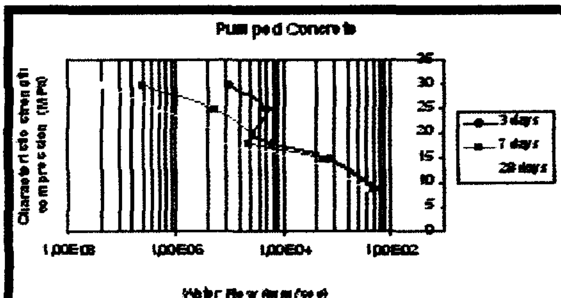
Table 4: Ordinary concrete test results.

Pumped Concrete						
	Compressive Strength (MPa)			**Water flow (mm/s)**		
Resist / Age	3 days	7 days	28 days	3 days	7 days	28 days
9 MPa	1.94	5.12	12.01	5.10×10^{-3}	4.71×10^{-3}	3.10×10^{-3}
15 MPa	3.94	9.54	17.54	7.07×10^{-4}	5.66×10^{-4}	1.88×10^{-4}
18 MPa	6.01	13.49	25.72	0.62×10^{-4}	0.22×10^{-4}	0.061×10^{-4}
20 MPa	6.74	12.98	24.12	0.27×10^{-4}	0.27×10^{-4}	0.064×10^{-4}
25 MPa	5.84	13.94	31.54	4.98×10^{-5}	0.53×10^{-5}	0.043×10^{-5}
30 MPa	12.95	24.96	33.29	1.00×10^{-5}	0.024×10^{-5}	0.0043×10^{-5}

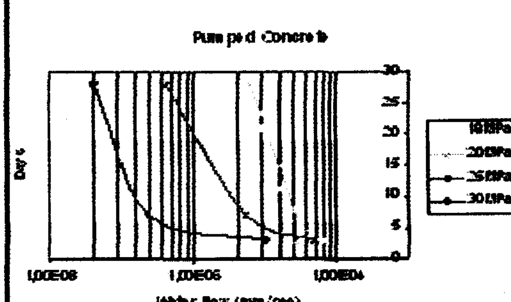
Table 5: Pumped concrete test results.

4. Discussion of the results

From the results of the tests were done some graphics that demonstrate the behavior tendency of the permeability of the concrete in function of compressive strength, age and characteristic strength compression. The graphics are presented for pumped concrete and ordinary concrete, graphics 1, 2, 3, 4, 5 and 6.



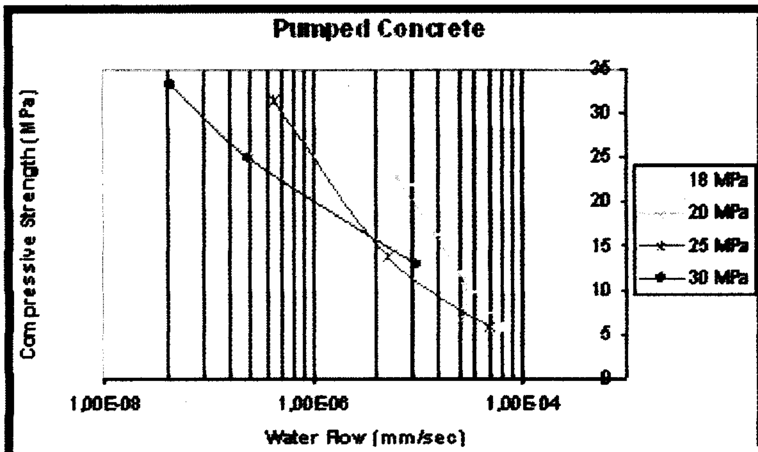
Graphic 1: Characteristic Strength Compression versus water flow for



Graphic 2: Days versus water flow

pumped concrete.	for pumped concrete.

According to the tendency curve of the graphic 3, some behavior equations are present for each curve (Table 6). The equations choice was made by the R^2 function (next to 1)

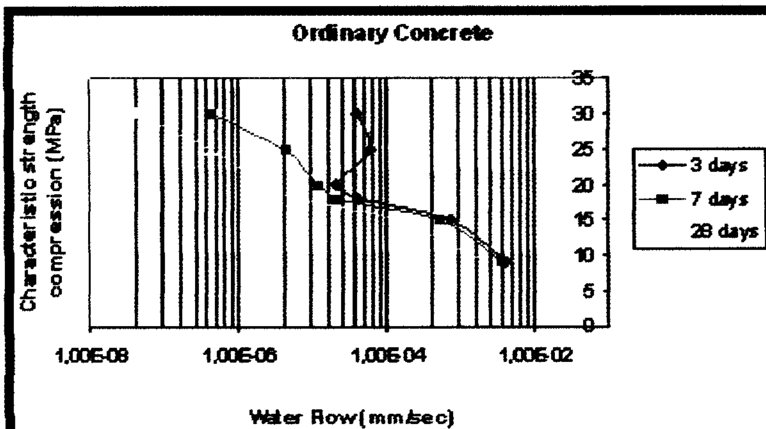


Graphic 3: Compressive strength versus water flow for pumped concrete.

Curve	Equation	R^2
30 MPa	$fck = 1.7565\ q^{-0.1737}$	$R^2 = 0.9999$
25 MPa	$fck = 0.1792\ q^{-0.3543}$	$R^2 = 0.9974$
20 MPa	$fck = -9.6628\ Ln(q) - 92.700$	$R^2 = 0.9296$
18 MPa	$fck = -8.5403\ Ln(q) - 77.219$	$R^2 = 0.9941$

Table 6: Equation curves of the graphic 3.

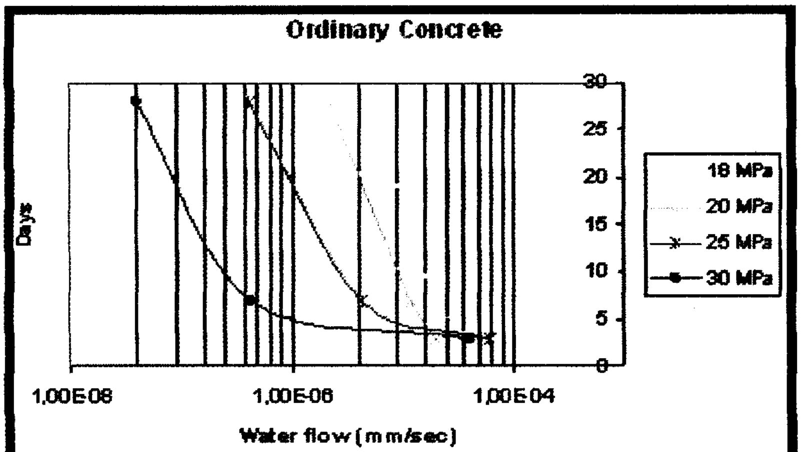
The equations of the tendency curve of the graphic 4 with the best R^2 function (approaching 1) are in table 7.



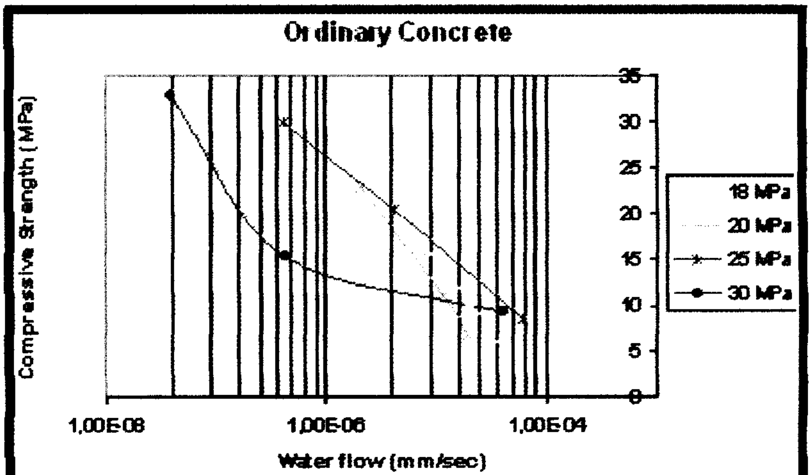
Graphic 4: Characteristic Strength Compression versus water flow for ordinary concrete.

Curve	Equation	R^2
28 dias	$fck = 5.0396\ q^{-0.1067}$	$R^2 = 0.9703$
7 dias	$fck = 4.9508\ q^{-0.1253}$	$R^2 = 0.9463$
3 dias	$fck = 3.8869\ q^{-0.1734}$	$R^2 = 0.9492$

Table 7: Equation curves of the graphic 4.



Graphic 5: Days versus water flow for ordinary concrete.



Graphic 6: Compressive strength versus water flow for ordinary concrete.

The equations of the graphic 6 are presented in table 8.

Curve	Equation	R^2
30 MPa	$fck = 1.4706\, q^{-0.1743}$	$R^2 = 0.9136$
20MPa	$fck = -7.0397\, Ln(q) - 69.068$	$R^2 = 0.9974$
18 MPa	$fck = -6.7069\, Ln(q) - 62.511$	$R^2 = 0.9993$
25 MPa	$fck = -4.2799\, Ln(q) - 32.849$	$R^2 = 0.9979$

Table 8: Equation curves of the graphic 6.

5. Conclusion

From the tests results was possible to observe that:

1. The passing water flow under pressure, expressed in mm/s, and the compressive strength of the concrete can be correlated through proper equations, where of the R^2 factor is a value superior than 0,90, indicating a good correlation adjusted between the curve and the standard curve referred ;
2. The tables 4 and 5 indicates the variation of the passing water flow under pressure and the characteristic resistance of the concrete (f_{ck}) in three different ages, in function of the concrete being pumped or

conventional, demonstrating that the older concretes has a lower water flow values. It also indicated that more resistant concretes, with a f_{ck} approaching 30 MPa, present lower flows and the best tendency curve for this event is $f_{ck} = 5{,}0396\ q^{-0{,}1067}$, where "q" is the passing water flow (mm/sec). To estimate the water flow, having the compressive strength, can be use the equation
$q = 2 \times 10^6 f_{ck}^{-9{,}0987}$, where the f_{ck} is expressed im MPa;

3. The evaluation of the permeability of a concrete from a "in situ" test using the GWT equipment showed to be trustable and possible of being used in laboratory and works field, esteeming an important variable on the evaluation of the concrete durability and useful life of the existing concretes in the structures or to be used in the constructions;
4. According to the results presented and based in previous experience of use of this type of equipment, it is suggested that the concrete usually found in the structures can be classified in four groups, in function of the passing water flow registered in the GWT equipment and having a standardized pressure of 0,40 BAR, such as presented in Table 9.

0 e 1,0 x 10^{-3} mm/sec (high permeability concrete)
1,0 x 10^{-3} e 1,0 x 10^{-4} mm/sec (average permeability concrete)
1,0 x 10^{-5} e 1,0 x 10^{-6} mm/sec (low permeability concrete)
1,0 x 10^{-6} e 1,0 x 10^{-7} mm/sec (high impermeability concrete)
1,0 x 10^{-7} e 1,0 x 10^{-9} mm/sec (higher impermeability concrete)

Table 9: Standard classification of the concretes according to the permeability test using the GWT equipment and based on the passing water flow.

Finally, it is worth to remember that the studies involving GWT equipment are still in progress and the objective is to provide parameters and standards for the evaluation of the concrete durability.

6. Bibliograph References

1. Sebe, Jamil. **Estudo da Permeabilidade à água do concreto de alto desempenho.** Tese de Doutorado. Curso de Pós-graduação, DEES, UFMG, Brasil 1998
2. Souza Coutinho, **Fabrico e Propriedades do Betão,** Publicações LNEC, Portugal, 1990
3. **Instruction and Maintenance Manual of GWT,** German Instruments, Dinamarca, 1993
4. Paulo Monteiro E Mehta. **Propriedades do concreto.** Editora Pini, Brasil, 1988