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Effects of Five Sources of Mixing Water on Durability of Concrete

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ABSTRACT

This paper presents the experimental approach and the first results obtained as a result of the effect of five Sources of mixing water on produce more durable concrete . Five types of water were used, namely simulated acid rain (AR), Rain water (RW), tap water (TW), Zamzam water (ZW) and sea water (SW) as mixing water for ordinary portland cement concrete (OPCC). The durability of these different types of water were tested toward their capacity to prevent the rebar corrosion. The results of workability, pH value, compressive strength, chlorides penetration and microstructure of different specimens mixed with each type of water were compared with those mixed with tap water (TW). In the present research, the effect of five sources of mixing water on durability of concrete mixes was investigated, incorporating different contents of silica fume. Chloride profile, gas permeability, Compressive Strength, Energy Dispersive X-Ray Analysis EDX, scanning electron microscope SEM, and water porosity tests are used for this propose.

1.INTRODUCTION

The concrete that withstands the conditions for which it has been designed without deterioration over a period of years is said to be durable. Durability means a longer span of life for concrete structures. Durable concrete can withstand rapid chloride penetration (RCPT), water porosity (WP), initial surface absorption (ISAT), and gas permeability (GP). Also, chloride is the most aggressive because the maximum limit is 0.3 and the sulphate limit is 4.0. A period of years is said to be durable. Durability means a longer span of life for concrete structures. Durable concrete can withstand rapid chloride penetration (RCPT), water porosity (WP), initial surface absorption (ISAT), and gas permeability (GP). Also, chloride is the most aggressive because the maximum limit is 0.3 and the sulphate limit is 4.0%, and concrete is always safe in sulphate [1]. Water is one of the most important materials used in cementitious mixtures, where it can occupy about 14–21% of the total volume [2]. So the quality of the water is very influential. The most widely used type of water for mixing purposes is tap water (TW). There have been numerous efforts to determine the effects of using seawater (SW) as the mixing water for traditional cement systems. According to Rashad et al. [2], traditional cement concrete that had been mixed and cured with SW had stronger tensile, compressive, flexural, and bond strengths than concrete that had been mixed and cured with freshwater at ages of 7 and 14 days. At ages 28 and 90 days, however, the compressive strength of the freshwater-cured specimens gradually increased. The Torah, the Bible, and the Quran are three holy texts from various faiths that all mention zamzam water (ZW). According to the story, ZW is sacred water and is considered a huge gift from God. In Mecca, ZW was used by millions of individuals to recover from illnesses [2]. When ZW passes through a magnetic field of rocks, this water gains a magnetic field and is called magnetic water or magnetised water [2]. As a result of magnetization, the surface tension of water, the number of hydrogen bonds, the self-diffusion coefficient, and the structure of water were affected. According to Elshami et al. [3], ZW can be used to lower the rate of metal corrosion in rainwater (RW) and artificial acid rain (AR). This might be connected to ZW molecule uptake at the electrode surface. The rate of anodic electrode disintegration was slowed down by this absorption. They proved that ZW could influence the cathodic reaction mechanism but not the anodic dissolution mechanism [3]. A lot of researchers ignorantly use chloride penetration cement below ground level [4].

Always use ground granulated glass furnace slag (GGBS), pulverised fuel ash PFA, and micro silica MS (OPC+PFA/GGBS or OPC+PFA/GGBS + MS). This is the best concrete you will get from this combination, and this concrete is referred to as durable concrete [5]. Always choose the right mix design for the right concrete. Check the availability of raw materials and prepare as per that. Recently tested durability of sulphate-resistant cement (SRC), it is not controlling durability limits. Keeping concrete as impermeable as possible is the straightforward goal of durability [6]. It can be done by reducing the w/b ratio in mixes, limiting the amount of OPC, and maximising supplementary cementing materials (SCMs) (microfine and pozzolonic materials, be they GGBS, PFA, or microsilica). The best way to keep concrete durable is to make efforts to reduce its permeability [7]. Also, to understand the type of durability, there is a difference between concrete made in a lab and concrete delivered on site [8]. Too often, studies prescribe high strength, low w/b ratios, sometimes with high levels of SCM, and low slump and assume a durable structure [9]. That might be fine in a controlled lab (though low slump never is), but get it to site and the contractor can't place and compact it, resulting in a non-durable structure due to voids or possibly uncontrolled water addition [10]. A concrete mix design is successful only if it satisfies all of its performance criteria, like workability, cohesiveness, strength, and durability [11]. If anyone among them is missing, it’s not work. Very often, a lot of researchers succeed in getting better workability and mix cohesiveness but unfortunately fail to achieve strength and durability [12]. Tests were made for chloride penetration, and water porosity was way behind in durability. While there is an improvement in durability linked to permeability, other factors are also at play (i.e., air entrainment). However, durability is much more than just material science. In this study, we introduce a holistic approach that also includes the application or exposure to the operating environment [13]. For a truly durable solution, the structural design plays a critical role in determining the potential for cracking, which impacts the reinforcing requirements, crack spacing, and width. A structure made of cracked, durable concrete in a harsh operating environment that does not recognise crack width may not be durable. Sometimes permeability is better to be high, and sometimes it is better to be low for durability [14]. The chemistry of the cement and other materials in the concrete and the type, shape, and size of the aggregate can have a bearing on durability. The exposure conditions need to be taken into account; the surface finish can be a factor; and the design of the structure needs to take account of the prevailing weather conditions, groundwater conditions, and sources of water. There are many, many other factors that can affect durability, and we can't simply say that increasing (or decreasing) any one property will universally improve durability for all conditions. It is sometimes a complicated set of conditions that need addressing (and almost all of these are addressed properly in current concrete standards) for each structure [15]. Another option to improve the durability and service life of concrete is to use a highly effective integral waterproofing admixture in the mix. In general, SCMs have a limited effect on reducing the water absorption rate and permeability of concrete. Full compaction is more important than a low w/c coupled with poorly compacted concrete [16]. The concrete placement, compaction, and curing are of the necessary quality. As part of the maintenance and repair of port structures, a large number of possibilities for techniques are proposed, but they are not always clearly defined. Therefore, this study was focused on evaluating durability indicators such as five sources of water, chloride penetration, and incorporating OPCC + 125 ml/l of ZW (AR + SW + RW +TW) as mixing water. The objective is to study the durable performance of remedial and preventive methods available for the maintenance and repair of reinforced concrete marine structures. Concrete and reinforced concrete slabs are cast with the same material before being placed in laboratory tidal conditions. It will enable us to interpret materials durability under accelerated ageing conditions. This paper presents the initial studies and characterizations concerning the different types of mixing water and the available specimens in tidal conditions.

2.EXPERIMENTAL PROGRAM

The principal objective of this experimental study is to characterize the durability of different types of mixing water used for reinforced concrete structures. There were four different concrete mixtures were prepared (Table 1). The first one produced TW as the mixing water control sample (chemical composition –ppm- is 29 Cl, 66 SO_3, 350 TDS). The other mixtures were made of OPCC (AR + SW + RW +TW+ZW). ZW can be considered as a type of alkaline water , which ZW has higher pH value 8.3 compared with those of TW 7.3. The natural rainwater (RW with pH around 7.8)) in Loire-Atlantique France was investigated. Secondly, acid rain (AR with pH 5) solution, prepared from distilled water and analytical grade reagents. Composition of AR is listed as follows –ppm- is 35.90, SO_3, 152 Cl, 62 TDS. Thirdly, ZW was delivered from Mecca city – KSA (chemical composition –ppm- is 78Cl, 123 SO_3, 450 TDS). Fourthly, SW (chemical composition –ppm- is 268.14 Cl, 2884 SO_3, 53,756 TDS). SW or ZW as mixing water increases the workability of the mixture from 118.5 ± 5% to 128.5 ± 5%

and 130 ± 5%, respectively in comparison with TW. These methods can take different forms like the substitution of tap water concrete by different types of water admixed with OPC concrete with or without the use of innovating materials like stainless steel.

This study focus then on two different sections:

- The durability of five types of water based on OPCC (AR + SW + RW +TW +ZW) at 90 days in tidal area ;

- The comparison of carbon (FeE500) and stainless steel (grade l.4362) performance.

- OPCC + 125ZW (AR + SW + RW +TW) meaning ZW (125 ml/l by weight of cement) tested and characterized are:

- OPCC+ (125ZW +AR) (aggregates size 0- l0 mm);

- OPCC+ (125ZW +SW) (aggregates size 0- 8 mm);

- OPCC+ (125ZW +RW) (aggregates size 0-6 mm);

- OPCC+ (125ZW +TW) (aggregates size 0- 4 mm).

This experimental work is casted in laboratory tests.

2.1. Concrete Cylinder Testing

For each concrete mixture, 22 cylindrical specimens (diameter: 11 cm; height: 22 cm) . After casting, all the specimens were moist-cured at 20 ± 2 °C and over 95% of relative humidity (R.H.) for 24 h, and water to cement ratio w/c equal to 0.44, then demoulded. Tests on reference and five slabs with different types of water were cast, in department civil engineering at IUT Saint Nazaire in France. and the mean data is given in supplementary materials. Supplementary cementing materials are one of factors that affecting on durability.

First five slabs for five types of water are aged in tidal area at IUT Saint Nazaire in France following a natural tide cycle of 24 hours (6 hours of immersion and 18 hours of drying). The initial material is characterized with classical techniques:

determination of gas permeability and chloride migration coefficient. Values obtained for these two parameters are classic. Values of diffusion coefficient achieved (based on migration results) ranged from D = 0.88 x 10-11 Table 2. The indicator used to evaluate the damage state of these specimens is the chloride profile Figure 1. The mass concentration in chlorides is compared to the threshold value noticed in the NF EN 206-1 standard (NF EN 206-1, 2004) [17] of 0.4% of the cement mass (ie 0.065% of the concrete mass if the latter is supposed to be dosed at 375 kg/m3 of cement). Concerning the beam specimens, the maximum concrete depth infected by chlorides is 6cm. The infected concrete is then detached from beams on a 6 centimeters layer by ahydrodemolition method. The four types of water are used on the different beams. Durability is appreciated at different time by proceeding to the realization of chloride profiles on slabs and by making some electrochemical and acoustic emission measurements on rebar's.

Table 1. Details of OPCC mix proportions

Mixture	Concrete mix constituent
CEM I 52.5 N	375 (kg/m^3)
Water	168 (kg/m^3)
Coarse aggregate	561 (kg/m^3)
Medium aggregate	432 (kg/m^3)
Sand	868 (kg/m^3)
Pull out test	55 (KN)

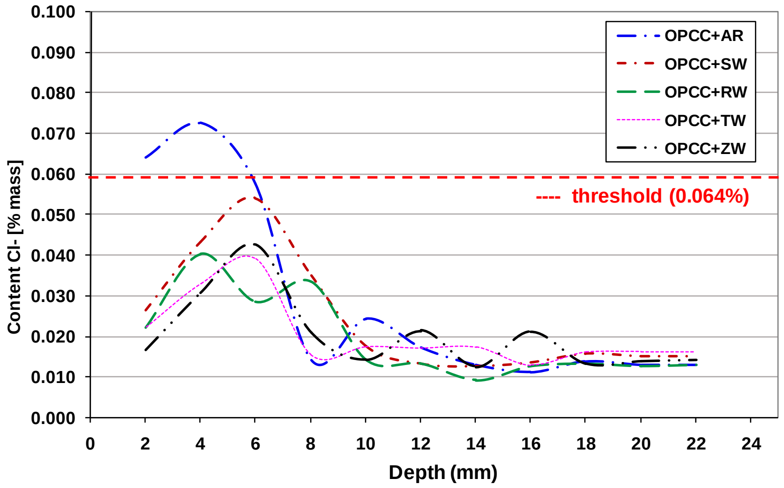


Figure 1. Chloride profile for slabs for OPCC (AR + SW + RW +TW +ZW) in tidal area.

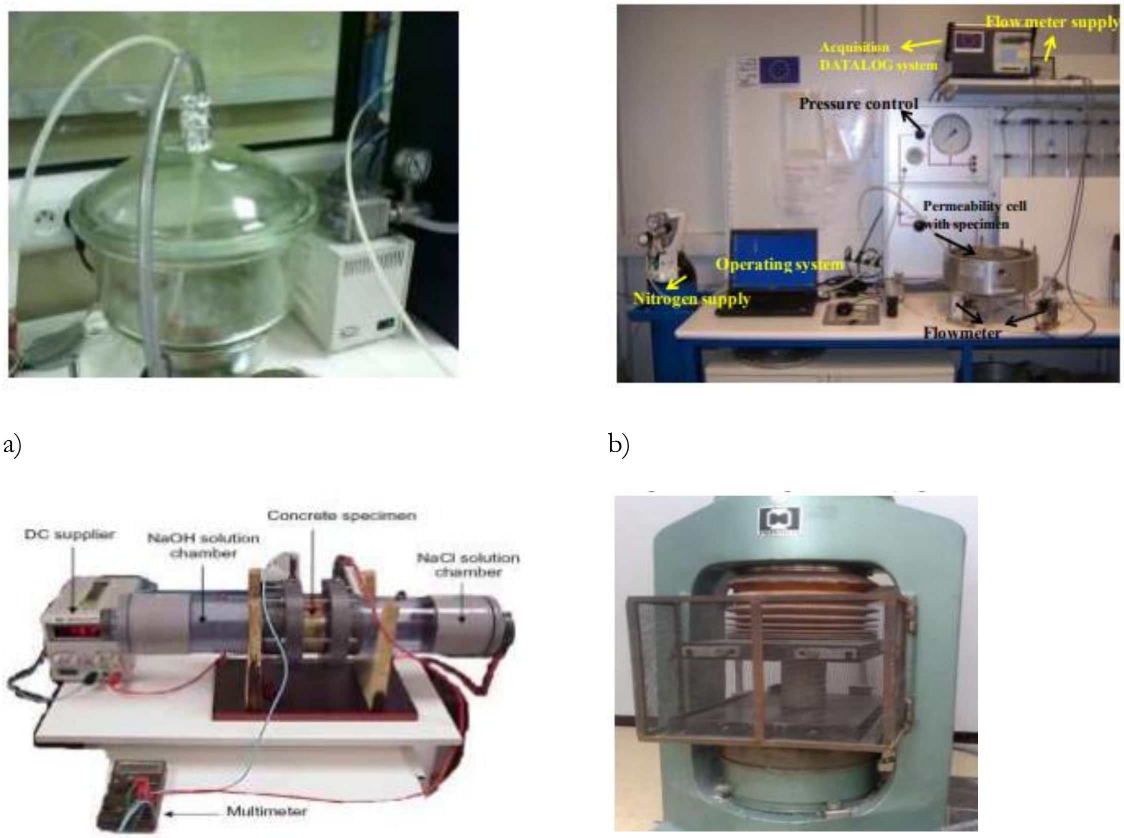
Table 2: Characteristics of slabs concrete in tidal area.

Parameters	Intrinsic permeability (m^2)	Migration coefficient (permanent flow, m^2. s-1)
AR	1.56 x 10-16	3.8 x 10-9

SW	1.65 x 10-16	6. 7 x 10-9
RW	1. 76 x 10-17	7.2 x 10-11
TW	1.88 x 10-17	8.8 x 10-11
ZW	0.83 x 10-18	1.7 x 10-12

2.2. Material tests in laboratory

have two objectives. At first, prepared OPC concrete cylindrical to get the desired slump, strength and chloride diffusivity. Other objective, slabs of 150 mm x 150 mm x 60 mm with one rebar have been realised with the five types of water. The indicators selected for this characterization stage are all subjected to a standard test , AFPC-AFREM, 1997[17] -Arliguie et al., 2007[18] - NF EN 13412, 2006 [19] Elshami et al ,2021[3] (Figure 2 a-d). The set of measurements are made on several samples to supply the data base concerning heterogeneity of materials as well as the estimation of measurement uncertainty.



a) b)

c) d)

Figure 2. Experimental set-up, a) porosity device, b) permeability device, c) chlorides migration device, d) mechanical set-up

The second kind of material tests concerns slabs of 15 cm x 15 cm x 6 cm made also with small amount of ZW (125 ml/l) (AR + SW + RW +TW). Some slabs are prepared with carbon steel rebars as well as stainless steel rebars. An accelerated ageing of slabs is realised in tidal-range conditions, with immersion-drying cycles, at IUT Saint Nazaire in France. To accelerate the ageing, cycles of 6 hours of immersion and 18 hours of drying are chosen. The drying is accelerated with a ventilation system near the upper side of slabs. To accelerate more the penetration of chlorides, slabs are only partially immersed. The saline solution used is composed by 35 g.L-1 of salt so nearly 20 g.L-1 of chlorides. A waterproof resin is applied on the lateral sides of slabs in order to simulate a propagation of the chloride front in a single direction. The durability indicator chosen for these tidal range tests is the depth of chloride ions penetration. Some samples are tested at different times to compare the evolution of the chloride ions penetration in the different materials. These tests should enable the determination of the kinetics of chloride ions diffusion within material used. Chloride profils are realized after the extraction of ions using the procedure described by AFREM (AFPC-AFREM, 1997) [17] and presented in Figure 3. Some methods (electrochemical measurements) are also used throughout this study in order to evaluate the potential of these methods towards corrosion estimation. The kinetic of rebars corrosion can be relied to the chloride ions diffusion due to an electrochemical monitoring. Besides, the benefit of using stainless steel rebars instead of classical ones is evaluated in terms of durability. Dial gauges are measuring instruments that can accurately measure displacements. To complete results, some concrete reinforced slabs of 15 cm x 15 cm x 6 cm with a real-time mechanical and electrochemical monitoring are developed and placed in accelerated tidal conditions (Figure 4).

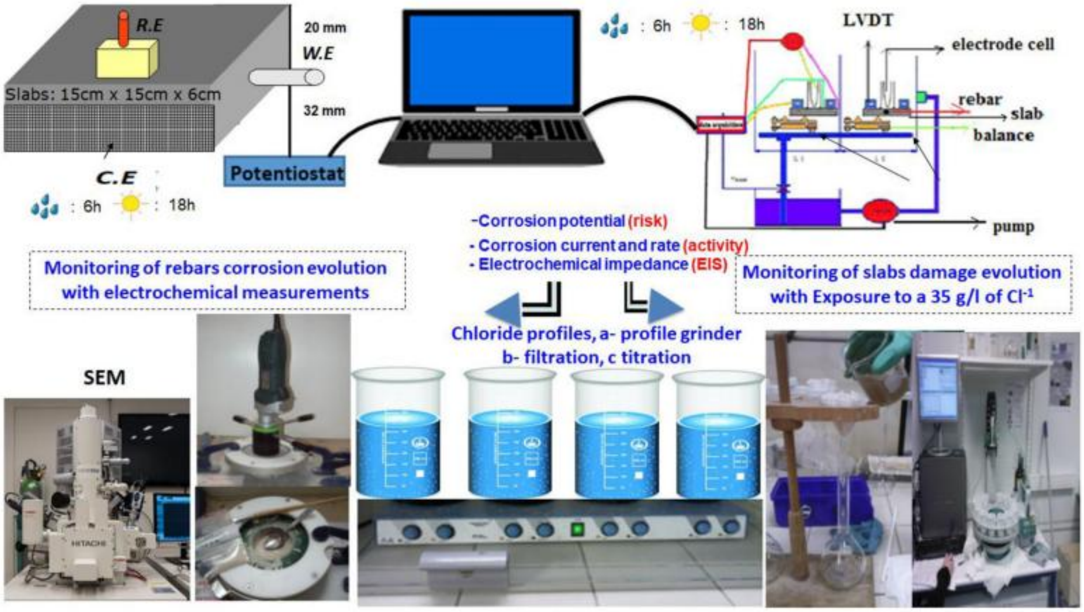


Figure 3. Experimental set-up for chloride profiles in tidal conditions

Figure 4. Experimental set-up for small slabs monitoring, (electrochemical and mechanical monitoring)

3.RESULTS AND DISCUSSION

3.1.Characterization of slabs

For OPC admixed with four types of water: porosity, permeability and mechanical characteristicsTable 3 and Figure 5 presents results obtained for porosity tests show a general trend (Table 3). OPC Concrete + 125ZW (RW +TW) have porosity significantly lower than the results for OPCC + 125ZW (AR + SW). We can suppose that the same material used for these two construction techniques is a more porous one than the two others due to its lower size of aggregates and the use of zamzam water effectively improves concrete by reducing the amount of calcium hydroxide (CH), saturation of cement particles, and density of the calcium silicate hydrate (C-S-H) gel. We can also note that the ZW influences the porosity values. Indeed, the ZW exhibits a slightly porosity than AR. The porosity of OPCC+ 125ZW (AR + SW)are relatively high. Permeability values are relatively dispersed (Table 3) for OPCC+ 125ZW (SW) due to the heterogeneity of the material. Concerning the mechanical characteristics, they seem close of values except for the ZW concrete which shows values far exceeding guaranteed values.

Table 3: Characteristics of slabs for OPCC + 125ZW (AR + SW + RW +TW)at 90 days

Materials / techniques	Porosity (%) (3 tests)		Permeability (m^2) (3 tests)		Compressive strength (MPa) (3 tests)		Young modulus (MPa) (2 tests)	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
OPCC + 125ZW(AR)	21,4	1,05	$1,70.10^{-16}$	$5,14.10^{-17}$	40,00	1,06	23000	75
OPCC+ 125ZW (SW)	19,3	0,55	$1,56.10^{-16}$	$7,4.\ 10^{-17}$	40,36	0,54	32500	-
OPCC+ 125ZW (RW)	15,6	0,78	$1,25.10^{-17}$	$5,00.10^{-19}$	50,07	0,32	34300	200
OPCC+ 125ZW (TW)	12,6	0,26	$2,09.10^{-17}$	$1,53.10^{-17}$	70,27	0,57	31800	1140

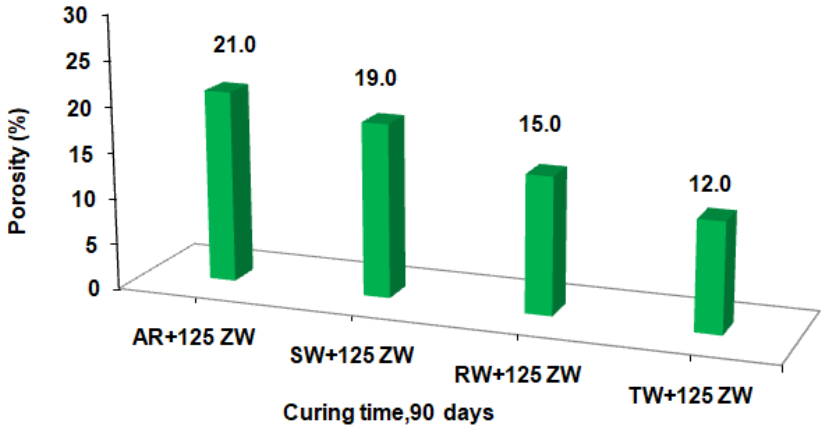


Figure 5 . Porosity values for OPCC + 125ZW (AR + SW + RW +TW) according to (AFGC, 2004)

On the other hand, as shown in Table 4 and Figure 6. if we compare values of porosity and permeability to the AFGC (Association Française de Génie Civil-French Civil Engineering Association) recommendations (AFGC, 2004) [20]. In table 3, we found lower porosity at age 90 days with OPCC+ TW, OPCC+ ZW concrete samples and higher porosity with SW, AR compared to the mean values with fresh rainwater RW. in addition to, porosity values show low potential durability's for all three samples for OPCC (AR + SW + RW) while permeability values are typical of high potential durability's for OPCC (RW + TW+ZW) or mean for OPCC (AR + SW).

Table 4. Comparison of permeability and porosity values for OPCC (AR + SW + RW + TW+ZW) according to (AFGC, 2004)

Materials / techniques	Permeability (m^2) (2 bars)	Potential durability (according to AFGC, 2004)	Porosity (%)	Potential durability (according to AFGC, 2004)
OPCC+ AR	290.10^{-16}	Mean	>16	Very low
OPCC+ SW	260.10^{-16}	Mean	>16	Very low
OPCC+ RW	$73.\ 10^{-18}$	High	>16	Very low
OPCC+ TW	30.10^{-18}	High	12-14	Mean
OPCC+ ZW	24.10^{-18}	High	12-14	Mean

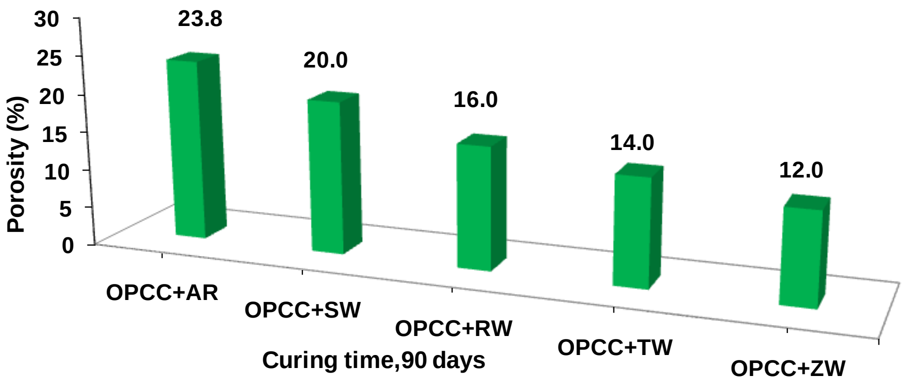


Figure 6. Porosity values for OPCC (AR + SW + RW + TW+ZW) according to (AFGC, 2004)

3.2.Compressive strength test results

As shown in Figures 7,8 this study concluded that higher compressive strength of traditional cement system by using ZW,RW and TW as mixing water in comparison with AR and SW .The incorporation of ZW increased the compressive strength in the early and later age[2,10,21]. In the same manner, the incorporation of ZW (125 ml) as mixing water with all types of water increased the compressive strength of OPCC at all ages. Whatever, incorporating AR and SW with ZW (125 ml) as mixing water led to a significant increase in the early ages compressive strength, whilst marginal increase was obtained at later age. This improvement in the workability and compressive strength could be related to the reduction in the number of water molecules due to magnetic field of ZW. Thus, higher specific area was obtained.

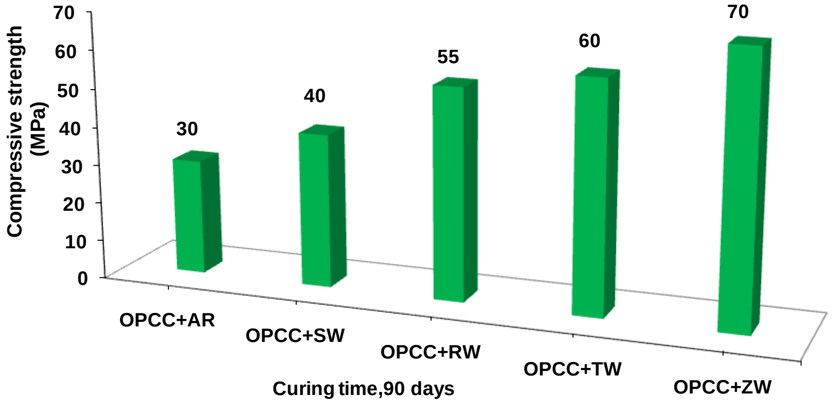


Figure 7. Compressive strength of OPCC (AR + SW + RW + TW + ZW) according to (AFGC, 2004

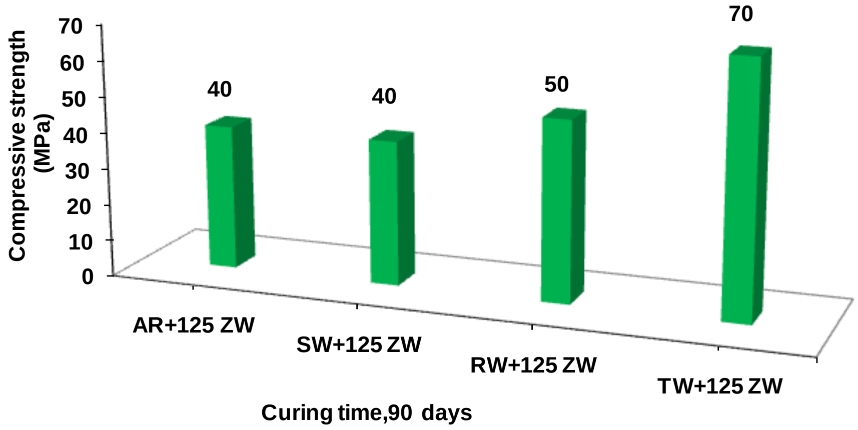


Figure 8. Compressive strength values for OPCC + 125ZW (AR + SW + RW +TW) according to (AFGC, 2004

3.3.Evolution of chloride profiles

The monitoring of chlorides penetration inside the different concrete aims to correlate initial parameters (porosity, permeability, mechanical characteristics) to the materials capacity to prevent durably the chlorides to reach metallic rebars. A first serie of tests on specimens cored in slabs in tidal area at CERIB laboratory has been made after 43 cycles of tidal. The collected free and total chloride profils are presented in the Figure 6. The free chlorides are lower than the total chlorides for low depth but after 8 mm the values are similar (excepted for the formed concrete) because it needs time for chloride to be bound. The standard NF EN 206-1 (NF EN 206-1, 2004) [17] provides a chlorides content limit of 0,4% (compared to the cement ratio) to begin rebars corrosion. The chlorides content limit reported to the concrete mass is then of 0,064% (supposing that the cement dosage is of 350 kg/m3) [22-26]. If we apply this value to the different chlorides profiles, we can determine the penetration depth corresponding to this threshlod (table 5). If we compare the behaviour of materials towards chloride ions penetration (Figure 9), we can observe that near the tidal surface, the samples having the most important ion content is OPCC+ 125ZW (AR). We can also notice that OPCC + 125ZW (SW + RW +TW) have relatively close critical depths (<10mm). Therefore, the OPCC+ 125ZW (AR) reaches the chlorides threshold for more important depths (10 to 15 mm) though maximal contents are not the highest. May be the cast samples contains already chlorides before the accelerated tidal test[2,3,26]. As expected, the highest critical depth is obtained for OPCC+ 125ZW (AR) which has higher porosity and the highest compressive strength.

Table 5. Penetration depth corresponding to this threshold

Materials / techniques	Threshold depth

OPCC + 125ZW(AR)	10 to 15 mm
OPCC+ 125ZW (SW)	4 to 7 mm
OPCC+ 125ZW (RW)	2 to 6 mm
OPCC+ 125ZW (TW)	3 to 6 mm

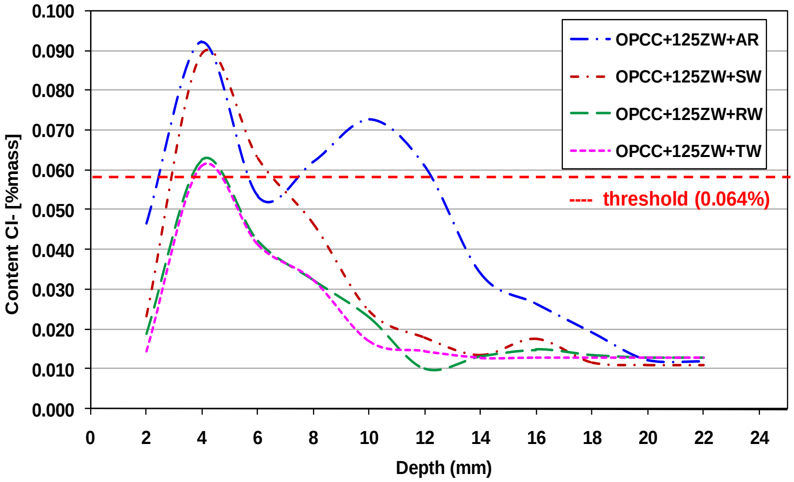
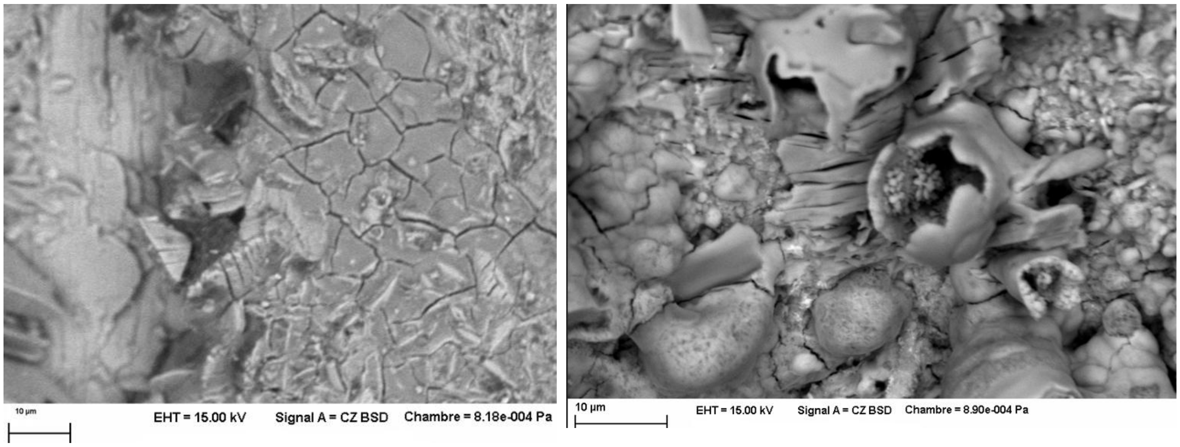


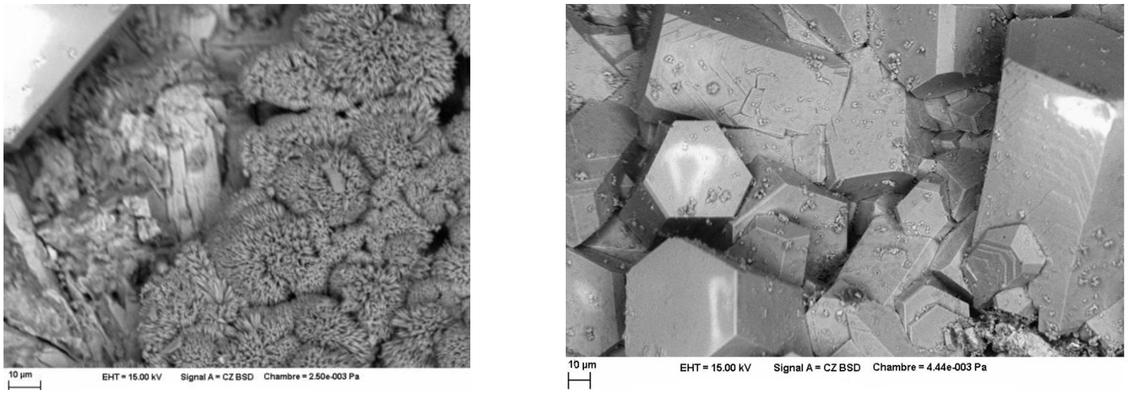
Figure 9. Chlorides profiles, for OPCC + 125ZW (RW + AR+ SW+TW) at 90 days in tidal area .

3.4.microstructure analyses

Figure. 10 represents SEM images of OPCC + 125ZW (RW + AR+ SW+TW) samples. It can be seen high amount of pores associated with the OPCC + 125ZW(AR) sample (Figure. 10a). These pores are the main reason for compressive strength reduction. Using OPCC + 125ZW (SW+ RW +TW) in comparison with OPCC + 125ZW (AR) as mixing water led to an improvement in the microstructure of the samples, of which lower amount of pores and homogenous microstructure can be obtained (Figure 10b–d). In the literature, some studies confirmed a reduction in the amount of pores [21], higher amount of CSH [22] and smaller crystals of Ca(OH)2 [23] of specimens manufactured from OPCC + 125ZW (RW +TW) in comparison with OPCC + 125ZW (AR) as mixing water [3,24]. Li et al. [25] found denser microstructure of traditional OPCC + 125ZW (SW) as mixing water instead of freshwater. Elshami et al, Shi et al [3,26] found lower porosity at 90 days of the microstructures of OPCC + 125ZW (TW) compared to those mixed with freshwater.



a) OPCC + 125ZW(AR) b) OPCC+ 125ZW (SW)



c) OPCC+ 125ZW (RW) d) OPCC+ 125ZW (TW)

Figure 10. SEM images of samples prepared with OPCC + 125ZW (RW + AR+ SW+TW) at 90 days in tidal area

CONCLUSION

First results presented here show initial characteristics of the effect of five Sources of mixing water on produce more durable concrete. It is possible to use incorporation of OPCC + 125ZW (RW+AR+ SW+TW) to improve workability, durability, compressive strength and microstructure. The higher specific area of water has a positive effect on workability and hydration process cement particles. In addition, OPCC + 125ZW (TW) has high pH value which has a positive effect of workability and hydration process, so the best water mixture on durability of concrete is OPCC+ 125ZW (TW). The real-time monitoring or the punctual tests of chlorides ingress and of the corrosion evolution will enable to collect precise information on damage. The samples having the most important ion content is OPCC+ 125ZW (AR),so the bad water mixture has a negative effect on durability of concrete is OPCC+ 125ZW (AR).

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