International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869 (O) 2454-4698 (P), Volume-5, Issue-4, August 2016

An investigation of the durability and compressive strength of air cured microconcretes containing different types of aggregates

Apostolos S. Marinos, John A. Marinos

Abstract— **This paper investigates how the type of aggregates affects the compressive strength of concrete and also its durability against chloride penetration and carbonation. Microconcretes (concrete without coarse aggregates) contained different types of sand (sand from crushed limestone, river silica sand) were produced. Water–to–cement (w/cm) ratios of 0.35, 0.4 and 0.5 were used in production of microconcretes. The durability of microconcretes against chloride penetration was tested with Rapid Chloride Permeability Test (RCPT) method. Also, the carbonation of microconcretes determined by means of phenolphthalein indicator and the compressive strength of microconcrete specimens was tested according EN 196 – 1. Tests results revealed that the types of sand (aggregate) that were used in this study affect equivalently the properties of microconcrete, like compressive strength and durability. Also it can be concluded from the test results that w/cm ratio affect critically the properties of microconcrete. Finally, from the correlation between chloride permeability results and electrical conductivity of microconcretes it can be concluded that electrical conductivity measurements can be used as a rapid and non-destructive method to estimate concrete resistance against chloride penetration.**

Index Terms—**Air Curing, Carbonation, Chlorides, Compressive Strength**

I. INTRODUCTION

Reinforced concrete is the most widely used composite material in structural practices due to ease in applications and low cost of construction. However, the service life of these structures can be affected critically by a number of environmental conditions [1]. The majority of concrete deterioration cases is connected to reinforcement corrosion due to carbonation – or chloride – induced depassivation of steel bars [2]. The chloride ions and carbon dioxide, which can be found in high concentrations in various environments, when they penetrate into concrete matrix, they can cause corrosion of the reinforcement, which leads to premature deterioration of concrete structure [3]–[14]. Therefore, it can be said that the resistance of concrete against chloride penetration and carbonation has an important effect on its durability and hence on a concrete structure's service life [15]–[17].

The main constituents of concrete are: Cement, Water, Coarse and Fine Aggregates. Although the basic properties and characteristics of concrete are mainly affected by the type of cement and cement hydration products, aggregates must also be considered as an important constituent of concrete. Due to the fact that the aggregates occupy about 60 – 70% per cent of the volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable [18]–[20].

In this study, microconcretes (concrete without coarse aggregates) with different aggregate type (sand from crushed limestone, river silica sand) were produced and their compressive strength and durability against chloride penetration and carbonation was studied, in order to investigate the effect of aggregate type on concrete properties. The effect of w/cm ratio on concrete properties was also studied. Finally, the electrical conductivity of microconcretes was estimated from Rapid Chloride Permeability measurements.

Apostolos S. Marinos, School of Chemical Engineering, National Technical University of Athens, Athens, Greece.
John A. Marinos, TITAN S.A., Athens, Greece.

II. EXPERIMENTAL PROGRAM

A. Materials

The materials used in this study were Portland-composite cement (CEM II / B–M (P-W) 42.5N according EN 197-1), potable water according EN 1008:2002, two types of fine aggregates (limestone sand, river sand) and superplasticizer. The chemical composition and the physical properties of cement and sands are given in Table 1. Fig. 1 presents the Particle Size Distribution (PSD) of cement and Fig. 2 the PSD of limestone sand and river sand. The PSD of cement was defined with Static Laser Light Scattering (SLS) method with a CILAS – 1064 Particle Size Analyzer. The PSD of sands was determined according to ASTM C 136 – 06. A chloride free, polycarboxylate based superplasticizer (SP) (Sika® ViscoCrete® – 300) was employed to achieve the desired workability in all mixtures.

B. Mix proportions and sample preparation

Six different microconcrete mixtures were designed and prepared in this study. The mixture proportions are presented in Table 2. As it is presented in Table 2, microconcretes A, B and C contained limestone sand as aggregate, while microconcretes D, E and F contained river sand as aggregate. Initially, the dry materials were mixed together at low mixer speed and then water and superplasticizer were added. Superplasticizer was added at the time of mixing, in order to keep flow table (EN 1015-3:1999) values in the range of 190 ± 5 mm for all mixtures.

Table 1 Chemical composition and physical properties of cement and sands

	CEM II 42.5N	Limestone Sand	River Sand
	(%)	(%)	(%)
SiO_2	22.1	-	97.8
Al_2O_3	6.27	-	0.85
Fe_2O_3	3.55	0.02	0.17
CaO	55.97	55.5	0.1
MgO	2.2	0.72	0.28
K_2O	0.71	0.01	0.65
Na_2O	0.3	-	-
SO_3	3.1	-	-
TiO_2	0.31	-	0.035
LOI	5.23	43.52	0.2
Blaine (cm^2/g)	**4461**	-	-
Sp. Gravity (g/cm^3)	**2.96**	**2.7**	**2.6**
Cement Compressive Strength according EN 196 – 1 (MPa)			
2 days	**28.9**		
7 days	**40.4**		
28 days	**50.7**		

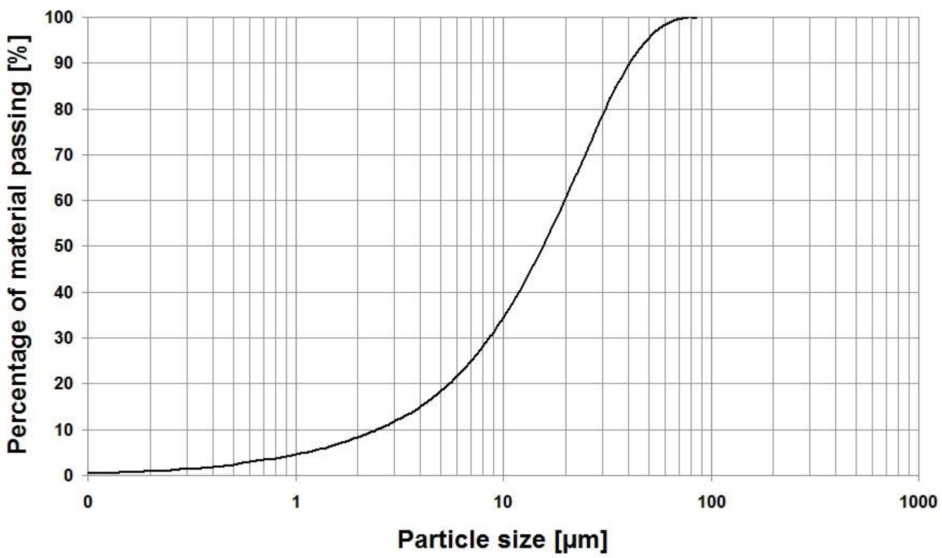

Fig. 1 Particle Size Distribution of CEM II 42.5N

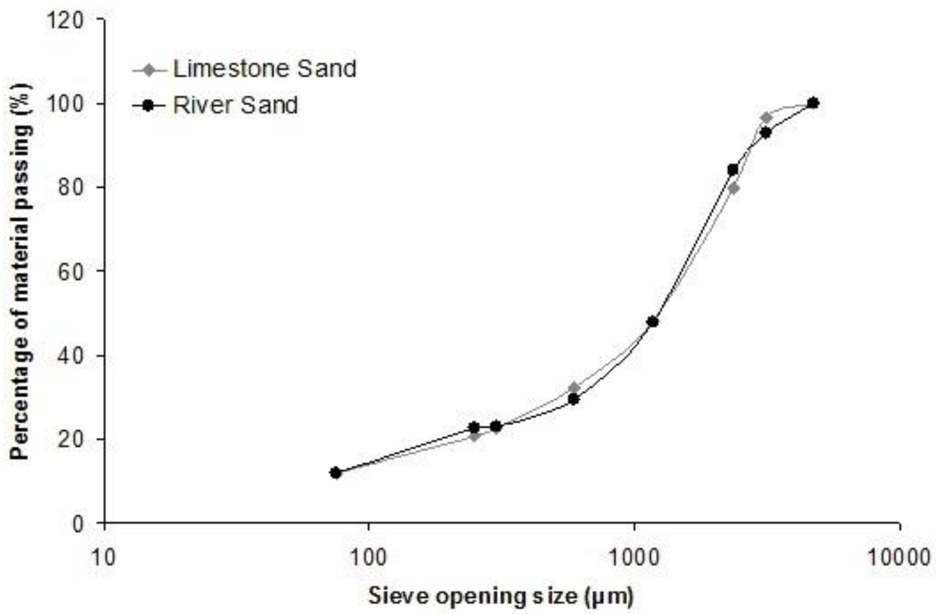

Fig. 2 Particle Size Distribution of sands

Table 2 Microconcrete mixture proportions

	Limestone sand			River sand		
Mixture	**A**	**B**	**C**	**D**	**E**	**F**
Materials	**kg/m³**			**kg/m³**		
CEM II 42.5N	496	519	532	487	507	521
Water	248	207	186	244	203	182
Sand	1488	1556	1597	1462	1522	1563
SP	3.7	6	7.6	3	6	7
w/cm	**0.5**	**0.4**	**0.35**	**0.5**	**0.4**	**0.35**
Flow Table (mm)	190	186	187	195	192	186

Prismatic specimens with dimensions 40 x 40 x 160 mm and cylindrical specimens with dimensions Φ150 x 300 mm were cast for each mixture. Prismatic specimens (Fig. 3) were cast according to EN 196-1. Cylindrical specimens (Fig. 4) were cast in steel moulds and compacted with a vibrating table.

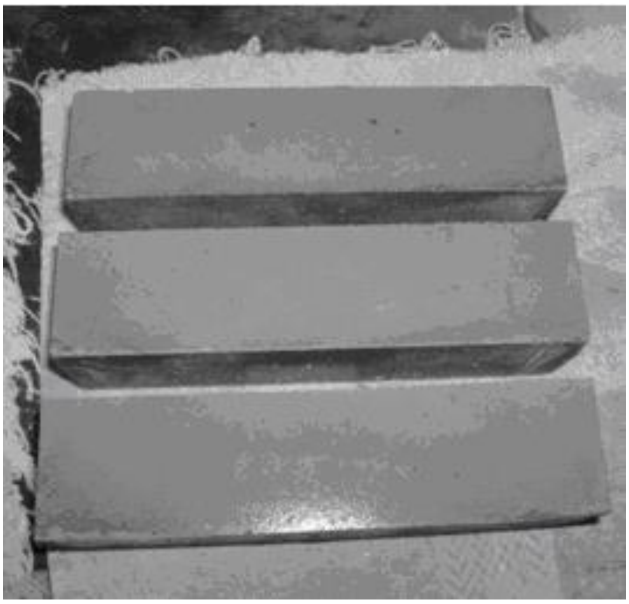

Fig. 3 Prismatic specimens (40 x 40 x 160 mm)

Fig. 4 Cylindrical specimens (Φ150 x 300 mm)

C. Curing

After casting, the cylindrical specimens were covered with a wet blanket to minimize water evaporation and cured under laboratory conditions for 24 hours. The prismatic specimens were covered with a plastic sheet and cured in a humidity chamber for 24 hours. After 24 h, all specimens were demoulded and left to cure under laboratory conditions (Air Curing - *Temperature: 19 – 23^{o}C, Relative Humidity: 55 – 70%*).

III. Test Methods

A. Compressive strength

The 40 x 40 x 160 mm microconcrete specimens were used for compressive strength measurements. Compressive strength was determined according to EN 196 – 1 [21]. For each mixture and at each curing age (28, 90, 180 and 360 days), three specimens were tested and the mean value of these measurements is reported below.

B. Chloride Permeability

The chloride permeability of microconcrete specimens was estimated according ASTM C 1202 [22]. This method, also called Rapid Chloride Permeability Test (Fig. 5), can be used to estimate the resistance (durability) of concrete against chloride penetration. The durability of concrete against chloride penetration is crucial for concrete structures' service life, since chlorides, when they reach the reinforcement, can cause corrosion, which leads to concrete deterioration and finally failure of the structure.

The chloride permeability of microconcrete specimens measured after 28, 90, 180 and 360 days of curing. In order to measure the chloride permeability of microconcrete specimens, cylindrical specimens with dimensions Φ95 x 50 ± 1 mm prepared (Fig. 6). First, a Φ95 x 300 mm core sample was drilled from each Φ150 x 300 mm cylindrical specimen, after seven days of curing. A 20 mm width slice was cut from the top of each core sample, in order to avoid possible inhomogeneities of the upper part of microconcrete specimens due to compaction. Then the core samples were cured under laboratory conditions until the test day. Finally, a 50 ± 1 mm width slice was cut from each core sample with a water cooled diamond saw and used to measure the chloride

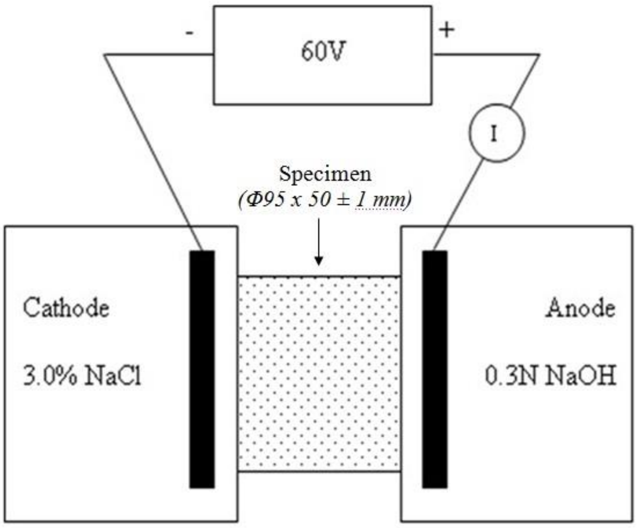

Fig. 5 Schematic diagram of Rapid Chloride Permeability Test

Fig. 6 A Φ95 x 50 ± 1 mm cylindrical specimen

permeability of microconcretes after specific curing periods. By applying a potential of 60V of direct current and measuring the quantity of electrical charge (Coulomb (*Cb*) passing through a Φ95 x 50 ± 1 mm specimen, we can estimate microconcrete durability against chloride penetration.

Fig. 7 A cylindrical specimen with dimensions Φ150 x 300 mm prepared for carbonation testing

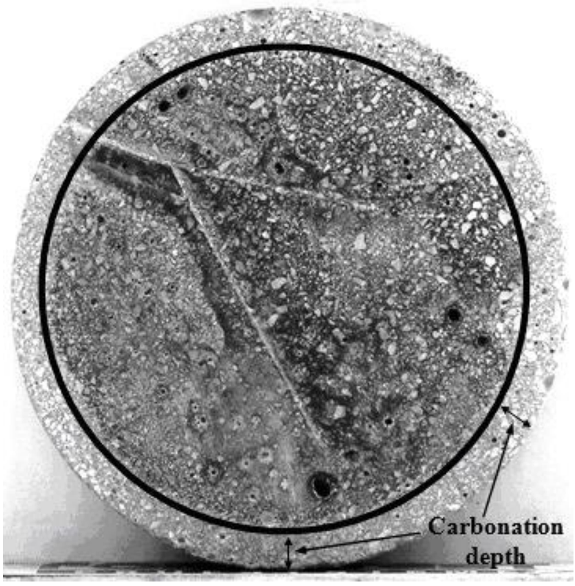

Fig. 8 Carbonation depth measurement

C. Accelerated carbonation testing

After curing under laboratory conditions for 5 days, two cylindrical specimens of each mixture (Φ150 x 300 mm) were placed in a chamber with controlled concentration of CO_2 (22 - 23%). The relative humidity inside the chamber was 55–70%. The bottom and top surface of the cylindrical specimens were sealed in order for CO_2 to penetrate through cylindrical surface (Fig. 7). After specific CO_2 exposure periods, a 20 mm width slice was cut from each cylinder with a diamond saw and the carbonation depth was determined by means of phenolphthalein indicator (Fig. 8).

IV. Results and Discussion

A. Compressive strength results

The compressive strength of microconcrete specimens contained limestone sand and microconcrete specimens contained river sand is presented in Fig. 9 and Fig. 10 respectively. From compressive strength results it can be concluded that for all w/cm ratios, microconcrete specimens with limestone sand and microconcrete specimens with river sand show similar compressive strength.

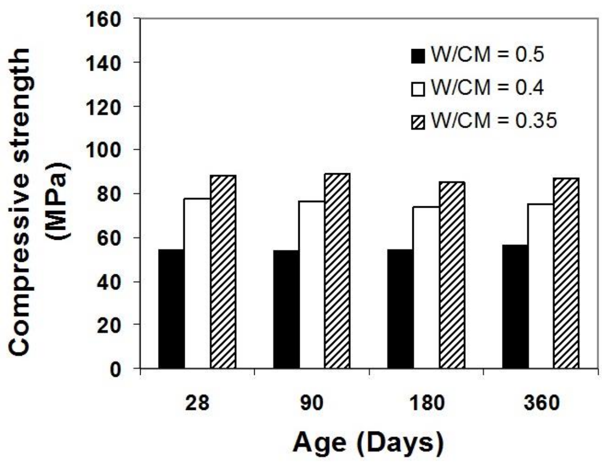

Fig. 9 Compressive strength of microconcrete specimens contained limestone sand

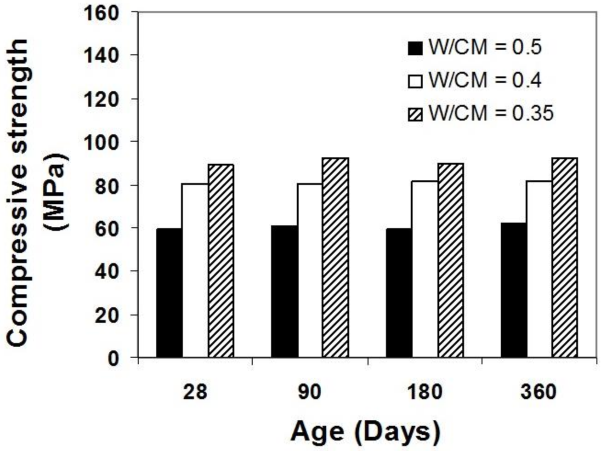

Fig. 10 Compressive strength of microconcrete specimens contained river sand

Also, comparing the values of compressive strength for different w/cm ratios, it can be concluded that the lower the w/cm ratio, the higher the compressive strength. A low w/cm ratio leads to a more dense microstructure and therefore to higher compressive strength.

B. Chloride permeability results

The value of electrical charge passed through microconcrete specimens during chloride permeability measurements is presented in Fig. 11 and 12. It can be observed from the results presented in Fig. 11 and 12 that for all three w/cm ratios, microconcrete specimens contained limestone sand show similar chloride ion permeability with microconcrete specimens contained river sand, for all four curing ages. Comparing the electrical charge values, it can be concluded that microconcrete specimens contained limestone sand and microconcrete specimens contained river sand show equivalent durability (resistance) against chloride ion penetration. Also, comparing the values of electrical charge for different w/cm ratio, it can be concluded that when the w/cm ratio is high (w/cm = 0.5), microconcrete specimens show high chloride permeability.

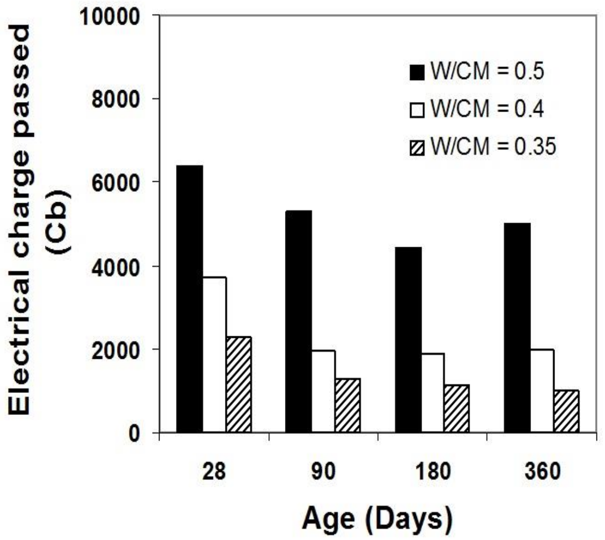

Fig. 11 Electrical charge passed through microconcrete specimens contained limestone sand

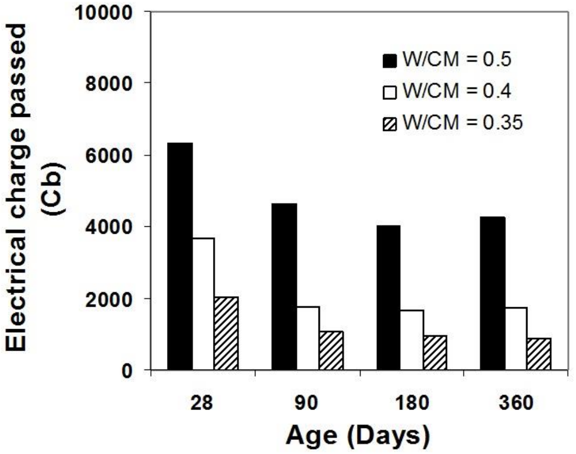

Fig. 12 Electrical charge passed through microconcrete specimens contained river sand

On the other hand, when the w/cm ratio is low (w/cm = 0.35), microconcrete specimens show low chloride permeability. A low w/cm ratio leads to a dense and less porous microstructure. Therefore, microconcrete specimens with low w/cm ratio show higher resistance against chloride penetration, compared to microconcrete specimens with high w/cm ratio.

C. Accelerated carbonation results

In order to estimate the carbonation of microconcrete specimens contained different types of sand, Φ150 x 300 mm cylindrical specimens were exposed to CO_2 for four different periods. The results of accelerated carbonation measurements are presented in Fig. 13 and 14. It can be observed from Fig. 13 and 14 that microconcrete specimens contained limestone sand and microconcrete specimens contained river sand show similar carbonation for all four exposure periods. Therefore it can be concluded from Fig. 13 and 14 that microconcrete specimens contained limestone sand and microconcrete specimens contained river sand show equivalent durability against CO_2 penetration. Also, from Fig. 13 and 14 it can be concluded that when the w/cm ratio is high (w/cm = 0.5), microconcretes show high carbonation depth. On the other hand, when the w/cm ratio is low (w/cm = 0.35), microconcretes show low carbonation depth.

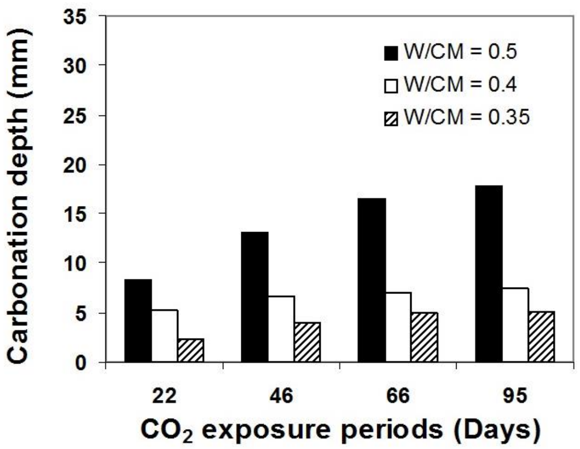

Fig. 13 Carbonation depth of microconcrete specimens contained limestone sand

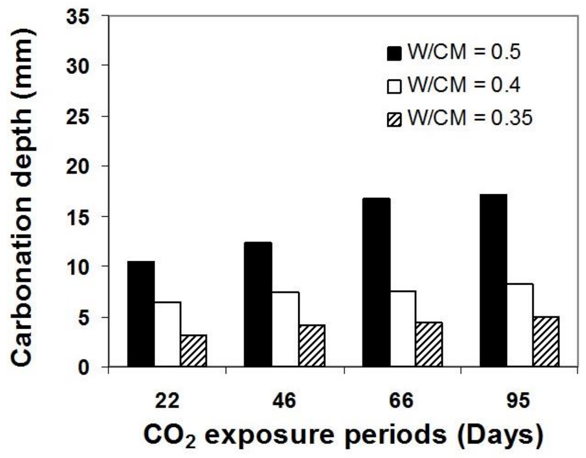

Fig. 14 Carbonation depth of microconcrete specimens contained river sand

Microconcretes with low w/cm ratio develop a dense and less porous microstructure. Therefore, microconcretes with low w/cm ratio show higher resistance against carbonation, compared to microconcretes with high w/cm ratio.

D. Correlation between w/cm ratio and electrical charge

Fig. 15 and 16 show the correlation between w/cm ratio and electrical charge passed through microconcrete specimens that cured under laboratory conditions for 28 days.

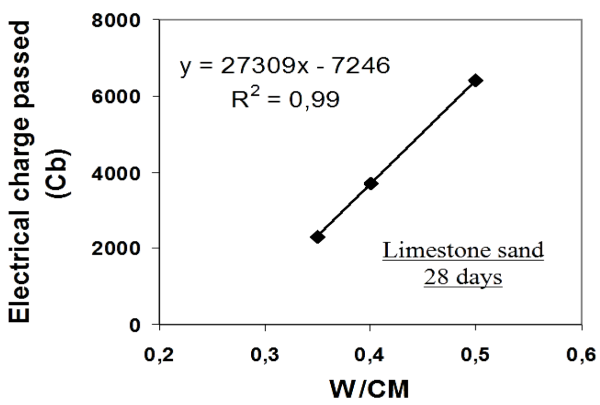

Fig. 15 Correlation between w/cm ratio and electrical charge

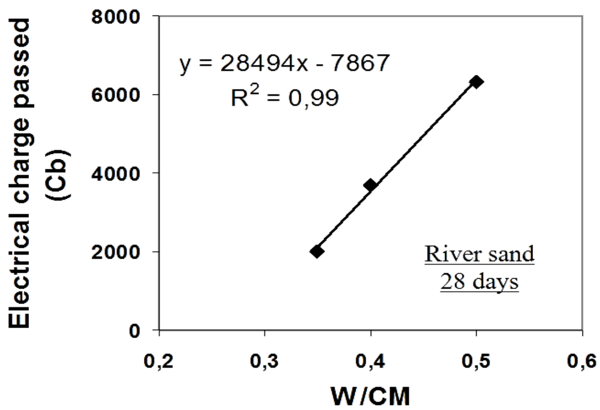

Fig. 16 Correlation between w/cm ratio and electrical charge

It can be observed from Fig. 15 and 16 that there is a high linear correlation (R^2 = 0.99) between w/cm ratio and the electrical charge passed through microconcrete specimens. Therefore, it can be concluded from Fig. 15 and 16 that w/cm ratio affects significantly and in an immediate way the durability of concrete against chloride penetration. The linear correlation between w/cm ratio and electrical charge passed through microconcrete specimens cured for 90, 180 and 360 days show similar regression results (R^2 > 0.95).

E. Correlation between w/cm ratio and compressive strength

Fig. 17 and 18 show the correlation between w/cm ratio and compressive strength of microconcrete specimens that cured under laboratory conditions for 28 days. It can be observed from Fig. 17 and 18 that there is a high linear correlation (R^2 = 0.99) between w/cm ratio and compressive strength of microconcrete specimens. Therefore, it can be concluded from Fig. 17 and 18 that the compressive strength of concrete can be affected crucially and in an immediate way from w/cm ratio. The linear correlation between w/cm ratio and compressive strength of microconcrete specimens cured for 90, 180 and 360 days show similar regression results (R^2 > 0.95).

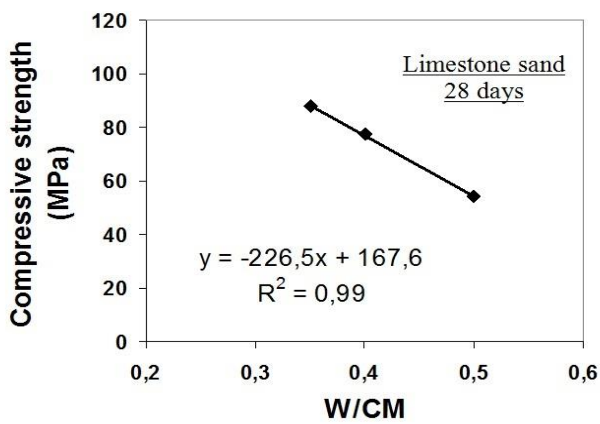

Fig. 17 Correlation between w/cm ratio and compressive strength

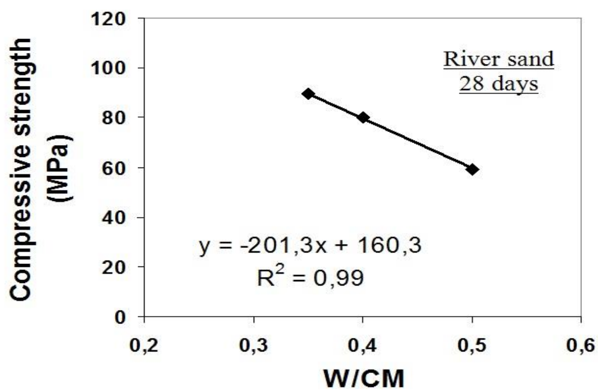

Fig. 18 Correlation between w/cm ratio and compressive strength

V. Electrical Conductivity

The results of electrical conductivity measurements can be used as an indication of concrete microstructure permeability properties. It has been reported in literature [23]–[26] that electrical conductivity (σ) measurements can be used as a non-destructive method for estimation of concrete durability against chloride penetration. In this study, the electrical conductivity calculated from ASTM C 1202 chloride permeability measurements, using (1):

$$\sigma = \frac{I_o * L}{A * V} \quad (1)$$

where

- σ: Electrical conductivity (S/m)
- I_0: The initial current that was measured at the beginning of chloride permeability measurements (Ampere)
- L: Specimen's thickness (m)
- V: The applied voltage (Volts)
- A: Specimen's exposure surface to chlorides (m^2)

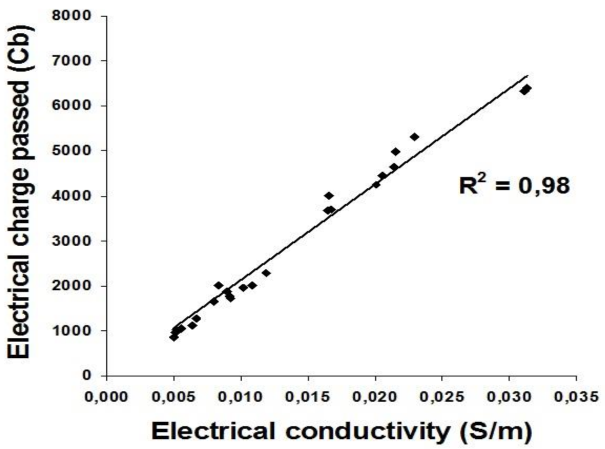

Fig. 19 Correlation between electrical conductivity and electrical charge passed through microconcrete specimens

A high linear correlation (R^2 = 0.98) is observed between electrical conductivity and electrical charge passed for all microconcrete specimens (Fig. 19). From Fig. 19 it can be concluded that electrical conductivity measurements can be used to investigate the durability of a concrete against chloride penetration, since, as Fig. 19 shows, a concrete with low electrical conductivity will show greater durability against chloride penetration.

VI. Conclusions

Based on the findings of the experimental program presented above, the following conclusions can be drawn:

- Microconcretes with limestone sand and microconcretes with river sand show equivalent compressive strength and equivalent durability against chloride penetration and carbonation.
- The w/cm ratio affects significantly the compressive strength, the chloride permeability and carbonation of microconcretes. Low w/cm ratio leads to a more compact and less porous microstructure and therefore to higher compressive strength and greater durability against chloride penetration and carbonation.
- Electrical conductivity measurements can be used as a rapid and non-destructive method to estimate concrete durability against chloride penetration.

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