American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-5, Issue-8, pp-120-127
www.ajer.org
Research Paper Open Access

Effect of Water to Cement Ratio and Age on Portland Composite Cement Mortar Porosity, Strength and Evaporation Rate

Enamur R. Latifee[1], Debasish Sen[2] and Md Rashedul Kabir[2]

[1]*Associate Professor, Department of Civil Engineering, Ahsanullah University of science and Technology, Dhaka1208, Bangladesh*

[2]*Lecturer, Department of Civil Engineering, Ahsanullah University of science and Technology, Dhaka1208, Bangladesh*

ABSTRACT: *Durability and the compressive strength of concrete are directly related to the porosity. Water to cement ratio is the main parameter behind the nature and amount of pores within the matrix. Porosity is also influenced by the degree of cement hydration and the length of moist-curing. Even after the standard moist curing period, i.e. 28 days the concrete can gain strength and porosity can be reduced under ambient relative humidity and temperature. However, this fact, that is the age effect on porosity reduction of the cement mortar or concrete, kept in air with ambient relative humidity and temperature for long duration could not be found in the literature. Therefore, in this research, different w/c were used with constant amount Portland Composite Cement to find out whether the mortar porosity decreases significantly over time, after 28 days of water curing, while kept in air and if there is any interaction effect between the age of the mortar and different w/c; regarding porosity. It was also intended to find out if water-loss rate variation with different w/c has similar trend as porosity variation with different w/c. It was found that, there is significant decrease in porosity with time for the first six weeks in air and after that it dwindles down gradually, and there is no interaction between age and w/c. Also, after 100 days in air, samples were submerged under water for 24 hours and then kept in air for the evaporation in subsequent days. It has been found that the water evaporation vs. w/c curve, using 11-day evaporation of water from different w/c specimens in ambient condition is almost parallel to porosity vs. w/c curve. Therefore, 11-day evaporation of aged saturated mortar or concrete sample, such as core can also be used as a durability index, which can be used for old structure evaluation.*

Keywords*: Cement, evaporation, hydration, mortar, porosity.*

I. INTRODUCTION

Concrete durability is directly related to permeability along with cement content, compaction and curing. Permeability is a function of pores inside. It is affected by the percentage of porosity, size distribution and the continuity of pores [1]. Concrete strength, durability, and volume stability is greatly influenced by voids in the hydrated cement paste (HCP). Therefore, porosity, i.e., ratio of voids volume to total volume, greatly influences concrete properties. Also porosity is considered as durability index [2, 3] of building material. In RCC, deteriorating agents i.e. chloride ions, carbon dioxide penetrate to corrode steel through the pores [4-6]. So the lower its permeability, the greater is its potential for durability.

The empty space (porosity) is influenced mainly by the water to cement ratio [6-8]. The products of hydration do not form a solid mass. Rather, their physical appearance is more like steel wool with a lot of empty space between the crystals. Within this mass lie both hydrated and unhydrated cement [9]. Also within this mass water is present which is known as physically bonded (gel water). The physically bonded water exists in the spaces between hydrated cement crystals.

The amount of gel water adsorbed onto the expanding surface of the hydration products is known as physically bound water, or Gel water. Gel water is typically present in all concrete in service, even under dry ambient conditions, as its removal at atmospheric pressure requires heating the hardened cement paste to 105^{o} C. The water consumed in the formation of the gel products is known as the chemically bound water, or hydrated water. The evaporable water describes water held in capillary and gel pores. This amount can be determined by oven drying a sample.

Here, the permeability of the paste is important because the paste envelopes all constituents in the concrete. The main influential factor behind the formation of pores is the water content in the mixture. Therefore, paste permeability i.e. continuity of pores, is directly related to water-cement (w/c) ratio [10] and the degree of cement hydration or length of moist-curing. Longer curing times and lower water cement ratios resulted in lower porosity values [11].

Many researchers already studied the strength and the related porosity as well as the physical, mechanical properties of the mortar in a large scale.

Kim et al. [12] studied how water cement ratio affects the durability as well as porosity of the cement mortar with constant cement amount. This investigation had the conclusion that the increase of w/c ratio from 0.45 to 0.60 results in the increase of water loss, porosity, chloride diffusion coefficient, air permeability, moisture sorptivity, and moisture diffusion coefficient etc.

Nwofor [13] investigated the effect of varying w/c ratios (i.e. 0.5, 0.6 and 0.7) of mortar joint on durability of block work. This study came to a recommendation that w/c ratio for building masonry on site should be 0.5 or 0.6 considering the compressive strength.

Shamsai et al. [14] inspected the effect of w/c ratio on abrasive strength, porosity and permeability of Nano-silica concrete. They concluded that less water-cement ratio in Nano-silica concrete results the increase of the abrasive strength but decrease of the conductivity coefficient and the porosity.

In this research, different w/c - 0.275, 0.4, 0.485, 0.55, 0.6, 0.65, 0.7, 0.75, and 0.8 were used with the European standard CEM II Portland Composite Cement which is the most widely used cement in Bangladesh. The investigation was aimed at finding out whether the mortar porosity decreases significantly over the time, after standard 28 days of water curing, while it is kept in air to simulate the actual environment. If the porosity decreases over time then durability will be increased.

Also the aim was to analyze the nature of porosity reduction with different water to cement ratios and if there was any relationship between w/c to porosity reduction rate. Also it was intended to see if the age after curing has interaction effect with different w/c regarding porosity.

II. MATERIALS

2.1 Cement

In this study, a commercially available Portland composite cement (CEM II) was used. The composition of the cement used in this experiment is given below (**TABLE I**).

2.2 Sand

The fine aggregate used in this experiment was river sand known as "Sylhet sand" with 2.36 mm maximum size. The physical properties of the sand are given in the following table (**TABLE II**) and the gradation is shown in the **Fig. 1**.

III. EXPERIMENTAL PROGRAM

3.1 Sampling

The 2 x 2 x 2 inches mortar cubes were prepared for the following water-cement ratios- 0.275, 0.40, 0.485, 0.55, 0.6, 0.65, 0.7, 0.75, and 0.8. Water reducer was used for water-cement ratio 0.4 and less. For w/c of 0.275, super plasticizer Euro Flow SP 72 (dosage- 0.9L per 50 Kg of cement) and for w/c of 0.4, plasticizer Euro Flow P 71 (dosage- 0.45L per 50 Kg of cement) were used. Test specimens were prepared at laboratory temperature (23°C) according to ASTM C 109 and subjected to lime water curing for 28 days.

3.2 Porosity Measurement

To measure open porosity the method of liquid absorption has been used which is reliable and effective [15, 16]. On 28th day, saturated surface dry (SSD) weight and weight under water of the samples were taken and transferred to a standard oven. Samples were kept in oven at 110°C for 24 hrs and oven dry weights of the samples were taken. Two samples were crushed in SSD condition to get the compressive strength according to the ASTM C109 specification.

After taking the oven dry weight, one sample was kept in air at laboratory temperature and relative humidity.

The samples were subjected to natural environment after standard 28 days of water curing, with the intention that these will be in equilibrium with the ambient relative humidity and temperature as with the case in the real concrete structure. In this study average ambient relative humidity and temperature were 63% and 26° C respectively. After certain days in air, in this case, 42 and 72 days in air (70 days and 100 days of age from the time of mixing); the porosity was measured again to compare the porosity of different w/c at different ages. To measure the porosity at the age of 70 and 100 days, the samples were transferred to lime saturated water for 24 hrs. Then SSD weight, weight under water and oven dry weights were taken as earlier. Total amount of water permeable porosity or open porosity was measured based on the saturated surface dry (SSD); weight under water and oven dry (OD) weights of the samples. The following equation was used for open porosity calculation:

$$Porosity\ (\%) = \frac{SSD\ weight - OD\ weight}{SSD\ weight - Weight\ under\ water}\ x\ 100 \qquad (1)$$

3.3 Evaporation Rate Measurement

One sample for each w/c were transferred to water after 100 days to make saturated, which were exposed to laboratory condition. After 24 hours, SSD weights were taken. Then samples were kept at laboratory temperature and relative humidity to become air dry. Air dry weight of samples was taken at 2, 4, 6, 8, 10,11th day. Evaporation of sample at days was measured by the following equation:

Evaporation (gm) = SSD weight – Air dry weight at day. (2)

IV. RESULTS AND DISCUSSION

4.1 Porosity and w/c

Porosity increased with increased w/c as shown in **Fig. 2**. However, there is a trend. The porosity vs. w/c curve was found similar to "S" curve, within the scope of the test. The curve flattens out from 0.7 to 0.8 w/c, indicating that there is little effect w/c on porosity within this range. This was found valid for 28 day, 70 day and 100 day porosity. Also, these three, i.e., 28 day, 70 day and 100 day porosity curves are parallel; therefore there is no interaction between the age and different w/c regarding porosity, within the test parameters.

For a certain w/c ratio degree of hydration increases over the days [17] which reduce the porosity. **Fig. 3** shows the porosity vs. age graph. This again shows that for all w/c there is significant reduction of porosity from 28 day to 70 day and gradually the differences diminishes from 70 day to 100 day period. The porosity reduction rate is not linear and to further validate the point, 100 day porosities were predicted from 28 day and 70 day porosity data by linear extrapolation which does not match with the 100 day's actual measured porosity as shown in **Fig. 4**.

The decrease in porosity from 28 day to 70 day for w/c below 0.5 was about 20.5%, and for w/c greater than 0.5 was about 12.8%. This indicated that lower w/c had greater porosity reduction rate within this time frame. The reason behind the phenomenon could be the distribution of hydrated masses. As the water content is increased, the particles of unhydrated cement are pushed further apart. This reduces the ability of the cement particles to bond by connecting nodes and to the aggregate as the nodes coming out from the hydrated cement for higher w/c are at a greater distance than the lower w/c. The reduction of porosity from 70 day to 100 day varied from 1 to 2% only, indicating that the hydration reaction virtually ceased. **Fig. 5** and **Fig. 6** show the reduction rates for different w/c.

4.2 Compressive strength vs. w/c

Compressive strength of concrete and therefore cement mortar is a mainly a function of water to cement ratio. Compressive strength of concrete follows Abrams rule, i.e., decreasing strength with increasing w/c in a curved path; but for cement mortar strength, no such rule or equation could be found. For concrete, Duff Abrams in 1919 developed a rule, known as Abrams' Law. The equation from the rule is:

$$f_c = \frac{k_1}{k_2^{w/c}}\ \text{(MPa)} \qquad (3)$$

Where, w/c represents the water/cement ratio of the mix originally taken by volume, and K_1 and K_2 are empirical constants. However, from the experimental data, as shown in **Fig. 7**, the 28-day compressive strength for CEM II cement with different w/c varied non-linearly, decreasing compressive strength with increasing w/c.

4.3 Compressive strength vs. porosity

Compressive strength for cement mortars depend on the cement matrix porosity and the compressive strength decreases with increasing porosity. The relationship is not linear as shown in **Fig. 8**, but compressive strength is better correlated to porosity than w/c, comparing the R^2 values of **Fig. 7** (R^2 is 0.905 for compressive strength vs. w/c) and **Fig. 8** (R^2 is 0.963 for compressive strength vs. porosity).

Finally to show that porosity varied most in the range of w/c between 0.525 and 0.725, a special mathematical function called spline was used. Spline function was used to generate the parametric curve whose shape closely follows the sequence of the actual input, called control points. Spline functions are defined as piecewise polynomials of degree n. the pieces join in the control points or knots and fulfill continuity conditions for the function itself and the first n-1 derivatives. Thus a Spline function of degree n is a continuous function with n-1 continuous derivatives. Spline functions are considered the most successful approximating functions for practical applications, where ordinary polynomials are inadequate in many occasions.

Fig. 9 shows the porosity vs. w/c at 70 days from the measured data. **Fig. 10** shows the spline curve derived using the measured data points of the **Fig. 9**. First derivative (dy/dx) and second derivative (d^2y/dx^2) of the generated spline curve are shown in **Fig. 11** and **Fig. 12** respectively. The rate of change of porosity with respect to w/c is almost zero below w/c 0.525 and above w/c 0.725 as shown in **Fig. 12**.

Fig. 13 shows the cumulative evaporation for 2, 4, 6, 8, 10, and 11 days after 100 days for different w/c. It is evident that first four days evaporation is different than later age evaporations. The evaporation for lower w/c is less than the higher w/c for the first four days which can be related to higher porosity for high w/c.

After four days, evaporation rate becomes slow and steady because water is coming out from the inner micro structure after initial surface evaporation. The evaporation rate reaches equilibrium after 11 days. **Fig. 14** shows 100 day's porosity, 11 days' evaporation w/c curves follow similar pattern.

V. CONCLUSION

This research effectively demonstrated the fact that cement mortar porosity with CEM II cement continues to decrease, therefore, improving durability, even at ambient temperature and humidity, in this case around 26° C and 63% respectively, after removing from water curing and keeping mortar cubes in air for couple of weeks. The pozzolanic action of the CEM II cement at later age might also have contributed to generation of hydration porosity reduction.

There is also, good correlation between evaporation and porosity and these two parameters showed same response with different w/c. The conclusions from the experiment are given below.

1. After the standard 28 days curing the hydration reaction continues and as a result the porosity decrease significantly until 70 days while kept in ambient temperature and RH of 26° C and 63% respectively for 42 days. This phenomenon is more profound for lower w/c (below 0.5). But from 70 to 100 days the reduction became insignificant, which is in harmony with cement mortar and concrete strength gain due to dwindling hydration reaction.
2. The porosity is better correlated to strength than w/c within the scope this experiment.
3. The porosity varied dramatically with w/c of 0.525 to 0.725 with CEM II cement, most common cement in Bangladesh and many other countries. This may be changed with other types of cement.
4. Total evaporation from mortar cubes with different w/c after 11 days matched the curve of porosity vs. w/c and became parallel indicating that evaporation after 11 days from SSD condition can be a good parameter of porosity and durability within the scope of the test.
5. It is also worth to note that the difference in weight between 10 to 11 days are negligible, therefore the inner micro structure of the mortar samples reached in equilibrium with the ambient relative humidity (RH).
6. The initial evaporation rate does not match with the porosity, since it is more related to surface evaporation, but the 11-day total evaporation matches well with the porosity and the curves were parallel.
7. Therefore, 11-day evaporation of aged saturated mortar or concrete sample, such as core can also be used as a durability index, which can be used for old structure evaluation.

REFERENCES

[1]. S. Ahmad, A.K. Azad, and K. F. Loughlin, A study of permeability and tortuosity of concrete, 30th conference on our world in concrete and structures, 2005, 23-24.

[2]. J. H. Bungey, and S. G. Millard, Testing of Concrete in Structures (Blackie Academic & Professional, 1996).

[3]. D. Benavente, MAG del Cura, R. Fort, and S. Ordóñez, Durability estimation of porous building stones from pore structure and strength, Engineering Geology, 74(1), 2004, 113-127.

[4]. T. Ishida, K. Maekawa, and T. Kishi, Enhanced modeling of moisture equilibrium and transport in cementitious materials under arbitrary temperature and relative humidity history, Cement and Concrete Research, 37(4), 2007,565-578.

[5]. A. A. Hamami, P. Turcry, and A. Aït-Mokhtar, Influence of mix proportions on microstructure and gas permeability of cement pastes and mortars, Cement and Concrete Research, 42(2), 2012, 490-498.

[6]. D. M. Roy, P. W. Brown, D. Shi, B. E. Scheetz, and W. May, Concrete microstructure porosity and permeability, No. SHRP-C-628. 1993.

[7]. R. Kumar, and B. Bhattacharjee, Porosity, Pore size distribution and in situ strength of concrete. Cement and Concrete Research, 33(1), 2003, 155-164.

[8]. H. S. Wong, and N. R. Buenfeld, Determining the water–cement ratio, cement content, water content and degree of hydration of hardened cement paste: Method development and validation on paste samples, Cement and Concrete Research, 39 (10), 2009, 957-965.

[9]. I. Soroka, Portland cement paste and concrete (Macmillan, London, UK, 1979).

[10]. D. P. Bentz, and P. E. Stutzman, Curing, hydration, and microstructure of cement paste, ACI Materials Journal, 103 (5), 2006, 348.

[11]. R. A. Cook, and K. C. Hover, Mercury porosimetry of hardened cement pastes, Cement and Concrete Research, 29 (6), 1999, 933-943.

[12]. Y. Y. Kim, K. M. Lee, J. W. Bang, and S. J. Kwon, Effect of w/c ratio on durability and porosity in cement mortar with constant cement amount, Advances in Materials Science and Engineering, Article ID 273460, 2014.

[13]. T. C. Nwofor, Durability of block work: The effect of varying water/cement ratio of mortar joint, Advances in Applied Science Research, 3 (3), 2012, 1848-1853.

[14]. A. Shamsai, S. Peroti, K. Rahmani, and L. Rahmani, Effect of water-cement ratio on abrasive strength, porosity and permeability of nano-silica concrete, World Applied Sciences Journal, 17(8), 2012, 929-933.

[15]. S. Kolias, Investigation of the possibility of estimating concrete strength by porosity measurements, Materials and Structures, 27(5), 1994, 265-272.
[16]. J. E. Unosson, P. Cecilia, and H. Engqvist, An evaluation of methods to determine the porosity of calcium phosphate cements, Journal of Biomedical Materials Research Part B: Applied Biomaterials,103 (1), 2015, 62-71.
[17]. L. Lam, Y. L. Wong, and C. S. Poon, Degree of hydration and gel/space ratio of high-volume fly ash/cement systems, Cement and Concrete Research, 30(5), 2000, 747-756.

Figures

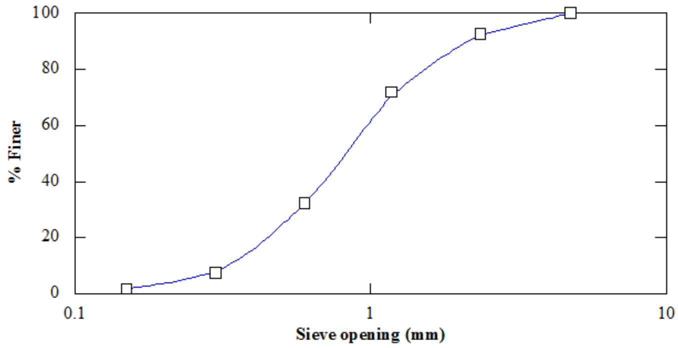

Figure 1: Gradation curve of the sand.

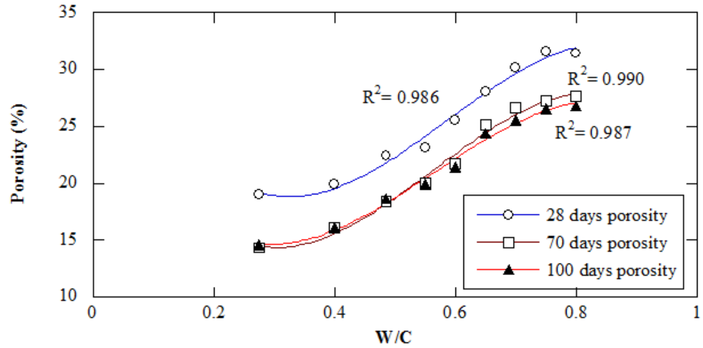

Figure 2: Different day's porosity of mortar for different water to cement ratios.

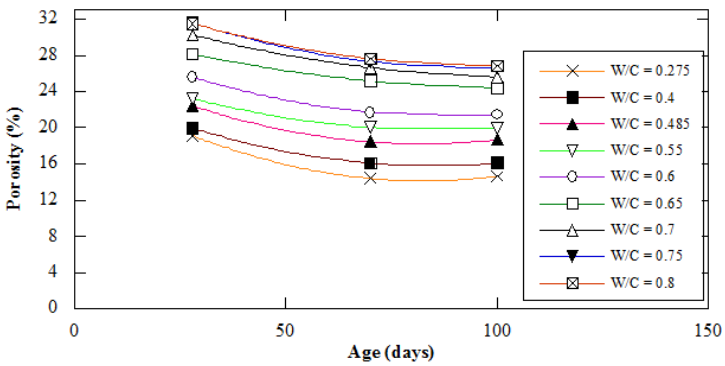

Figure 3: Porosity over days for different water to cement ratios.

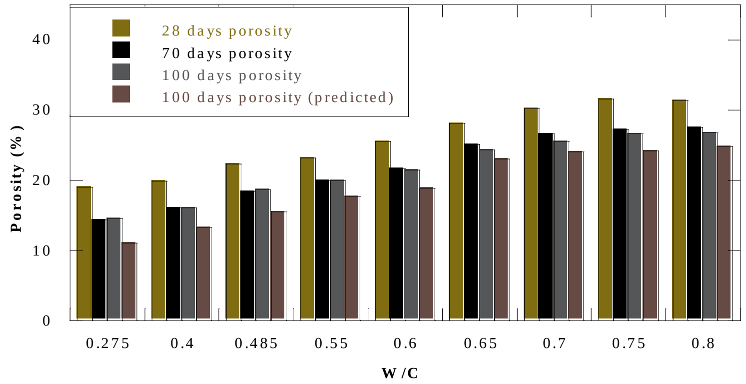

Figure 4: Chart of different day's porosity for different water to cement ratios.

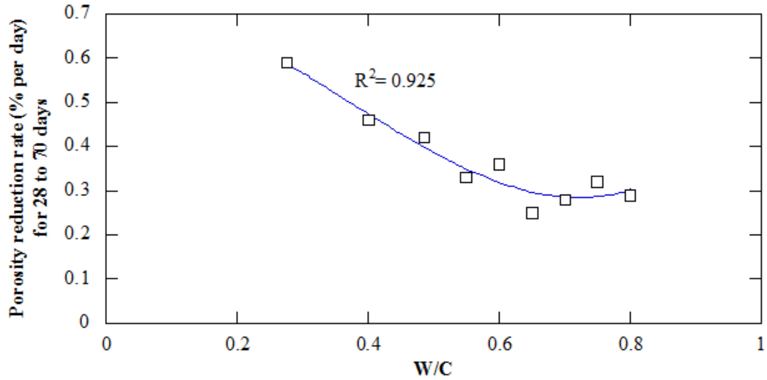

Figure 5: Porosity reduction rate of mortar during 28 to 70 days for different water to cement ratios.

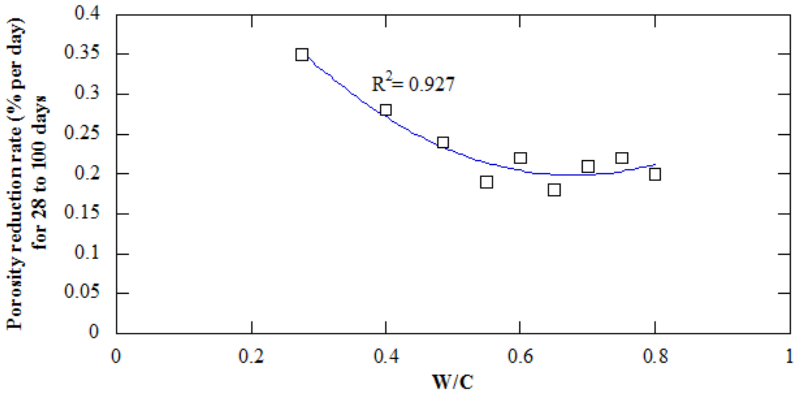

Figure 6: Porosity reduction rate of mortar during 28 to 100 days for different water to cement ratios.

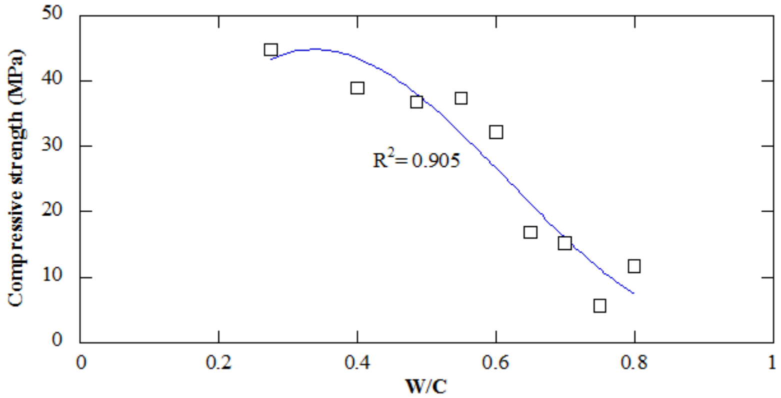

Figure 7: 28 day's compressive strength of mortar for different water to cement ratios.

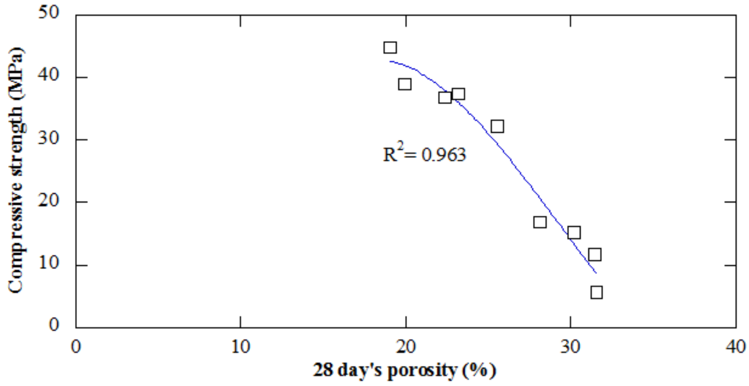

Figure 8: Correlation of 28 day's compressive strength of mortar with porosity.

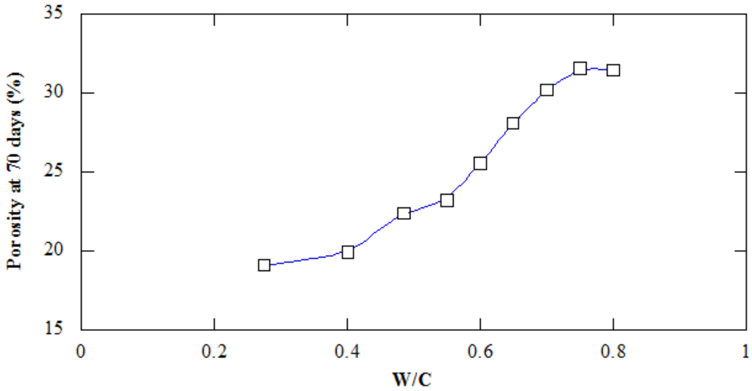

Figure 9: 70 day's porosity of mortar for different water to cement ratios (smooth curve).

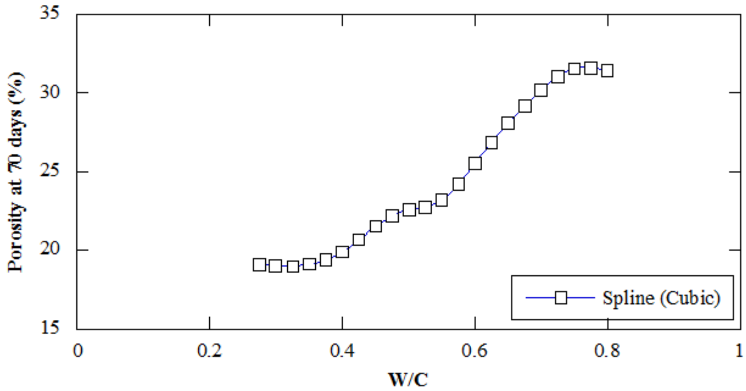

Figure 10: 70 day's porosity of mortar for different water to cement ratios (Spline curve).

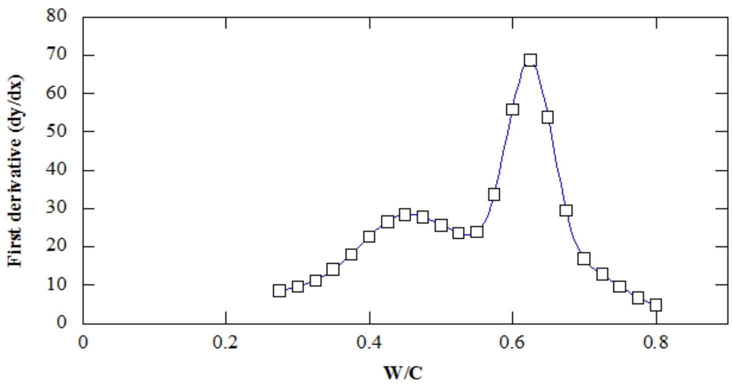

Figure 11: Gradient of 70 day's porosity of mortar versus water to cement ratios curve.

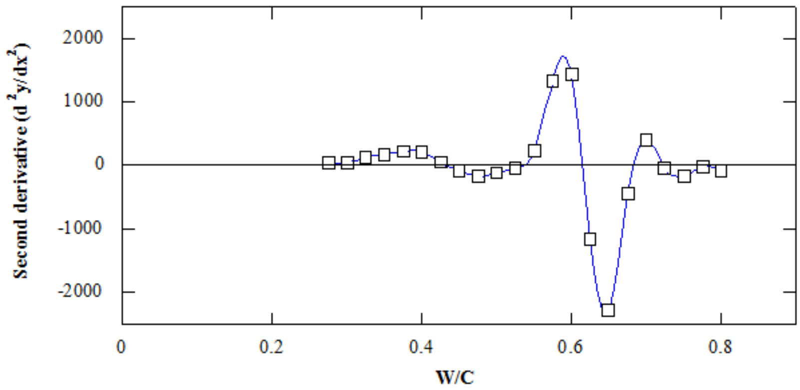

Figure 12: 2nd derivative of 70 day's porosity of mortar versus water to cement ratios curve.

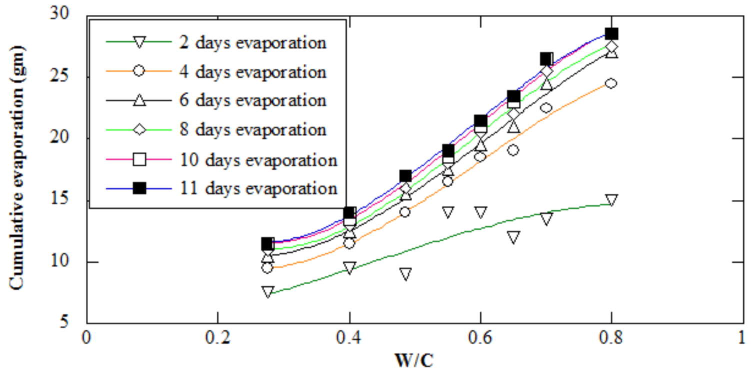

Figure 13: Different day's evaporation of mortar for different water to cement ratios

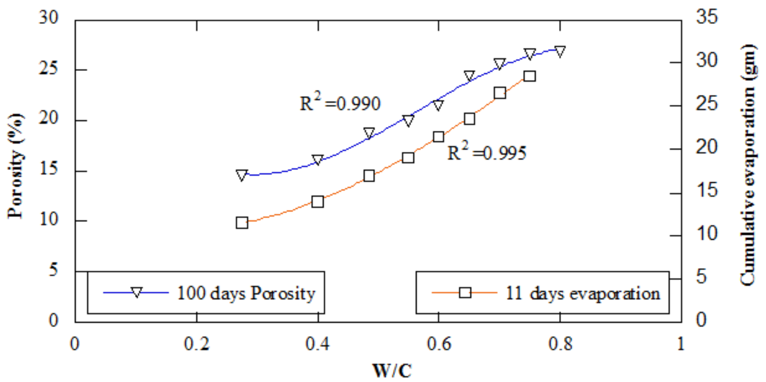

Figure 14: 100-day porosity and 11-day evaporation of mortar for different water to cement ratios.

Tables

Table I: Composition of cement

Ingredient	***Percentage***
Clinker	70-79
Gypsum	5
Fly Ash, Slag	21-30

Table II: Physical properties of sand

Physical Properties	***Specification***
Bulk Specific gravity (OD)	2.35
Absorption (%)	2.25
Fineness modulus (FM)	2.94