# Effectiveness of wax/water emulsions (w/w) of curing compounds for mortar

Efectividad de emulsiones aceite/agua
en el curado del concreto

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## Abstract

Twenty-nine emulsions were proved experimentally to implement them as a form of treatment for Water Retention efficiency (WR) and prevention of rapid evaporation of free water on concrete. All emulsions were evaluated in two different concentrations of Total Dissolve Solids (TDS) (at lower level 10 %-15 % w/w and at higher level 27 %-30 % w/w). At higher TDS, cationic emulsion B2 showed the best percentage of WR 91 % (IC 95 %97.5% - 99.99%). There were others emulsions that present a significant response of WR (emulsions G non-ionic, F non-ionic and G2 cationic). At lower level of TDS, emulsion D has showed to be the best with 74 % of WR, therefore emulsions A1, A3, B, C, E had very good water retention with 95 % CI ranged from 52 % to 74 %. All emulsions evaluated at lower TDS showed worst WR than emulsion evaluated at higher TDS (B2, G, F and G2). In a multivariate analysis, environmental variables like relative moisture (RLV), Temperature and Water Adding (Water.gr) have not affected. However, interaction of high levels of RLV and lower levels of temperature showed a positive correlation with retention water in emulsions G2 and D after 72 hours of drying. In conclusions cationic emulsions G, F, G2 and B2 evaluated at higher level of TDS were better than those evaluated at lower level of TDS. To implement curing compound for concrete is not recommended to use curing compounds at lower levels of TDS.

### Key words

Curing compounds for concrete, waxes, environmental factor, Total Dissolve Solids, multivariate analysis, environmental variables.

## Resumen

Se evaluaron experimentalmente 29 emulsiones, utilizando diseños factoriales y análisis de varianza ANOVA, con el fin de implementarlas como una forma de tratamiento para la retención de agua (WR) y la prevención de la evaporación rápida en procesos de secado de concreto. Todas las emulsiones se evaluaron en dos concentraciones diferentes de sólidos disueltos totales (TDS) (en el nivel más bajo, 10 %-15 % p/p y en el nivel más alto, 27 %-30 % p/p). A mayor TDS, la emulsión catiónica B2 mostró el mejor porcentaje de WR 91 %, con un intervalo de confianza del 95 % (IC 95 %), que varió de 97.5 % a 99.99 %; además, hubo otras emulsiones que presentaron una respuesta significativa de WR (emulsiones G no iónico, F no iónico y G2 catiónico). A un nivel más bajo de TDS, la emulsión D demostró ser la mejor, con un 74 % de WR; por tanto, las emulsiones A1, A3, B, C, E tuvieron muy buena retención de agua con un IC del 95 %, el cual osciló entre el 52 % y el 74 %. Todas las emulsiones evaluadas con TDS más bajos mostraron peor WR que las emulsiones evaluadas con TDS más altos (B2, G, F y G2). En un análisis multivariante, variables ambientales, tales como la humedad relativa (RLV), la temperatura y la adición de agua (Water.gr), no afectaron de manera significativa la eficacia de la mejor emulsión probada en alta y baja TDS. Sin embargo, la interacción de niveles altos de RLV y niveles más bajos de temperatura mostró una correlación positiva con la retención de agua en las emulsiones G2 y D, después de 72 horas de secado.



### Palabras clave

Compuestos de curado para concreto, ceras, sólidos disueltos totales, análisis multivariante, variables ambientales.

# Introducción

Curing could be defined like the process in which the concrete is protected from loss of moisture and kept within a reasonable temperature range. The result of this process is increased strength and decreased permeability. Curing process is a key stept in mitigating cracks in concrete, which durability severely impacts (Chyliński, Michalik, and Kozicki 2022).Throughout history, many labor-intensive methods have been used to control moisture during the curing process for newly placed concrete. Older methods such as: water ponding, covering with wet burlap or plastic sheeting were implemented to improve curing and to prevent water evaporation from the exposed surfaces. These methods are not acceptable anymore because they require more monitoring at the beginning of the process, its labor expend many time, can not be applied easily over extensive areas, and it is not give a better aesthetic appearance like the use of curing compound for concrete (CCs) (Kropp et al., 2012).

After the first year of service on some urban paving projects, many for seasonal countries have been observed an increase in concrete scaling, mainly due to chloride laden snow whose subsequent melting left evidence of deterioration of the pavement. All paved roads are expected to last for a specific period of time (20-30 years). Concrete must also be able to withstand heavy loads, fatigue, changing weather conditions, abrasion and possible chemical reactions. The duration and type of curing plays a big role in determining the required materials necessary to achieve a high level of quality (El-Maaty Behiry, 2012).
The infiltration of water on asphalt or concrete could be prevented trough a correct curing, in both cases this phenomenon is unavoidable and originates from several sources: it can infiltrate through cracks on the surface, interconnectivity of the air-void system or cracks from the bottom or the sides because of an increase in the ground water level. Another factor leading to the presence of water is inadequate drying of the aggregate during the mixing process. Lack of drying the aggregate during the mixing process can lead to the presence of water in the pavement as well (Kringos & Scarpas, 2008).

Durability of asphalt and concrete mixtures depends on different environmental factors: temperature, precipitation and air. In mild climates, where good-quality aggregates are available, the most evident cause of deterioration of asphalt mixtures is heavy traffic causing distress, fatigue cracking, rutting (permanent deformation) and raveling. Nevertheless, when a severe climate is present, stress increases due to poor materials, incorrect curing of concrete, inadequate control, heavy traffic and water are key elements in the degradation of concrete pavements (El-Maaty Behiry, 2012). According to the level of moistures, many factors affect the degree of moisture damage in asphalt-concrete mixtures; some of them are related to the formation of hot mix asphalt such as aggregates and bitumen; other variables related to mixture design and construction (air void level, film thickness, permeability, and drainage); environmental factors (temperature, pavement age, freeze-thaw cycles, and the presence of ions in the water); type of traffic conditions; and the properties of the additives (Özen, 2011). As traffic becomes heavier and the volume of truck increases, the amount of stripping becomes greater and the problem could be worse. More moisture damage typically occurs in areas where there are considerable amounts of rain and snowfall.

Curing Compounds like wax/water emulsions (CC) came on approximately 40 years ago offering an attractive improvement to retain moisture. CC are used to achieve the best use of concrete and to ensure an adequate performance of it. These compounds are designed to prevent evaporation of free water by forming a continuous hydrophobic membrane on concrete surface and isolating the plastic mortar from the atmosphere, optimizing the properties for better performance when it is used (Mindess et al., 1981). For maximum performance, to reach the desired structural and durability properties, it is well known that adequate curing is paramount, especially if the concrete is going to be subject to wear, to be exposed to aggressive solutions or drastic weather conditions (such as freezing and thawing).

Nowadays, there are different types and specifications of membrane forming of CC like: wax emulsion, linseed oil emulsion and polyamide emulsions (PAMS) and others newer formulations of curing and sealing compounds like chlorinated rubber epoxy and clear acrylic (Brewer et al., 1999).

Curing is more important today because: 1. After placing the concrete, newest cement are stronger and allow contractors to take away formwork sooner after the cements dry. It takes less time for the concrete to gain strength. 2. When using High Performance Concrete (HPC), lower quantities of water are been used because this increases the self-desiccation and curing is necessary to control this phenomenon. 3. Today many of concrete mixtures included mineral admixtures like ground granulated blast furnace slag and fly ash, which reacts slowly; to guarantee the resistance and correct properties of these mixtures during longer periods after curing time.

HPC, it is a concrete that acquire higher strength and higher durability thanks to their ingredients and proportions, which are particularly chosen depending on the necessary properties for a specific structure. The concrete that is going to be used contains fly ash, which help to enhance strength gain, improve durability, and control the quantity of the initial heat generation; this type of concrete, being cured, will become in a paste that is more resistance to chemical attack and lower permeability compared to convencional concrete (Meeks & Carino, 1999).

Since 1900's, there have been different requirements for a proper use of curing compounds in concrete: adequate water content, maintain adequate temperature, preservation of reasonably uniform temperature throughout the concrete body, adequate protection from damaging mechanical disturbances during the early period of curing, and adequate time for sufficient hydration (Goel et al., 2013). Some codes were created to enhance and evaluate each property of the concrete for different concrete institutes, one of them is ASTM C 156: standard test method for water loss from a mortar specimen through liquid membrane-forming compounds for concrete. This code will be a guide to proceed properly in the implementation of curing compounds in concrete.

This research was done in a petrochemical company which manufactures asphalt-concrete mixtures with potential to be used in countries with drastic climate change. The purpose for this research is to evaluate different types of curing compounds on the surface of concrete as a form of treatment for water retention and prevention of rapid evaporation. Also, to determine the effect of the best emulsions concentration on water retention. Finally we evaluate the influence of particle size, viscosity, pH and environmental conditions (room temperature and relative humidity) during the drying process in emulsions.

## Method

### Materials and mixture proportions

Type of cement used for preparing concrete and mortar specimens was CEM II/B-V 32,5 R®, also known as Portland-fly ash cement of a class 32,5 R (rapid (higher) early strength, tend to gain higher strength over a longer period). Its main constituents are Portland clinker between 65-79 % w/w, siliceous fly ash between 21-35 % w/w and others 0-5 % w/w. Gypsum is used as a setting regulator. This type of cement has the following properties: good workability, reduce bleeding, reduce heat hydration leading to a reduce risk of early thermal cracking, increase resistance to both the conventional (ettringite) and the thaumasite (TSA) form of sulfate attack and decrease rate of chloride ingress leading to a reduce risk of corrosion reinforcement. The total mass of mortar needed was 3,145 g, where 4/7 parts of it was sand Rhin.0/2.18713.2 (1797,14 g), 2/7 parts of cement (898,57 g) and 1/7 part of tap water (449,28 g).

The most important aspect for preparing concrete that affects all of this properties is the amount of water used in the mix, this called cement: water ratio of by weight.

## Curing Requirements

Laws and Standards used to performance this project are listed below, all experimental condition were according to those laws:

*ASTM C 156*: Standard Test Method for Water Loss from a Mortar Specimen through Liquid Membrane-Forming Curing Compounds for Concrete:

This test method covers laboratory determination of the efficiency of liquid membrane-forming compounds for curing concrete, as measured by their ability to reduce moisture loss during the early hardening period.

Many factors affect the laboratory test results. Test results obtained may be highly variable as indicated by the precision statement. Critical factors include the precision of the control of the temperature and humidity, preparation and sealing of the mortar specimen when the curing product is applied, and the uniformity and quantity of application of the curing membrane. Molds shall be of metal, glass, hard rubber, or plastic, and shall be watertight and rigidly constructed to prevent distortion during molding of the specimens or handling of the mold containing fresh mortar. They shall have a minimum surface area of 12000 $mm^2$ (18.6 $in.^2$), and a minimum depth of 19 mm (3/4 in.). The top surface shall be round, square, or rectangular with length not more than twice the width Room temperature and of all materials when used in this test shall be 23 ± °٢C (°٤ ± ٧٣F) unless otherwise specified, and the room humidity shall be ٥٠ ± 10 %, except the cases where temperature and relative humid were changed intentionally.

A set of three or more test specimens shall be made in order to constitute a test of a given curing material. To Determine the sand content of the mortar by adding dry sand to a cement paste having a water-cement ratio of 0.40 by weight. Note: The sand: cement ratio required varies with the source of the cement. A ratio of 2.5:1 is suggested as a starting point Flow may be determined on a 3 to 4 kg batch of mortar, which is conveniently mixed in the mixer.

If no rate is specified, apply the curing compound at the rate of 5.0 $m^2$ /L (200 $ft^2$ /gal). The method of application shall be in accordance with the manufacturer's recommendations. Application shall be made expeditiously to only one specimen at a time.

Specimens shall be stored in the test cabinet for 72 h, then removed, and immediately weighed. The purchaser may specify other test times (Nahata, Kholia, and Tank 2014).

**British Standard BS 8110, code of practice for design and construction of concrete structures**

Curing is the process of preventing the loss of moisture from the concrete whilst maintaining a satisfactory temperature regime.

Curing and protection should start immediately after the compaction of the concrete to protect it from: premature drying out, particularly by solar radiation and wind; high internal thermal gradients; low temperature and frost". Surfaces should normally be cured for a period not less than 3 days for OPC, RHPC, SHPC with a temperature above 10ºC (Arya 2018). Water-cement ratio attends an important role in producing concrete strength and workability. The lower the ratio, the greater is the strength of concrete. In the British standard specifications the w/c ratio required for a proportion of 1:2:4 is 0.58 (Wang et al., 2020)

***CEB-FIP (Euro-International Committee for Concrete-International Federation for Prestressing) Model Code 1990***

This code will help to standardize and harmonize basic criteria for the design and construction of concrete throughout the member countries. Concrete Technology, deals with curing and protection of concrete.

In order to obtain the potential properties to be expected from the concrete, through curing and protection over an adequate period of time are vital. It is essential that curing and protection start immediately after compaction of the fresh concrete (Gardner 2005).

Concretes made of cements containing high amounts of constituents other than portland cement clinker (CEM II 32.5, CEM III 32.5, and CEM IV 32.5), the duration of curing should be 3 days, T > 10ºC, exposed to medium sunshine or medium wind velocity or relative humidity RH: 50 % <RH<80 %", except where temperature and relative humid were changed for experimental reasons in this project". Rate of development of impermeability should have a water-cement ratio 0.5-0.6 for cement class R.(Shetty & Jain, 2019).

***European Committee for Standardization, Prestandard ENV 206: Concrete Performance, Production, and Compliance Criteria.***

In order to obtain the potential properties to be expected from the concrete especially in the surface zone, thorough curing and protection for an adequate period is necessary:

Curing and protection should start as soon as possible after compaction of the concrete. For medium strength development of concrete, temperatures of the concrete during curing above 15 ºC, and exposed to medium sunshine or medium wind velocity or relative humidity not lower than ٥٠ % the concrete should be cured for 3 days. A concrete with a medium rate of strength development the w/c ratio should be less than 0.5, for cement strength class 32,5R and 42.5 (Buyle-Bodin & Hadjieva-Zaharieva, 2002).

## Test specimens

Cubical concrete specimens were molded to evaluate and compare the humidity loss in mortar. Each mortar was filled up in plastic boxes with a measurement of 240*245*40 $mm^3$ and an average weight of 172,45 g.

All the constituents to make the mortar were mixed in a major classic chef mixer machine approximately for 9 to12 minutes to obtain uniform consistency. After mixed, each box was completely filled with the mortar in one layer and stroked the surface flat. Therefore, the water on the surface of the mortar was removed after one hour and a specific dose of curing agent was sprayed on the surface of each mortar. The weight of each sample was taken after 1,2,3,4,24,48 and 72 hours of drying.

All the process was dried at room temperature and relative humidity during a period of 48-72 hours under laboratory conditions.

## Surface preparation

Prior to the application of the curing agent over the surface, the weight of the sample was taken again after removing the extra water that bled during the first hour of drying at room temperature. Using the convex part of a spoon tried the surface of the concrete was made to look as uniform and flat as possible.

***Curing compounds used***

Twenty-nine different types of emulsions were selected. Almost all samples were formulated differently with a 10 %, 15 %, and 28-30 % concentration of wax. Approximately 18g of curing compounds were used over the concrete for each specimen and applied directly after an hour of concrete bleeding and it was allowed to dry for 48 to 72 hours. The curing agent was sprayed with a plastic atomizer to assure a homogeneous layer covering the surface of concrete.

Table 1 presented the principal characteristics of the emulsions evaluated in this project.

**Table 1**
*Types of emulsions evaluated*

| CHARACTERISTICS | |
|---|---|
| Anionic emulsion based on pure waxes for curing | A |
| Emulsion A modified, anionic | A1 |
| Emulsion A modified, anionic | A2 |
| Emulsion A modified, anionic | A3 |
| Emulsion A modified, anionic | A4 |
| Emulsion A modified, anionic | A5 |
| Emulsion A modified, anionic | A6 |
| Emulsion A modified, anionic | A7 |
| Emulsion A modified, anionic | A8 |
| Emulsion A modified, anionic | A9 |
| Emulsion A modified, anionic | A10 |
| Emulsion A modified, anionic | A11 |
| Cationic emulsion based on pure waxes for curing | B |
| Emulsion B modified, cationic | B1 |
| Emulsion B modified, cationic | B2 |

| | |
|---|---|
| Emulsion C modified, anionic | C1 |
| Emulsion C modified, non-ionic | C2 |
| Non-ionic emulsion based on pure waxes for curing | C |
| Not specified, anionic | D |
| Not specified, non-ionic | E |
| Non-ionic emulsion based on pure waxes for curing | F |
| Emulsion F modified, non-ionic | F1 |
| Emulsion F modified, cationic | F2 |
| Non-ionic emulsion based on pure waxes for curing | G |
| Anionic emulsion based on emulsion G | G1 |
| Cationic emulsion based on emulsion G | G2 |
| Not specified, cationic | H |
| Not specified, cationic | I |
| Not specified, cationic | J |

*Note*. Own source

## Test procedure

### *Water retention*

All samples of CC showed on Table 1 were formulated at different levels of concentration: 10 %, 15 %, and 28-30 %. The response variable (water retention) was calculated after drying during 48 or 72 hours to find the major retention of water as follow:

$$Water\ Retention = 1 - \frac{|Initial\ water - Evaporated\ water|}{Initial\ water} \quad (1)$$

To determine which emulsion is the best, a Randomized Completed Design was performed and ANOVA test was used to determine the emulsions that increased significantly water retention (WR), additionally a Tukey test was performed to determine homogeneous groups with a confidence of 95 % (González & Vaamonde Lise, 2013; Montgomery, 2012).

***Best emulsion at highest and lowest level of Total Dissolved Solids (TDS) concentration***

To determine the best emulsion based on highest and lowest level of TDS concentration, a factorial experimental design was used: the first factor was type of emulsion (A, B, C…) and the second factor was doses at different levels. High concentration of TDS is defined in a range of 27 %-30 % w/w and a lower level of TDS was defined as 10 %-15 % w/w. ANOVA was used to determine which emulsions increased water retention.

***Environmental variables affecting water retention***

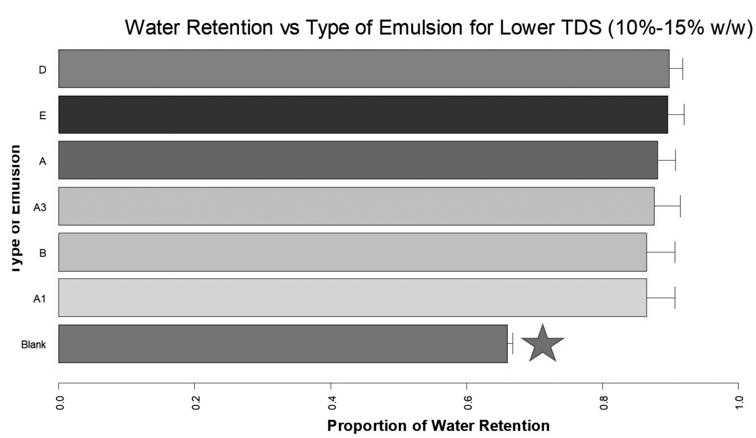
To determine the effect of environmental variables on water retention a Canonical Discriminant Analysis; Proximate Analysis; Classification and Regression Tree Analysis of all quantitative variables (pH, viscosity, total dissolved solids, room temperature and relative humidity and water added to concrete test specimen) were used to determine how them could affect or maximize the percentage of water retention. Data was fitted out using a multi-correlation matrix and we selected the model which has the highest canonical coefficient. Additionally a canonical multivariate discriminant analysis was used to determine the differences of the best emulsions based on the variables describe previously. For this design we accepted a canonical model coefficient rather than 80% (De'ath & Fabricius 2000; Ford, 2005; González & Vaamonde Lise, 2013).

## Results

**Water retention in higher and lower Total Dissolved Solids (TDS) concentration**

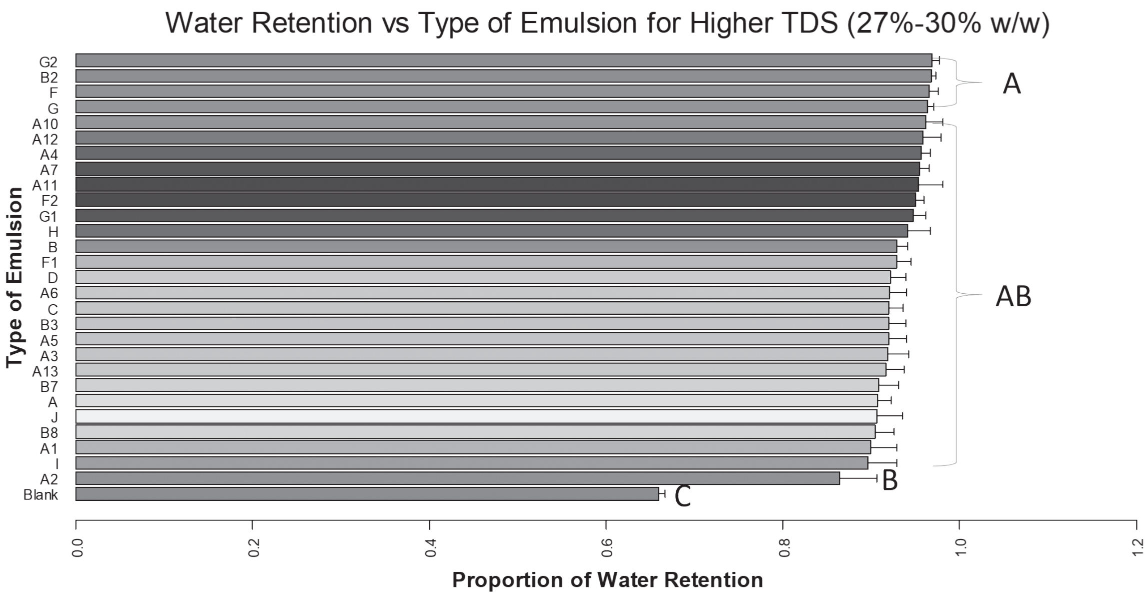
Emulsions listed in Table 1 were evaluated at lower and higher TDS concentration. A Randomized Uni-factorial Design (RUD) was performed where the main factor was "Type of Emulsion". In this design we subset a filter of Total Dissolve Solid (TDS) >0,27 % and drying time (DT) >48 hours. A Tukey test of homogeneous groups was implemented to identify better emulsion; the results was shown in Figure 1:

**Figure 1:** water retention vs type of emulsion for lower TDS (10% - 15% w/w)




***Note.*** Own source

**Figure 2:** water retention vs type of emulsion for higher TDS (27% - 30% w/w)




***Note.*** Own source

Figures (1 and 2) shows the Proportion of water retention vs. Type of Emulsion for lower (Figure 1) and higher (Figure 2) TDS concentration. On Figure 1, a Kruskall-Wallis test was implemented and the asterisk indicates tendency but not statistical differences (*P-value > 0.5*). On Figure 2, letters on the right side indicate homogenous groups according to Tukey test with 95 % confidence intervals. For both Figures, data filter was done on DT>48 h (Time of Curing (DT)) using R statistical software (Core Team, 2014).

In Table 2, we present the summary stats of retention water for emulsions A, A1, A3, B, D and E. Retention water (WR) is the proportion of water retained after a drying of 48 hours. Standard error is associated to the treatment combining Type of emulsion and TDS proportion; LL indicates Lower Level and UL Upper Level at 95 % of confidence. Homogeneous test using Tukey is determined with a 95 % confidence interval.

**Table 2** *Characteristics of the Emulsions Evaluated at Lower Concentration of TDS (10 %-15 %)*

| Type of Emulsion | TDS Proportion | Sample size (N) | Retention Water (median) | LL (CI-95%) | UL (CI-95%) | Group (Tukey Test) |
|---|---|---|---|---|---|---|
| A | 0.1 | 4 | 0.6877 | 0.6501 | 0.7304 | A |
| A | 0.15 | 4 | 0.6898 | 0.6567 | 0.7142 | A |
| A1 | 0.1 | 4 | 0.6537 | 0.6197 | 0.6876 | A |
| A3 | 0.1 | 4 | 0.6848 | 0.6611 | 0.7147 | A |
| B | 0.1 | 4 | 0.6527 | 0.6260 | 0.6812 | A |
| Blank | 0 | 130 | 0.6506 | 0.5238 | 0.8132 | A |
| D | 0.1 | 7 | 0.6996 | 0.6301 | 0.7302 | A |
| D | 0.15 | 4 | 0.6972 | 0.6604 | 0.7380 | A |
| E | 0.1 | 8 | 0.6944 | 0.6390 | 0.7403 | A |

***Note.*** Own source

According to Figure 1and Table 2, at lower concentration of TDS (10-15 % w/w), there is not an emulsion that showed statistical differences between all the specimens evaluated including the blank: all emulsions have a 95 % confidence interval (CI) ranged between 58 % and 74 % of water retention after 48 hours of curing; nevertheless, emulsions A1 and B had shown the worst tendency.

Conform to Figure 2, at higher concentration of TDS (27 %-30 % w/w), emulsions who had shown a better response retaining water are in order of appearance: G2, B2, F and G, they were classified with the letter A according to Tukey Test and have a 95 % CI ranged from 93 % to 97 % of WR.

Emulsions A, A1, A3, A4, A5, A6, A7 A10, A11, A12, A13, B, B3, B7, B8, C, D, F1, F2, G1, H, I and J are in a second status of water retention presenting a CI between 90 to 94 % and whose nomenclature was AB; those emulsions could have a good response on the study (statistically different from blank), but its necesary to improve them. Emulsion A2 had the worst tendency and its CI was from 84 % to 92 % and was classified into group B which corresponds to Tukey Test, but statistically different from blank.

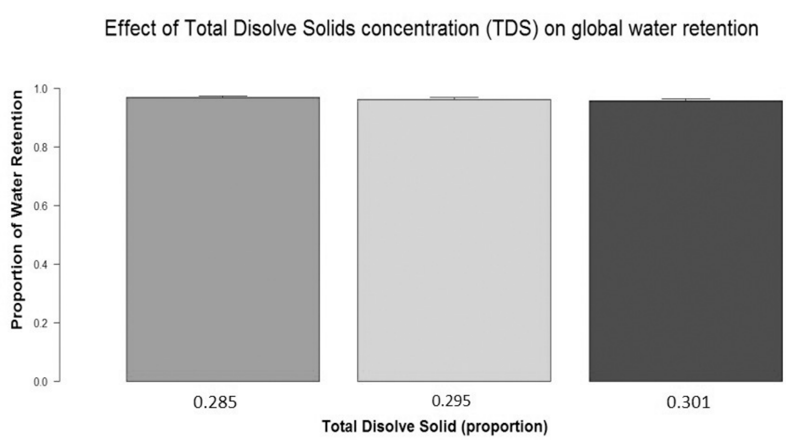
In conclusion, for both studies (lower and higher concentration) emulsions B2, G2, F and G evaluated at higher percentage of TDS had better water retention than emulsions A, A1, A3, B, D and E evaluated at lower percentage of TDS. In the last group, all the emulsions did not show a statistical significant difference in response of WR respect with the blank (no curing used on it), which indicates that at lower doses of TDS (0.1-0.15 w/w) these emulsions were detrimental for water retention in concrete (Figure 1). Emulsions B2, G2, F and G with a 95 % CI ranged from 95.5 % to 99 % of water retention were selected and they had a better response compared with all the emulsions evaluated.

Trying to explain how physical properties affects water retention on emulsions, we are going to determine how different concentration of TDS modify the percentage of water retention on a selected emulsion.

**Effect of different levels of Total Dissolve Solid (TDS) on selected emulsion**

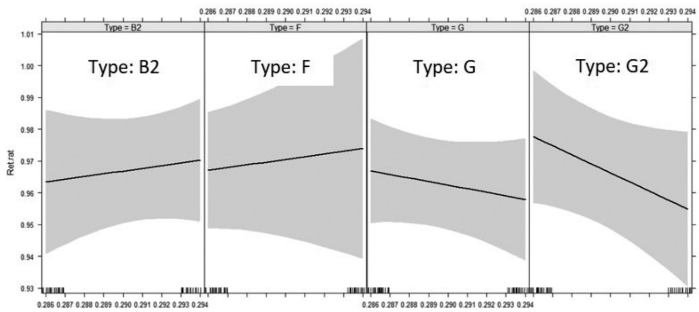
To determine the effect of different levels of TDS, emulsions B2, G2, F and G were selected according to Figure 1 and 2. A Uni-factorial Design was performed and the results are presented in Figure 3 and 4:

**Figure 3:** effect of total dissolve solids concentration (TDS) on global water retention




***Note.*** Own source

**Figure 4.** Proportion of Water Retention (Ret.rat) vs Type od Emulsion and TDS proportion.




Anova Table (Type II tests)

Response: Ret.rat

| | Sum Sq | Df | F value | Pr(>F) |
|---|---|---|---|---|
| Type | 0.0144 | 5 | 0.1939 | 0.9648 |
| TDS | 0.0377 | 1 | 2.5422 | 0.1117 |
| Type:TDS | 0.0778 | 3 | 1.7500 | 0.1564 |
| Residuals | 5.3674 | 362 | | |

*Note*. Own source. ANOVA table is presented on upper center of Figure 4: there are not statistical differences between the interaction of TDS and Type of Emulsions (Anova, P-value > 0.05)

InFigure 3, emulsions B2, F, G and G2 could be used as a curing compound with a TDS proportion rather than 0.285, this range of concentration guarantee a water retention in a bigger value of 0.955 after 48 hours; in fact, as it can be seen it in Figure 4, there is not a statistical difference between all TDS evaluated and the Type of emulsions according to the ANOVA table; nevertheless emulsions B2 and F presented a similar water retention behavior: at level of 0.286 of TDS, these emulsions exhibit a lower tendency in water retention (95 % CI from 0.955 to 0.998) and in a higher level of TDS (0.301) exhibit the best result of water retention (95 % CI from 0.97 to 1.000). Emulsions G and G2 show the opposite behavior: at lower level of TDS (0.286) showed the best percentage of water retention (G2: CI from 0.976 to 0.998 and G: CI from 0.975 to 1) and for a higher percentage of TDS (0.301) showed the worst efficiency in water retention (G2: CI from 0.962 to 1.000 and G: CI 0.945 to 1.000). All emulsions were statistically different with the blank (Table 3, Tukey test).

To evaluate the behavior of lowers TDS emulsions, the following Table showed the summary stat of Water Retention (WR) for these emulsions: Rows highlighted on Table 3 exhibit the best treatment of every emulsion used.

**Table 3:** *Statistical Summary of Water Retention for emulsions A, A1, A3, B, D and E. Retention water (WR) is the proportion of water retained after a drying of 48 hours.*

| Type of Emulsion | TDS Proportion | Sample Size (N) | WR Median | Standard Error (SE) | LL (CI - 95%) | UL (CI - 95%) | Group (Tukey test) |
|---|---|---|---|---|---|---|---|
| Blank | 0.000 | 130 | 0.651 | 0.0076 | 0.636 | 0.665 | B |
| B2 | 0.285 | 15 | 0.976 | 0.0109 | 0.955 | 0.998 | A |
| B2 | 0.295 | 21 | 0.988 | 0.0068 | 0.975 | 1.000 | A |
| F | 0.285 | 29 | 0.993 | 0.0099 | 0.974 | 1.000 | A |
| F | 0.301 | 21 | 0.988 | 0.0091 | 0.970 | 1.000 | A |
| G | 0.285 | 29 | 0.996 | 0.0109 | 0.975 | 1.000 | A |
| G | 0.295 | 21 | 0.989 | 0.0106 | 0.968 | 1.000 | A |
| G2 | 0.285 | 18 | 0.987 | 0.0056 | 0.976 | 0.998 | A |
| G2 | 0.295 | 13 | 0.983 | 0.0194 | 0.945 | 1.000 | A |
| G2 | 0.301 | 21 | 0.987 | 0.0128 | 0.962 | 1.000 | A |

*Note*. Own source. *Standard error is associated to the treatment combining Type of emulsion and TDS proportion; LL indicates Lower Level and UL Upper Level at 95% of confidence. Homogeneous test using Tukey is determined with a 95% confidence interval. Treatment Highlighted indicates the best treatment associated to every emulsion used.*In next section we consider the effect of environmental variables on the emulsions selected previously, the best emulsions selected were: G2, G, B2 and F with a median of retention water rather than 0.985 (Tables 2 and 3).

## Influence of environmental variables on better emulsions

### *Environmental effects on water retention for emulsions B2, F, G2 and G*

Independently of the previous analysis, better emulsions were evaluated to establish how their behavior is affected by different environmental variables like: relative humidity (RLV), concentration of total solids dissolved (TDS), room temperature (Temp.) and grams of Water used (Water.gr). To this, a Multivariate Analysis was performed and the blank was chosen as reference for all emulsions evaluated. Emulsions A, A1, A3, B and D were used as a negative control for this analysis. The result is presented on Figure 3.

Figure 5) shows the ellipses that grouped similar emulsions based on quantitative variables; Figure 6 shows a canonical discriminant box and whiskers diagram to specify the quantitative variables that explain differences between emulsions, and Figure 7 shows the proximity of all emulsions based on TDS, RLV (% Relative Humidity) and proportion of Water Retention (Ret.rat). Other variables used for the analysis are Temperature (Temp.) and Water added to test specimen concrete in grams for every treatment (Water.gr); as you can see on Figure 6 This canonical model explains the 89,3 % of the observed variability.

In Figure 5, ellipses represent the way that every emulsion behaved based on quantitative variables (TDS, RLV, Temp and Ret.rat or WR). As it can be seen, three different groups appeared: first group, called "First", is located upper on left corner of the Figure 5 and it is formed by emulsions B2, F, G and G2; a second group, it is called "Transition", conformed by emulsions A1, D and E is located between Blank and the first group; and group third named "Control" conformed by Blank, emulsions A3, B and A. All groups (First, Transition and Control) classify the emulsions according to similar behaviors based on quantitative variables analyzed (TDS, RLV, Water.gr, Temp. and Drying time).

Based on Figure 6 and Figure 8, proportion of Water Retention (Ret.rat) and TDS are the variables that explain in a better form the differences between the groups, in fact "First" and "Transition" groups had a tendency to have a better TDS and Retention Water (Ret.rat) than blank (arrow direction and length of the line indicates the effect of the variable on the Type of emulsions). As it hope, percentage of Relative Humidity (RLV) vary in an inverse way with temperature (Temp.) and did not affect significantly the Water Retention of each emulsions (the length of arrows are smaller).

Finally, emulsions B2, F, G and G2 were classified using a Canonical Discriminant Analysis as the better emulsions associated with a higher level of TDS and a higher level of retention water (Ret.rat) with a TDS>0.9; Water.gr > 412 but < to 430 and temperature > 26 °C in the majority of the cases (Figure (4)), additionally these emulsions shows the lowest variability associated to the longitude of Box and Whiskers (Figure 6). Environmental variables like RLV, Temperature and Water Adding (Water.gr) did not affect in a significant way the efficacy of these emulsions based on the longitude of the arrows compared with TDS and Ret.rat; but it is favored to have a higher RLV and lower Temperature to improve retention water of these emulsions (Figure 6. Arrows of RLV are in same direction of Ret.rat arrows, this imply that Ret.rat tends to increase in order to increasing RLV). Additionally, emulsions classified in "First" group presented similar characteristics, some of them are specified in Figure 4: Water Retention are rather than 0.9 and Water.gr are between 419g and 436 g; this indicates that a concrete mix with higher amount of water could be contribute with emulsions in a correct curing concrete.

**Figure 5:***Canonical Discriminant Analysis applied to emulsion B2, G2, F and G with Blank, emulsions A, A1, B, D, E and F as a controls*

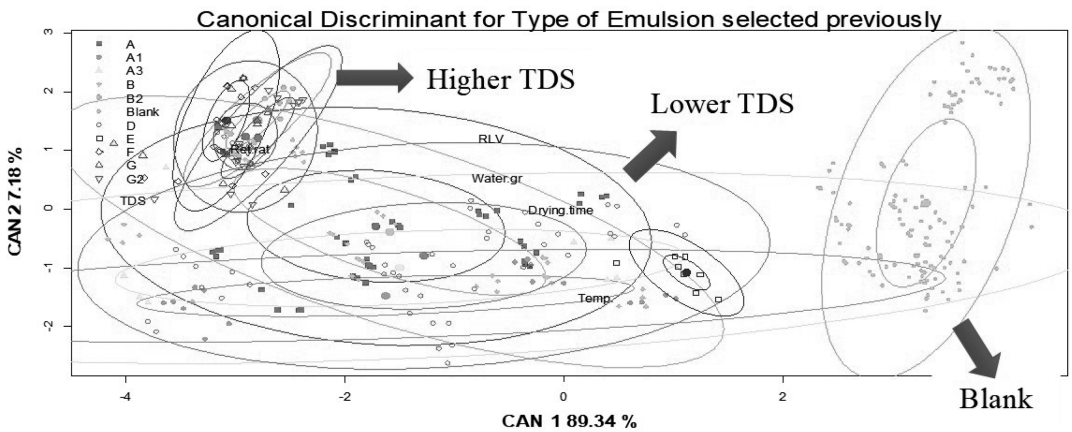



**Figure 6:***Canonical Discriminant Analysis applied to emulsion B2, G2, F and G with Blank, emulsions A, A1, B, D, E and F in one dimension*

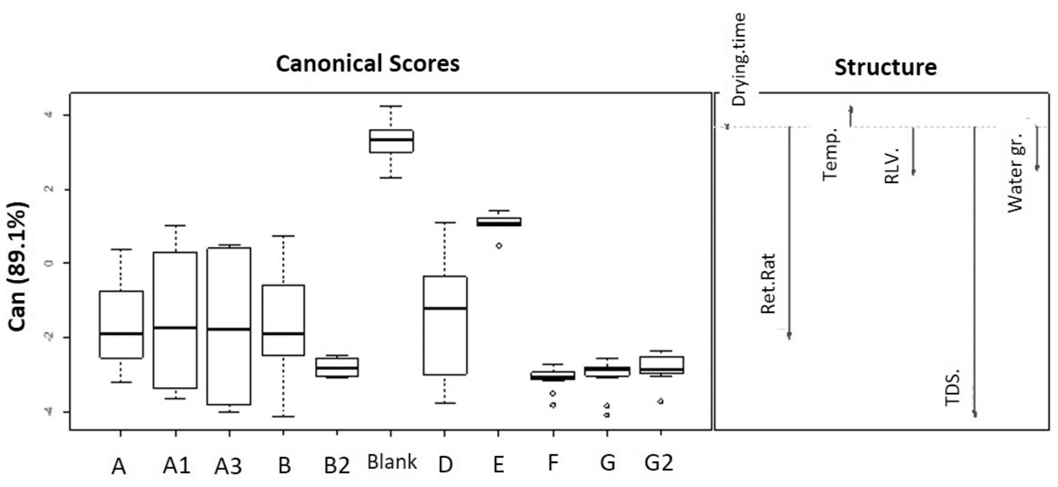
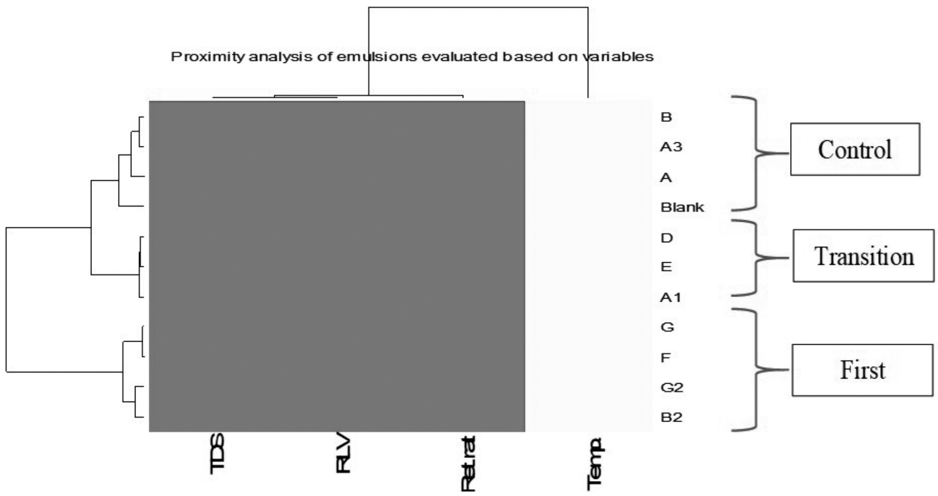


**Figure 7:** *cluster analysis of emulsions according to TDS, RLV, Ret.rat and temperature*




*Note*. Own source.

***Environmental effects on water retention for the best emulsion analyzed: B2***

To characterize appropriately the best emulsion found it in this study (B2), a Multi-correlational Analyzes could be conducted in R software. In Figure 5, we present the result according to this objective.

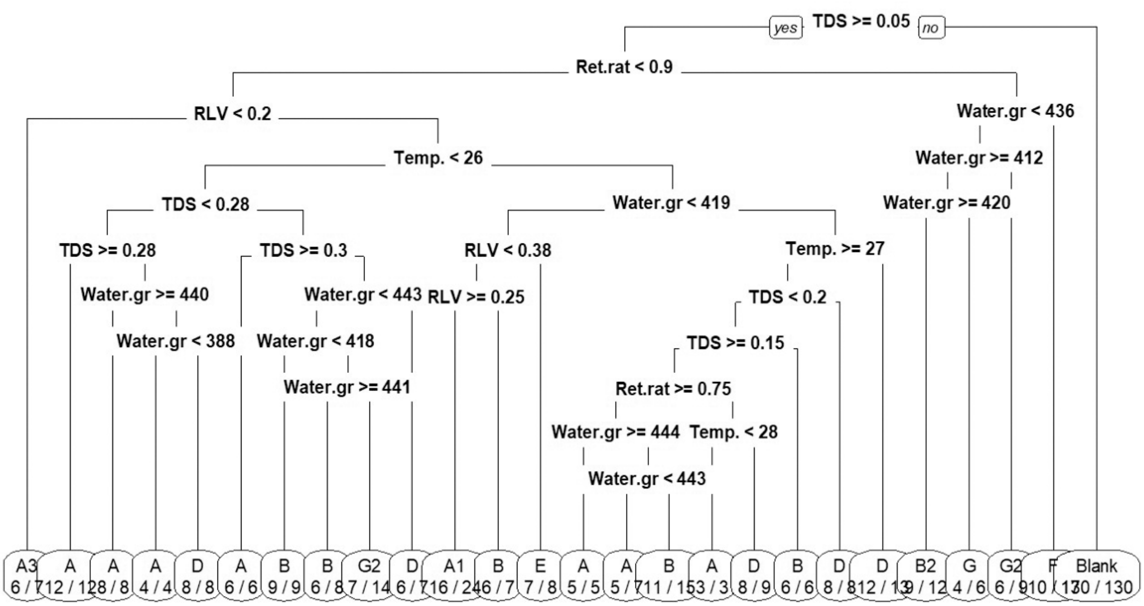
Figure 9 shows the model coefficient matrix that correlate all independent variables with Water Retention (Ret.rat) (R-squared > 0.9). This Figure present matrix scatter plot and tendencies lines associated to the interaction of dependent variable (first column) with all independent variables. Finally this figure present the hierarchical partitioning analysis that describes how the variables affect the variation of Water Retention.

According to Figure 9 emulsion B2 turns out to be more affected at the Drying time, follow by RLV, Water.g and TDS. Figure 5(A), all these variables have a significant participation on the regression model (*P-value < 0.05)*, only the Drying time variable explain nearly the 80 % of variation of Water Retention (Figure 5(C)): at 0 hour of Drying time the retention water is 100 %, while at 72 hours of Drying time the retention water is approximately 93

% (Figure 9, interaction panel between Ret.rat and Drying.time at first row); RLV explains nearly 15 % of Ret.rat, according to previous results (Figure 7), in fact, Ret.rat could be favored by high RLV values, this can be explained because at high levels of RLV, the coefficient of mass transfer between the concrete surface and air could be lower compared to lower values of RLV in air (Treybal, 1968). By last, TDS and Water.gr explain only 6 % of Ret.rat: this is because emulsion B2 was evaluated in few values of TDS (0.285 and 0.295) and few values of Water.gr (412 – 420), but, as a shown on Figure 2(B), its capacity of water retention increased as the level of concentration of TDS was increasing.

**Figure 8**

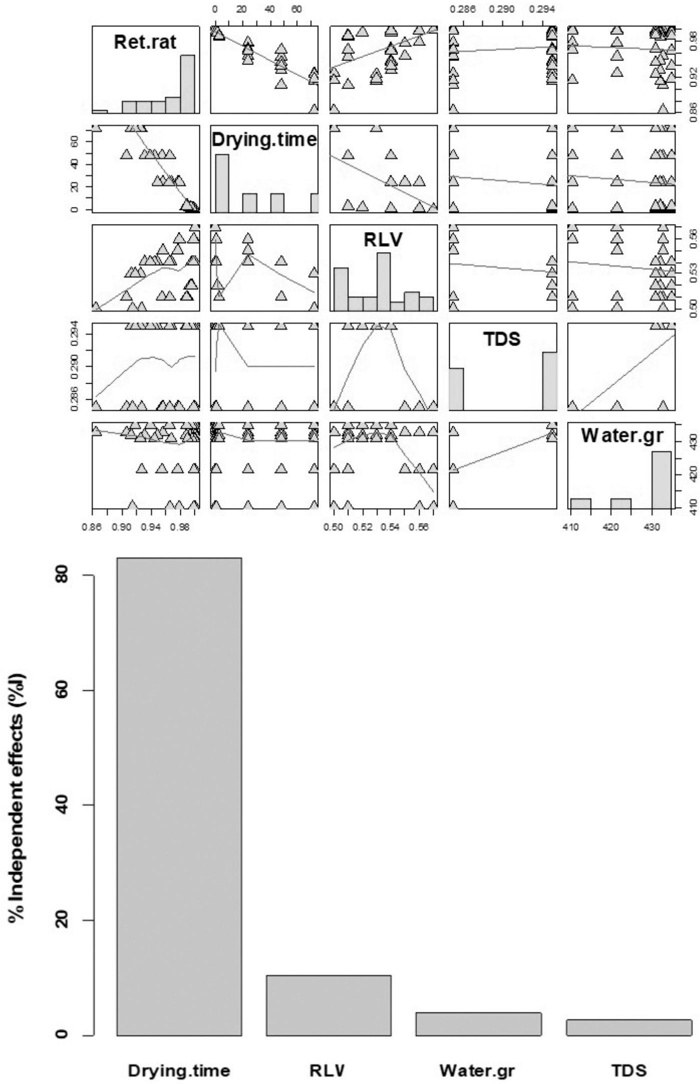
*Classification and Regression Tree Analysis that determines the types of emulsion based on different variables*




*Note*. Own source. . *It is noted that first group (B2, B, G2 and G) are classified in a Ret.rat rather than 0.9. The numbers below emulsions denotes number of cases of total cases described in the study*.

**Figure 9.**

*Multi-correlation and hierarchical partiotining analysis to evaluate the effect of Drying time, percentage of Relative Humidity (RLV), Water added to Concrete test specimen (Water.gr) and Total Dissolve Solids (TDS) on Retention Water (Ret.rat) for emulsion B2*




*Note*. Own source

## Comments

All the specimens of concrete were made in the same way (equal quantity the cement and sand) and a little variation in the quantity of water, but it is really important to understand that the specimens treated with a low percentage of TDS have not a huge impact retaining water. This could be because using less quantity of solids dissolved less and weaken will be the membrane-forming fraction formed, as result having a lower capacity to retain water or avoiding the quickly dry of the concrete caused by faster evaporation of water of the mortar or for being exposed to not favorable conditions in the environment.

The study at lower concentration of TDS was made to see and improve the behavior of water retention for all emulsions evaluated but the analysis had shown that there is not a single significant response that helps to use these emulsions in a lower concentration of TDS that guarantee a good performance as membrane for water retention.

According to ASTM C 156, if the amount of curing to use for curing the mortar is not specified, it should be use a rate of 200 $ft^2$/gal, in this project was used this number as a base and the amount of curing used was 150 $ft^2$/gal, which is not to far from the reference. Besides, depending on the type of cement to use, the relation water-cement could be different as the type of curing, the environmental conditions and different properties of concrete to enhance. This amount of cure has a favorable response to be implemented with emulsions that have a higher concentration of TDS .

According to ASTM 156, the environment conditions of the room are: temperature 23 ± 2 °C, relative humidity of the room shall be ٥٠ ± 10 % and drying time of 72 h, in fact, during this study, temperature of the room was around 21.5 ºC and room humidity of 49,61 %. This allowed the concrete to dry adequately and develop all its properties like strength and avoids self-desiccation. Also, in this study was employed the same time for almost all emulsions but for some of them was not possible to dry for that period of time, only was measured until 48 h to 72 h of dried.

Hydration is the step where concrete develop all of its properties, because that, a proper moist, curing and w/c ratio are important when it is decided to make concrete. Water/Curing (W/C) ratio of 0,42 is good for hydrated all the cement particles but it is used different rates of w/c ratio (0.4-0.7) depending on performance targets that are wanted. In this project a W/C ratio of 0.5 was implemented a little bit higher than the recommend for the code ASTM C156. Although, according to literature when it is used cements with high quality less W/C ratio is needed to develop properties like: compressive strength and durability (Jensen and Hansen 2001).

When the amount of water of the mix increases, the porosity, the shrinkage, the color and the strength are affected because more water than the necessary creates a diluted paste that is susceptible to cracking and micro-cracks, developing weak zones on the concrete. It is necessary a good mix design to have a good quality of concrete, and one part for having a good mix is a low w/c ratio (Wang et al., 2020).

## Conclusions

Twenty nine emulsions were tested in two scenarios, at lower concentration of Total Solid Dissolved (TDS 10 % – 15 %) and at higher TDS concentration (27 % – 30 %), to enhance their as curing compound for Water Retention (Ret.rat) as a response variable after 48 hours of Drying time: at lower TDS concentration no one emulsion showed statistical differences with blank (95 % confidence interval (CI) with Ret.rat that differ between 52 % and 74 % after 48 hours of Drying time); at higher concentration of TDS, emulsions B2, F, G and G2 exhibit an 95 % CI ranged from 95 % to 97 % after 48 hours of drying time with statistical differences with blanks and with the others emulsions evaluated at lower concentration of TDS according to Tukey test.

Discriminant Canonical Analysis shows that TDS and Water Retention (Ret.rat) were important variables, these explained in a better way the differences between the groups of emulsions. This analysis allowed to classify emulsions into three groups: "First" group conformed by the best emulsions (B2, F, G and G2), "Transition" group conformed by emulsions A1, D and E and "Control" group that did not have any significant difference with blank. In order to that, "First" group had the tendency to be more accurately; also, it had a major concentration of TDS and Ret.rat than "Control" and "Transition" groups. These ones are more reliance to be used as a curing compound for concrete than those ones at lower concentration of TDS.

Emulsion B2 demonstrated to be the best emulsion at the time of retaining water when it was evaluated to a concentration of 27-30 % of solids dissolved and showed an small change in Ret.rat from 100 % at 0 hour of Drying time to 93 % of water retention after 72 hours of drying. Additionally, its changeability wasn't much thanks to the fact that it was not so affected by the external variables like temperature and relative moisture RLV, also Ret.rat could be benefit with higher values of RLV.

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