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# Influence of Soap Factory Wastewater on the Physical and Mechanical Performance of Concrete

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**ABSTRACT**

The management of water resources is one of the major priorities in all countries of the world and even more so in developing countries such as Cameroon. The purpose of this research project is to assess the influence of the use of soap wastewater on the physical and mechanical performance of concrete. The experimental test program was designed to assess the impact of varying the concentration of soap factory wastewater as a replacement for tap water. Cylindrical concrete test pieces were made by varying the proportion of wastewater from soap factories at a rate of 0%, 40%, 60%, 80% and 100%; depending on the water/cement ratio of 0.5, 0.6 and 0.7. These cylindrical concrete specimens were tested at the ages of 3, 7, 28, 60 and 90 days; the load was applied consistently and the breaking stress was measured automatically at failure. The results of the experimental tests carried out in this project indicate that the use of wastewater from the soap factory for the preparation of concrete as a replacement for tap water induces a decrease in the value of the subsidence at the abrams cone of the concrete, delays the start of the setting of the cement, leads to a reduction in the compressive strength of the concrete, causes the formation of pores in the concrete matrix at early ages. Correlations have been developed to quantify the loss in the strength of concrete as a function of the polluted water content and the variation of the water / cement ratio.

## 1. Introduction

Industrial discharges with a high concentration of toxic heavy metals are very dangerous for the environment because of their persistence and their non-degradable nature [1]. In Cameroon and in particular in the city of Bafoussam, soap production factories such as SCS (Cameroonian soap company) discharge polluted effluents into the environment without any purification treatment [2]. This point pollution results in the degradation of the water quality of the city's water network, this polluted water is widely used for concrete production operations. Likewise, the strong growth of the population combined with economic development significantly increases the need for drinking water.

The discharge of untreated polluted effluents into the environment is a real public health problem. The riparian populations who use this water are extremely exposed to water-borne diseases. Diseases caused by water are indeed one of the main public health problems in underdeveloped countries [2]. Concrete is nowadays the most used building material; even more concrete is the most used man-made material in the world [3]. The high cost of wastewater treatment could be reduced by using it to produce concrete [4]. Hence the interest in developing techniques to reuse wastewater, especially in concrete.

To date, several studies have looked at the impact of the use of treated or untreated polluted water compared to the use of drinking water for the production of concrete. These studies

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concluded that, the use of treated industrial wastewater in the production of concrete instead of drinking water results in a 6.9% decrease in the compressive strength of cement sand mortar to the age of 28 days [5]. Other work has shown that the addition of secondary treated wastewater in varying proportions (25 to 100%) increased the compressive strength to 39 MPa after 28 days [7]. A greater increase was noted in tensile strength, which was double that obtained with the standard design.

Another study [8] reported the effect of washing water on the durability properties of concrete. Wash water was substituted for fresh water in proposals ranging from 0% to 100%. Water-cement ratios ranged from 0.5, 0.6 and 0.7, respectively. In this study, the wash water used was tested to have high alkalinity and total dissolved solids exceeded the standard limit [9], Thus contributing to the formation of a matrix with much more voids and therefore making it weaker. It was also noted that, by increasing the percentage of wash water for concrete making, drying shrinkage and weight loss due to acid attack increased, in addition the slump of fresh concrete and the resistance to compression decreased. However, the unit weight and temperature of fresh concrete was not affected by the use of wash water.

The recycling of wastewater in the production of ready-mixed concrete was discussed in the final report of [10]. Past research results show that wastewater can be used in the production of concrete. Thus, the use of washing wastewater, for example, has a minimal effect on the properties of fresh and hardened concrete. Due to the wide variability of pollutants present in each type of wastewater, it is difficult to draw a definitive conclusion regarding their use or not in the production of concrete. Neville [11] studied in detail the research literature on the use of effluent water to produce concrete and concluded that there is still much work to be done to achieve this. The aim of this article is to study the impact of the potential use of wastewater from soap factories on the physico-mechanical properties of concrete.

## 2. Material and method

The soap factory wastewater used in this study was sampled in the town of Bafoussam, which is located 294 km north of the political capital Yaoundé, more precisely at the level of the effluent discharge point of the Cameroonian soap factory (SCS). The results of the physicochemical analysis of the water used are summarized in Table 1 below.

### *1.1 Materials*

The concrete used is made up of a mixture of gravel, river sand, cement and drinking water and/or soap factory effluent. The characteristics of the different materials are described below.

The cement we used to make the concrete was regular Portland cement. Table 2 below summarizes the physical and mechanical properties.

The cement we used to make the concrete was regular Portland cement. Table 2 below summarizes the physical and mechanical properties.

To produce the concrete used in our study two types of water were used:

- **B1**: Drinking water from the city of Bafoussam;
- **PW**: water polluted with effluents from the Cameroonian soap factory (SCS).

All the samples of soap factory wastewater that we used for making concrete in this study were characterized by measuring physical and chemical parameters: pH, Temperature, Turbidity, Electrical cond, TDS, DOC , BOD5, DOC / BOD5, BOD5 / DOC, Calcium, Magnesium, Potassium, Sodium, Bicarbonates, Carbonate, Nitric, nitrogen, Nitrate, Ammoniacal nitrogen, Ammonium, Nitrite, Chlorine, Sulphate, Sulfur, Soluble Phosphorus, Aluminum, Cadmium, Copper, Chromium, Iron, Lead, Zinc, and Dissolved oxygen; then these values obtained were compared to the acceptable limit values for the water used for the manufacture of concrete. Table 1 above summarizes the results of the physical and chemical properties of the waters studied, from which it follows that the wastewater from the soap factories used here is basic and carries a non-biodegradable organic load (COD/BOD5 ratio greater than 3), [12]. However, the concentrations of Zinc, Lead, Cadmium and BOD5 are lower than the limit values prescribed in [9], and the concentrations of Sulphate and Nitrate are higher than the prescribed values. The analysis of the physico-chemical parameters was carried out at the Soil Analysis and Environmental Chemistry Research Unit, FASA, University of Dschang (Cameroon).

**Table 1:** Properties of used soaping wastewater

| **Parameters** | **Physicochemical analysis results** | | | **Acceptability limits for concrete ASTM (C94 ,1996)** | **Acceptability limits for concrete ASTM (C1602-18)** | **Acceptability limits for concrete EN 1008 2003** | **Acceptability limits for concrete EPA Construction 2012** |
|---|---|---|---|---|---|---|---|
| | **Minimum value** | **Maximum value** | **Mean ±SD** | | | | |
| PH | 7.4 | 13.2 | 10.53 ± 2.67 | | 6.5- 8.5 | ≥4 | 6.5- 8.5 |
| Temperature ° C | 22.9 | 24.8 | 23.61 ± 0.86 | | | 35 | |
| Turbidity (NTU) | 2 | 520 | 201.86 ± 201.83 | | | | |
| Electrical cond (µS / cm) | 320 | 19980 | 9490.00 ± 9054.89 | | | | |
| TDS (mg L-1) | 130 | 13430 | 5362.86 ± 4597.07 | | | | |
| COD (mg L-1) | 125.32 | 959 | 414.85 ± 259.216 | | | | |
| BOD5 (mg L-1) | 23 | 99 | 48.43 ± 26.19 | | | | < 20,000 |
| COD / BOD5 | 3.79 | 19.67 | 9.42 ± 5.22 | | | | |
| BOD5 / COD | 0.0508 | 0.26 | 0.14 ± 0.07 | | | | |
| Calcium (mg L-1) | 2.4 | 26.4 | 7.09 ± 7.98 | | | | |
| Magnesium (mg L-1) | 3.4 | 10.21 | 4.93 ± 2.23 | | | | |
| Potassium (mg L-1) | 13.31 | 26.53 | 22.02 ± 4.75 | | | | |
| Sodium (mg L-1) | 3.8 | 452.06 | 167.46 ± 180.94 | | | | |
| Bicarbonates (mg L-1) | 2135 | 75640 | 24948.13 ± 31917.52 | | | | |
| Carbonate (mg L-1) | 6 | 13134 | 2250.00 ± 4511.40 | | | | |
| Nitric nitrogen (mg L-1) | 1.12 | 4814.32 | 1137.04 ± 1849.77 | <1.00 | | | |
| Nitrate (mg L-1) | 4.96 | 21327.44 | 5037.09 ± 8194.50 | | | ≤500 | |
| Ammoniacal nitrogen (mg L-1) | 1.12 | 4.48 | 2.56 ± 1.15 | | | | |
| Ammonium (mg L-1) | 3.7 | 14.78 | 8.45 ± 3.81 | | | | |
| Nitrite (mg L-1) | 3,67 | 15782,3 | 3727.44 ± 6063.93 | | | | |
| Chlorine (mg L-1) | 39.05 | 223.65 | 112.08 ± 62.79 | ≤500 | 1000 | ≤500 | 250 |
| Sulphate mg L-1 (mg L-1) | 1049.6 | 9725.2 | 5046.51 ± 3368.62 | ≤3000 | | ≤2000 | |
| Sulfur (mg L-1) | 346.37 | 3209.32 | 1665.35 ± 1111.65 | | | | |
| Soluble Phosphorus (mg L-1) | 5.64 | 1700.05 | 1113.11 ± 692.77 | | | | |
| Aluminum (mg L-1) | 0 | 0.03 | 0.01 ± 0.01 | | | | |
| Cadmium (mg L-1) | 0.03 | 0.19 | 0.10 ± 0.05 | | | total Combined < 2000 | |

| | | | | |
|---|---|---|---|---|
| Copper (mg L-1) | 0 | 0.04 | 0.01 $\pm$ 0.01 | |
| Chromium (mg L-1) | 35.76 | 1381.08 | 717.47 $\pm$ 412.30 | |
| Iron (mg L-1) | 0.28 | 17.82 | 7.13 $\pm$ 5.86 | |
| Lead (mg L-1) | 0.21 | 2.49 | 0.68 $\pm$ 0.75 | ≤100 |
| Zinc (mg L-1) | 0.51 | 1.98 | 1.72 $\pm$ 1.97 | ≤100 |
| Dissolved oxygen (mg L-1) | 0.32 | 1.92 | 1.10 $\pm$ 0.48 | |

**Table 2:** Properties of ordinary Portland cement

| Physical characteristics | | Chemical characteristics | |
|---|---|---|---|
| **Parameter** | **Value** | **Compound** | **Quantity (%)** |
| Consistency [14] | 28.90 | $SiO_2$ | 20.2 |
| Specific gravity (ASTM C188 - 17, 2017) | 3.0 | $Al_2O_3$ | 5.7 |
| Initial setting time [22] | 105 min | MgO | 5.3 |
| Final setting time [22] | 230 min | $SO_3$ | 2.2 |
| Specific surface area (ASTM C115 - 10, 2010) | 332 $m^2$/kg | CaO | 58.1 |
| Fineness (Blaine Test)] | 0.000277 $m^2$/kg | $Fe_2O_3$ | 6.0 |
| CS at 3 days [17] | 37.35 MPa | Loss of ignition | 2.9 |
| CS at 28 days [17] | 42.55 MPa | $K_2O$ | 0.8 |
| Soundness (ASTM C151, 2018) | No expansion | $Na_2O$ | 0.4 |

The choice of Sanaga sand is motivated by the good reputation it enjoys across the country. In order to avoid the impact that variation in grain size could have, we have chosen to use the same granular fractions which are 0/5. Preliminary tests carried out in the laboratory on the sand made it possible to ensure its compliance with the rules [13-15] for use as concrete [16]. This sand will be noted SS for Sable Sanaga. The properties of the Sanaga sand obtained are shown in Table 3.

**Table 3:** Physical properties of the Sanaga sand

| Physical properties | Minimal value | Mean value | Maximum value |
|---|---|---|---|
| Absolute volumetric mass $\rho_s$ (kg/m$^3$) | 2560 | 2620 | 2880 |
| Apparent volumetric mass $\rho'_s$ (kg/m$^3$) | 1425 | 1509 | 1594 |
| Sand equivalent SE (%) | 95.3 | 95.8 | 96.3 |
| Water content W (%) | 3.05 | 3.135 | 3.22 |

Given the proximity of the Bamougoum quarry which is in the city of Bafoussam, we decided to take aggregates of two granular fractions (5/15 and 15/25). The geotechnical characterizations were made on these aggregates according to the reference [13,17] at the Materials Laboratory of the IUT-FV of Bandjoun Table 4 below shows the different characteristics. The sieve analysis was carried out according to the reference [15] Figure 2.

**Table 4:** Properties of aggregates

| | Physicals properties | | | | | Mechanical properties | |
|---|---|---|---|---|---|---|---|
| | **Apparent density (g/m$^3$)** | **Density (g/m$^3$)** | **Porosity (%)** | **Water content (%)** | **Absorption (%)** | **Los Angeles** | **Micro-deval coefficient** |
| Gravel 5/15 | 1.48 | 2.7 | 1.01 | 0.12 | 0.44 | 27.98 | 16 |
| Gravel15/25 | 1.47 | 2.7 | 1.01 | 0.12 | 0.44 | 28 | 18 |

### *2.2 Method*

For the concrete formulation we opted for the Dreux-Gorisse method [18] which is currently the most used method because it is more practical and is based on experimental results. In this research project, we made two types of concrete with a water-cement ratio of 0.5, 0.6 and 0.7. These concretes are respectively designated B1, PWX. They were kept at a temperature of 20 ° C. The different mixing proportions are shown in Table 5.

In this study, effluent water from the SCS soap factory Figure 1 was used as a replacement for tap water at 0%, 40%, 60%, 80% and 100% by weight. The results of the physicochemical analysis of the water from the soap factory effluents are contained in the following table.

The following Figure 1 shows the soap factory effluents discharged by the Cameroonian soap company into nature.

**Table 5:** Mix proportion of concrete (kg/m$^3$)

| Mixed symbol | Portland cement | Water | Sludge water | River sand | Crushed limestone |
|---|---|---|---|---|---|
| B1(0.5) | 347 | 173 | 0 | 910 | 966 |
| B1(0.6) | 309 | 185 | 0 | 910 | 966 |
| B1(0.7) | 279 | 195 | 0 | 910 | 966 |
| PW40(0.5) | 347 | 104 | 69 | 910 | 966 |
| PW40(0.6) | 309 | 111 | 74 | 910 | 966 |
| PW40(0.7) | 279 | 117 | 78 | 910 | 966 |
| PW60(0.5) | 347 | 69 | 104 | 910 | 966 |
| PW60(0.6) | 309 | 74 | 111 | 910 | 966 |
| PW60(0.7) | 279 | 78 | 117 | 910 | 966 |
| PW80(0.5) | 347 | 35 | 139 | 910 | 966 |
| PW80(0.6) | 309 | 37 | 148 | 910 | 966 |
| PW80(0.7) | 279 | 39 | 156 | 910 | 966 |
| PW100(0.5) | 347 | 0 | 173 | 910 | 966 |
| PW100(0.6) | 309 | 0 | 185 | 910 | 966 |
| PW100(0.7) | 279 | 0 | 195 | 910 | 966 |

**a)** **b)**

**Figure 1. (a)** Effluents released by the Cameroonian company of Soap factory in Bafoussam, kamkop
**(b)** One of the meeting areas between the effluents and a watercourse in the town of Bafoussam

The methodologies of the experiments carried out in this study are presented below:

- The fresh concrete unit weight test was performed according to ASTM C138; [19]
- The concrete slump test was performed according to ASTM C143; [20]
- The compressive strength test on cylindrical specimens Ø 16 32 cm of concrete were carried out at ages 3, 7, 28, 60.90 days in accordance with ASTM C39; [21].

- Standard Test Methods for Vicat Needle Hydraulic Cement Setting Time ASTM C191, 2013; [22].

The proportions of concrete mix used in this study are described in Table 6. B1 denotes concrete made with tap water only and PWX (Z) denotes concrete in which tap water was substituted with soap factory effluent water; with (X) the percentage of substitution, and (Z) the water/cement ratio.

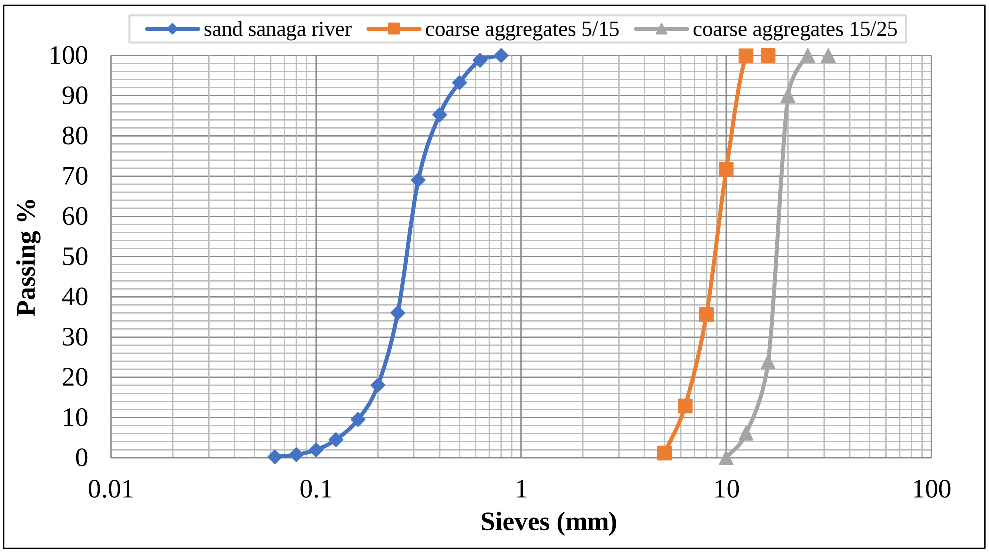



**Figure 2.** Sieves analysis of aggregates (fines and coarse)

## 3. Results and discussion

### *3.1. Properties of fresh concrete*

### *3.1.1. Workability test*

The following figure shows the results obtained with regard to the subsidence test, where PWX denotes the concrete obtained by adding X percent of polluted water by weight. We found that increasing the percentage of polluted water resulted in a decrease in slump test results of the concrete. This reality is due to the fact that the polluted water of used soap works contains high concentration of sediment, in particular suspended organic matter from the use of palm oil for the production of soaps. Likewise, the increase in the water/cement ratio results in an increase in the fluidity of the concrete and therefore an increase in the subsidence values at the slump test.

The slump test on fresh concrete determines its workability based on quantity of water used. The substitution of B1 by PW40, PW60, PW80, PW100 causes the reduction of the workability of the concrete mixes made. Indeed, the slump of the fresh concrete measured was 2.4, 2.4, 2.8, 4.1 cm for PW40, PW60, PW80 and PW100 respectively, while the concrete mixed with B1 was 5.2 cm for the water/cement ratio (0.5) , then the slump of fresh concrete measured for the water/cement ratio (0.6) was 4.23, 4.2, 5.8, 6.2 cm for PW40, PW60, PW80 and PW100 respectively, while the slump of concrete mixed with B1 was 7.8 cm and finally the slump of the fresh concrete measured was 4.3, 4.9, 6.8, 8 cm for PW40,PW60, PW80 and PW100 respectively, while the concrete mixed with B1 was 8.4 cm for the water/cement ratio (0.7 ). The slump value therefore decreases gradually for mixes from PW100 to PW40 due to the spongy surface of the mud particles with high absorption properties. The same observation was made in previous studies by [23].

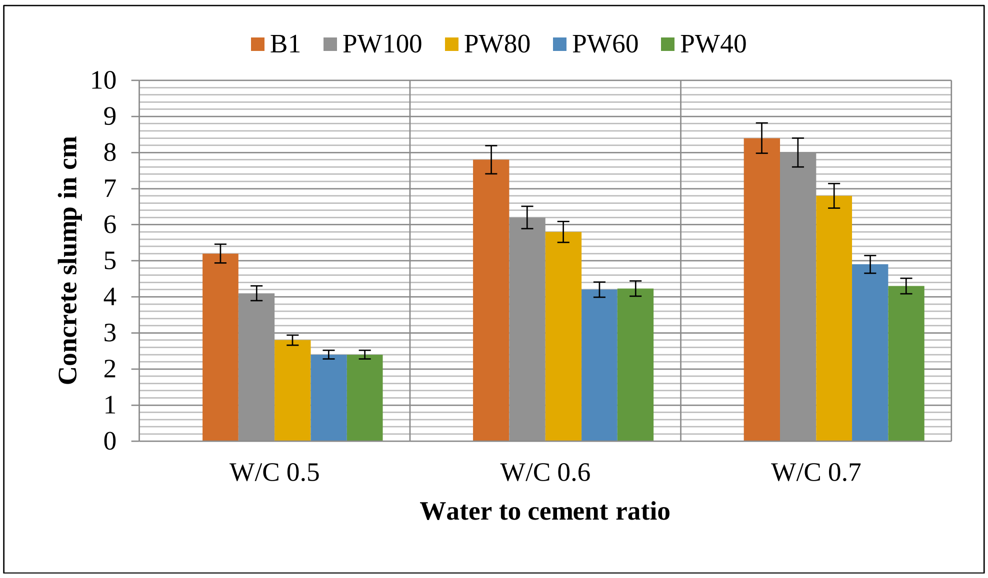



**Figure 3.** Slump of fresh concrete

*3.1.2. Unit weight of fresh concrete*

Figure. 4 represents the results obtained with regard to the unit weight of the fresh concrete. In fact, the tendency is that concrete made with a high percentage of water polluted with soap has a high fresh unit weight. However, the difference with concrete made from B1 tap water is not very important. This is linked to the specific density of polluted soap water (1.026) which is slightly higher than that of tap water (1.00). However, the increase in the water to cement ratio results in a reduction in the unit weight of the concrete, mainly due to the increase in the water content.

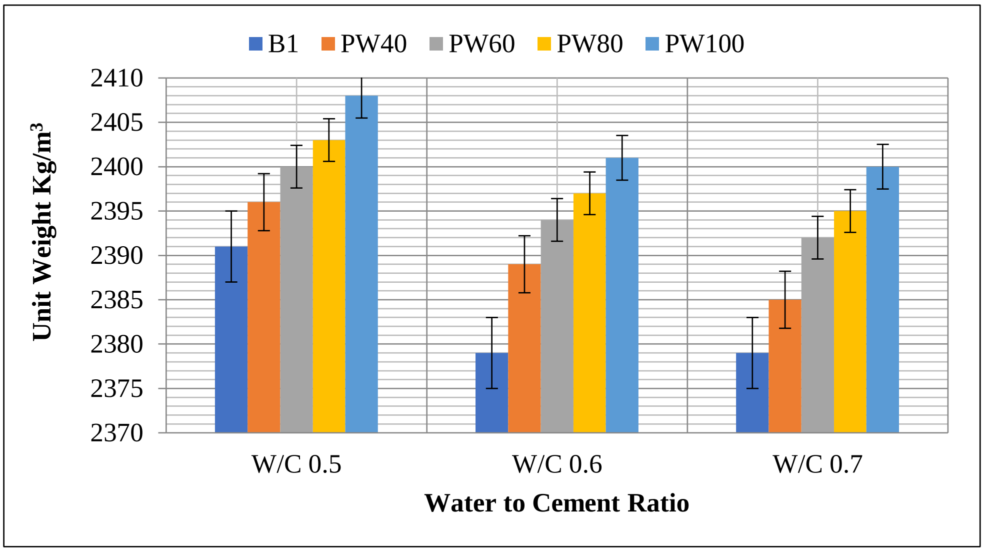



**Figure 4.** Unit weight of fresh concrete

*3.1.3. Setting time*

Figures 5, 6 and 7 show the change in setting time as a function of the concentration of polluted water in the soap factory and the water/cement ratio. It shows that the increase in the percentage of polluted water in the soap factory has the effect of delaying the onset of setting of the cement; in addition, the increase in the water to cement ratio also induces a longer hydration period.

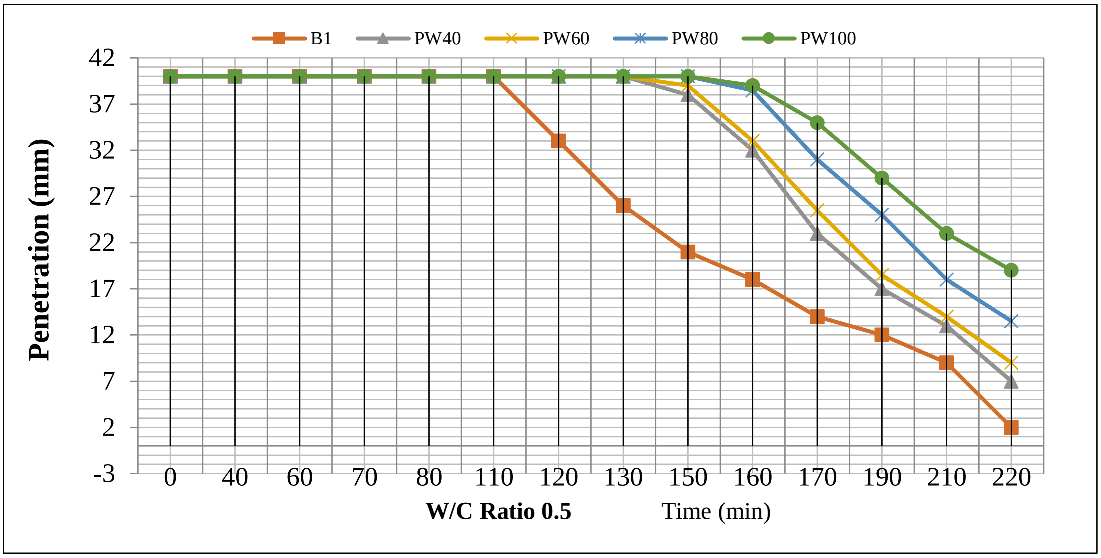



**Figure 5.** Setting time with water-to-cement ratio of 0.5

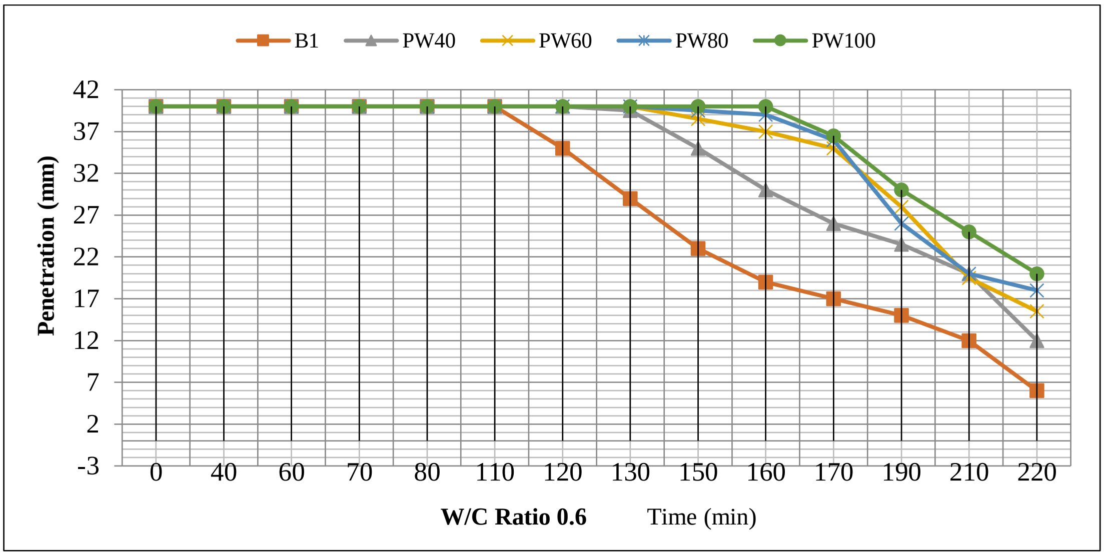



**Figure 6.** Setting time with water-to-cement ratio of 0.6

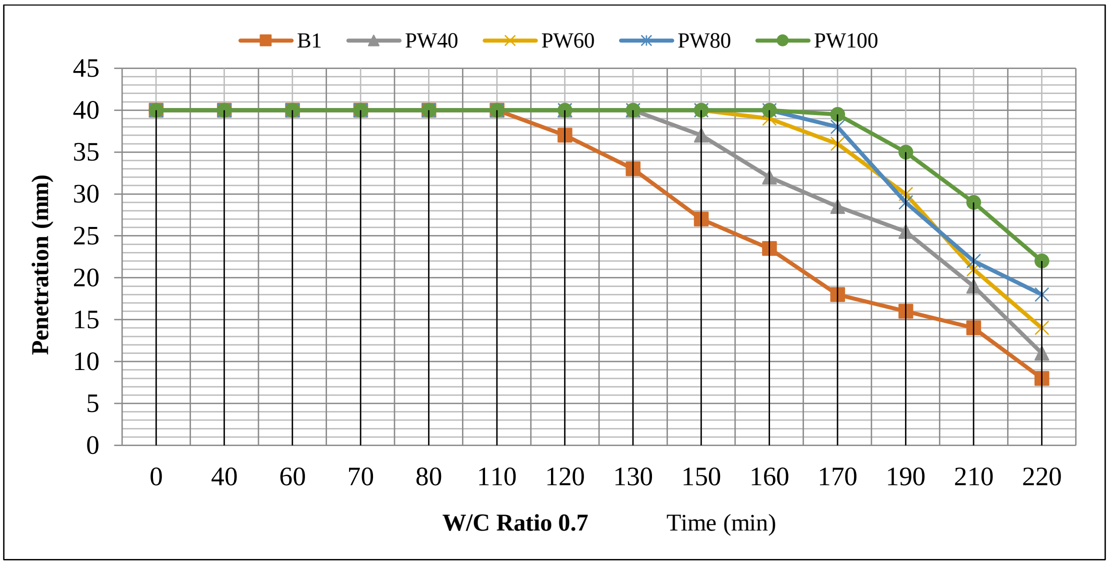



**Figure 7.** Setting time with water-to-cement ratio of 0.7

Figures 5, 6 and 7 presents the initial setting time results for three mortar mixes that have the same formulation and differ only in the water/cement ratio (0.5, 0.6 and 0.7). the results obtained indicate that in the case in point the use of soap factory wastewater generally leads to an increase in the time at which it begins to set, in fact the higher the rate of substitution of drinking water by drinking water. soap factory effluent increases the longer the start of setting time, the more it should be noted that the increase in the water/cement ratio also induces an extension of the start of setting time. These results can be explained by the presence in this mixing water of a high concentration of alkaline nitrate which would therefore induce, due to their high concentration, a retarding effect on the time of the onset of setting of the cement mortar. Similar results were found by [24].These results obtained are similar to previous studies [6].

### *3.2. Properties on hardened concrete*

#### *3.2.1 Compressive strength*

The following Figures 9c, 9d and 9e give the results of the compression test carried out on controlled concrete specimens (B1), and those carried out on specimens obtained by varying the percentage of water contaminated by soap effluents (PW40, PW60, PW80 and PW100); it appears that the increase in the percentage of contaminated water leads to a reduction in the compressive strength of concrete at all ages evaluated. This is linked to the presence in the interstitial solution of a high concentration of alkalis from the wastewater from the soap factory, which reacts with the reactive silica of the aggregates, resulting in the formation of pores which appear in the matrix, thus inducing loss of resistance. Figure 8 shows the appearance of the concrete surface after demoulding (24h).

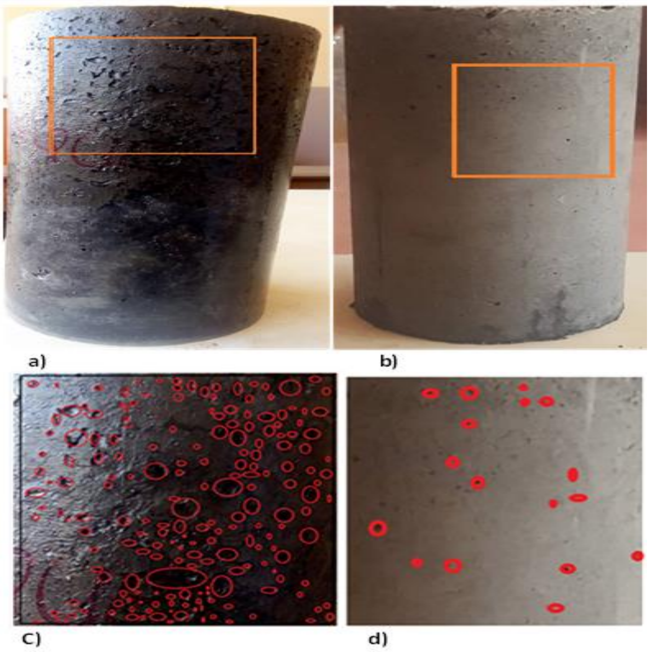


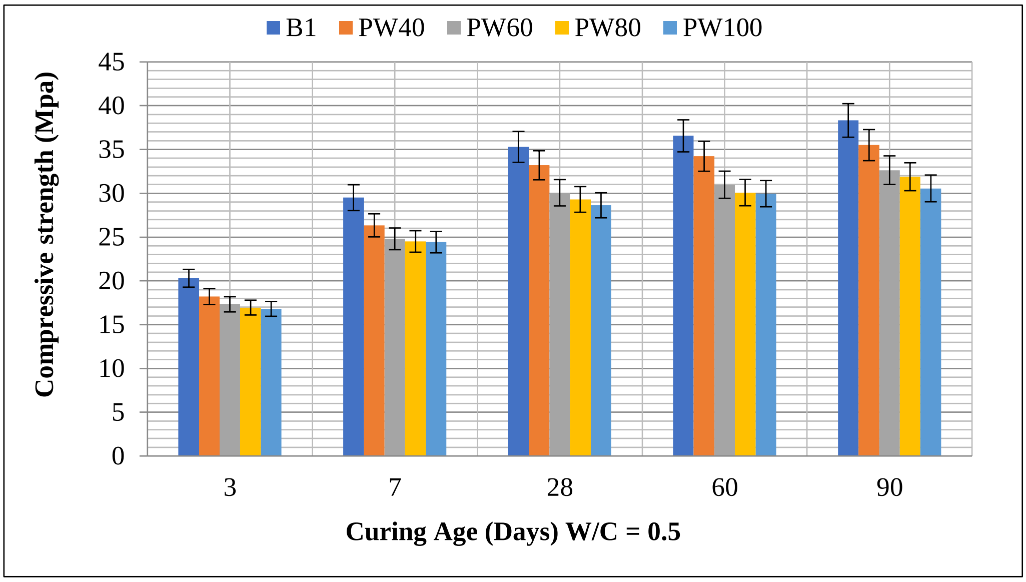

**Figure 8.** Facing of the matrix of concrete samples after demoulding (24 hours) a) Prepared PW100 concrete specimen showing the formation of pores in the matrix after 24 hours; b) Concrete test piece B1 made with tap water; c) Pore identification of sample a ; d) pore identification of sample b

Visual observation of concrete specimens made with polluted soap water allows us to notice from the first days of maturation the formation of pores at the level of the concrete matrix. This is linked to the triggering of a degradation reaction that takes place,produced during the hydration phase of the concrete due to the presence of sulphate harmful to the cement matrix. This increase in porosity can also contribute to the reduction of the density of the concrete thus made [11].

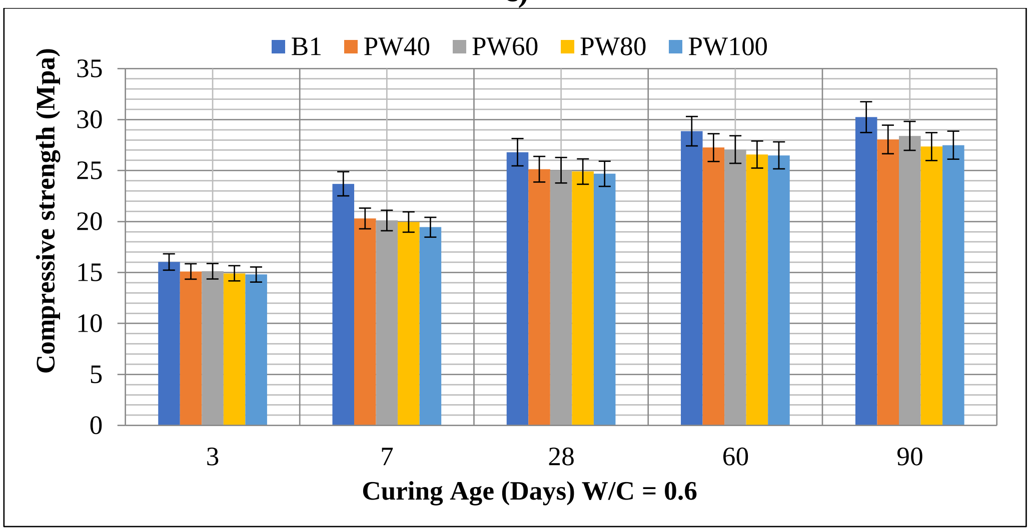
The number of pores formed indicate a proportionality with the compressive strength of the concrete; in fact, the fewer the pores, the greater the resistance to compression. The pores induce the creation of weak points inside the concrete matrix, this linked to the separation of the grains between them; which results in a loss of compressive strength. These results are confirmed by those of [26].

**a)**

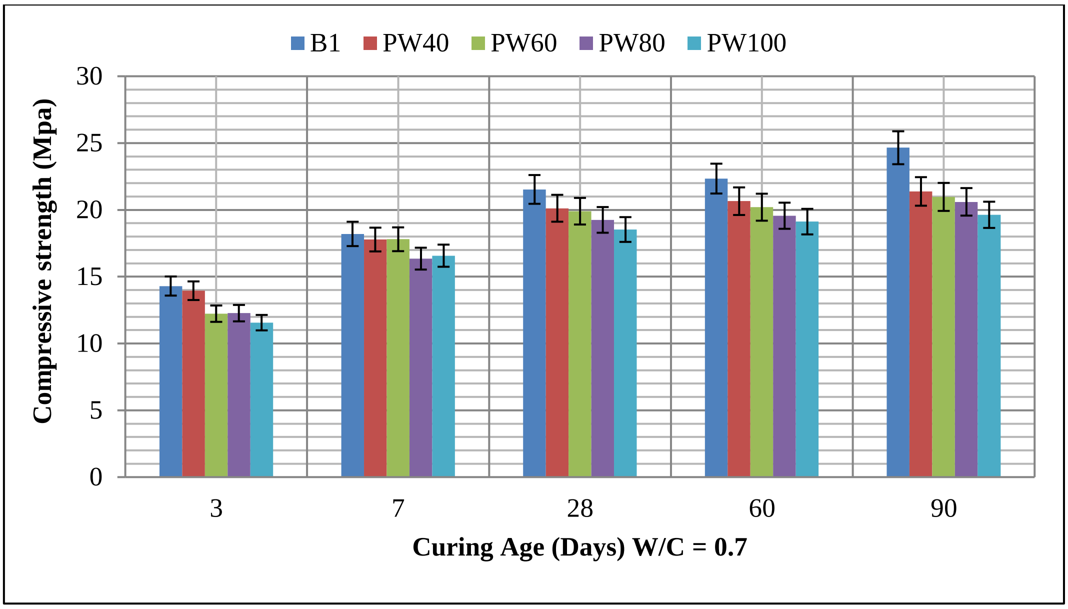
**b)**




**c)**




**d)**



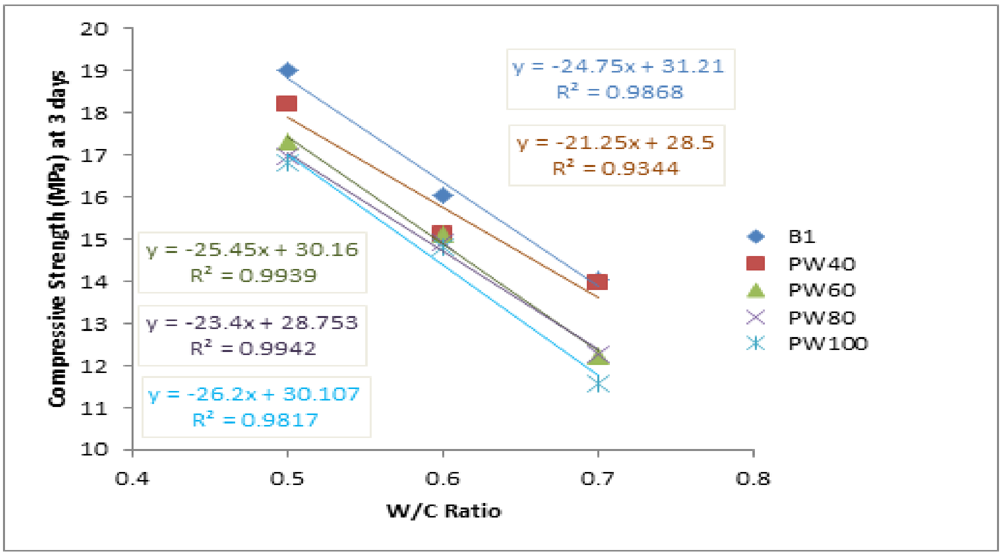

**e)**

**Figure 9.** a) Arrangement of the specimen between the two platens of the press ; b) Specimen loading ; c) Compressive strength of B1, PW40, PW60, PW80, PW100 concretes at the ages of 3,7,28,60 and 90 days, With a water-to-cement ratio of 0.5 ; d) Compressive strength of B1, PW40, PW60, PW80, PW100 concretes at the ages of 3,7,28,60 and 90 days, With a water-to-cement ratio of 0.6 ; e) Compressive strength of B1, PW40, PW60, PW80, PW100 concretes at the ages of 3,7,28,60 and 90 days, With a water-to-cement ratio of 0.7.

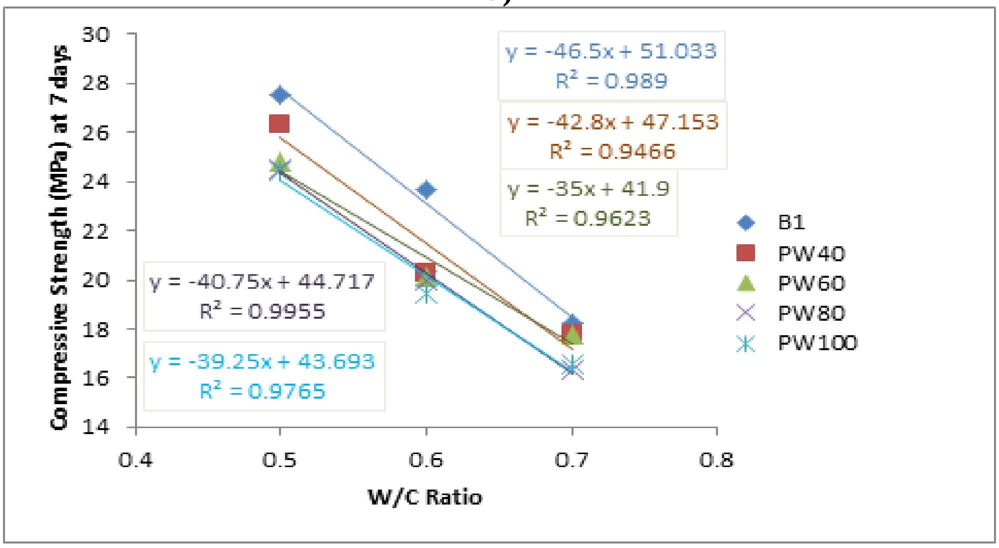
According to the results presented in Fig.9, the use of untreated industrial soap factory wastewater instead of drinking water in the production of concrete causes a decrease in the compressive strength at all ages. Moreover, taking into account the ASTM C150/C150M-1624 standard, the minimum value of a 3-day compressive strength of a concrete made with Portland cement is at least 10 MPa and the minimum value of its strength at 7 days of age is at least 17 MPa. It therefore follows that the test specimens made with drinking water and industrial wastewater from the soap factory meet these minimum values and are acceptable.

### *3.2.2 Correlation analysis*

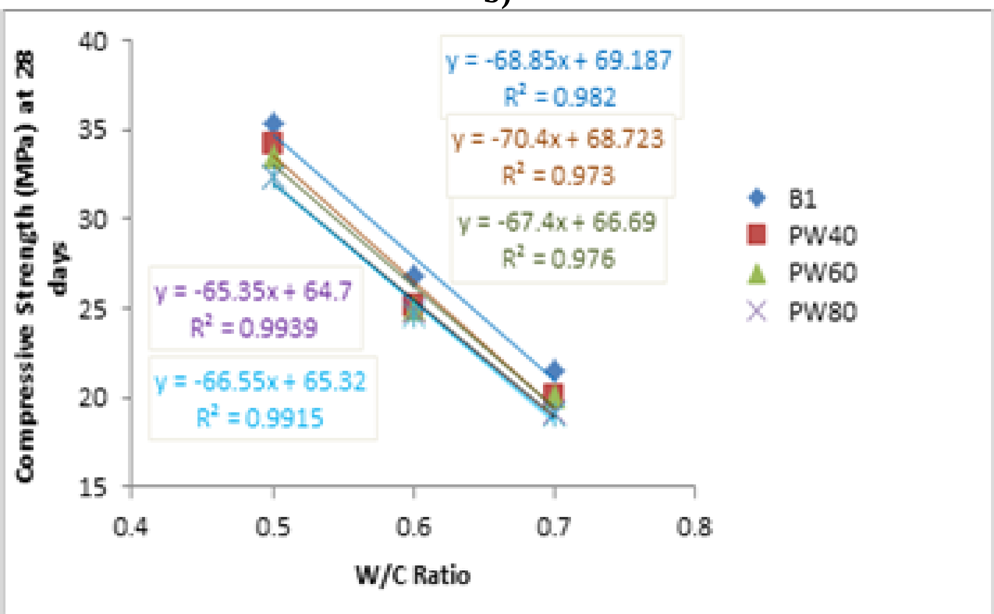
In general, concrete mixes have compressive strength properties which vary, this situation is notably influenced by factors such as the characteristics of the aggregates, the water to cement ratio, the quality of the water used for mixing. so therefore it seems important to model the relationship between different parameters such as compressive strength and water to cement ratio. The following Figure 10 shows the linear regression relationship between the compressive strength at different ages, the percentage of soap effluent used in making concrete, and the cement to water ratio. Table 6 summarizes the linear regression equations as well as the correlation coefficients obtained.


Compressive Strength (MPa) at 3 days
W/C Ratio
y = -24.75x + 31.21
R² = 0.9868
y = -21.25x + 28.5
R² = 0.9344
y = -25.45x + 30.16
R² = 0.9939
y = -23.4x + 28.753
R² = 0.9942
y = -26.2x + 30.107
R² = 0.9817
B1
PW40
PW60
PW80
PW100

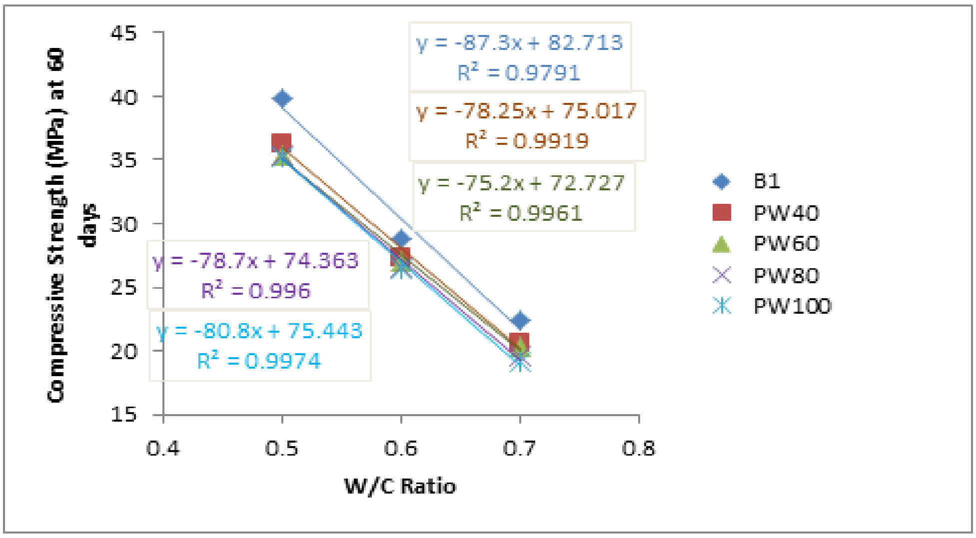
**a)**


Compressive Strength (MPa) at 7 days
W/C Ratio
y = -46.5x + 51.033
R² = 0.989
y = -42.8x + 47.153
R² = 0.9466
y = -35x + 41.9
R² = 0.9623
y = -40.75x + 44.717
R² = 0.9955
y = -39.25x + 43.693
R² = 0.9765
B1
PW40
PW60
PW80
PW100

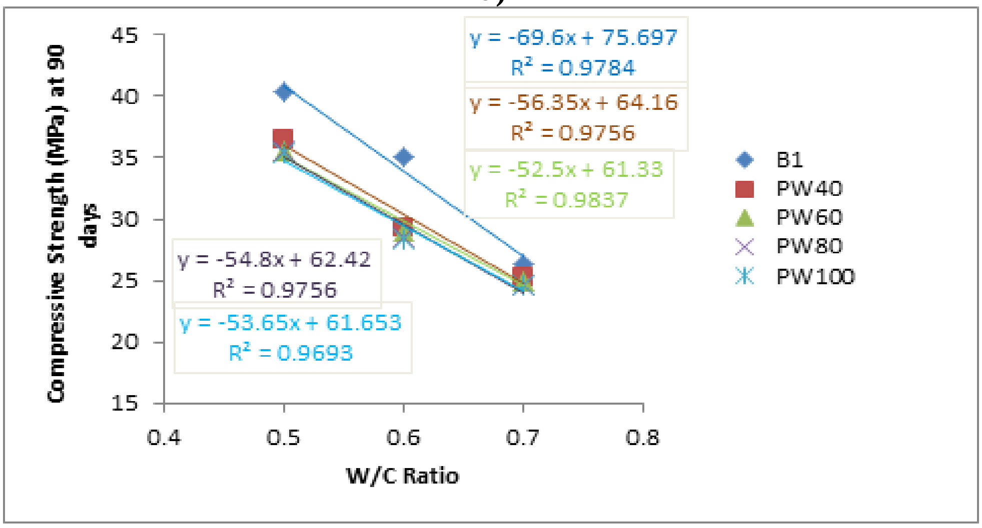
**b)**


Compressive Strength (MPa) at 28 days
W/C Ratio
y = -68.85x + 69.187
R² = 0.982
y = -70.4x + 68.723
R² = 0.973
y = -67.4x + 66.69
R² = 0.976
y = -65.35x + 64.7
R² = 0.9939
y = -66.55x + 65.32
R² = 0.9915
B1
PW40
PW60
PW80

**c)**




**d)**




**e)**

**Figure 10.** Linear correlation between the compressive strength at 3,7,28,60,90 and the cement to water ratio

The experimental data obtained, represented in Fig. 10, were used to develop a correlation equation between the compressive strength and the water/cement ratio. The correlation equation is expressed by the following relationship:

$$ZI = \frac{a}{(f_c^{'})^b}$$

ZI : Concrete durability index

$f_c^{'}$ : Compressive strength

a and b : Coefficient obtained after linear regression.

In general, a regression coefficient R2 greater than 0.85 implies an excellent correlation between the various parameters to be adjusted [27]. Therefore, the results in Table 6 indicate a good correlation between the compressive strength and the water/cement ratio in concrete.

Regarding the level of correlation between the compressive strength as a function of the increase in the water-to-cement ratio, it can be seen that the increase in the water-to-cement ratio has the direct impact of reducing the compressive strength. Concrete and this has all ages. In addition, it is also observed that increasing the concentration of soap wastewater in concrete has the effect of reducing these compressive strength properties.

**Table 6:** Summary of the correlation analysis between the compressive strength of concrete and the variation of the water / cement ratio

| N° | Correlation | Concentration of polluted water | a | b | Regression coefficient |
|---|---|---|---|---|---|
| a) | Compressive strength at 3 days and water to cement ratio | B1 | -24.75 | 31.21 | $R^2 = 0.9868$ |
| | | PW40 | -21.25 | 28.5 | $R^2 = 0.9344$ |
| | | PW60 | -25.45 | 30.16 | $R^2 = 0.9939$ |
| | | PW80 | -23.4 | 28.753 | $R^2 = 0.9942$ |
| | | PW100 | -26.2 | 30.107 | $R^2 = 0.9817$ |
| b) | Compressive strength at 7 days and water to cement ratio | B1 | -46.5 | 51.033 | $R^2 = 0.989$ |
| | | PW40 | -42.8 | 47.153 | $R^2 = 0.9466$ |
| | | PW60 | -35 | 41.9 | $R^2 = 0.9623$ |
| | | PW80 | -40.75 | 44.717 | $R^2 = 0.9955$ |
| | | PW100 | -39.25 | 43.693 | $R^2 = 0.9765$ |
| c) | Compressive strength at 28 days and water to cement ratio | B1 | -68.85 | 69.187 | $R^2 = 0.982$ |
| | | PW40 | -70.4 | 68.723 | $R^2 = 0.973$ |
| | | PW60 | -67.4 | 66.69 | $R^2 = 0.976$ |
| | | PW80 | -65.35 | 64.7 | $R^2 = 0.9939$ |
| | | PW100 | -66.55 | 65.32 | $R^2 = 0.9915$ |
| d) | Compressive strength at 60 days and water to cement ratio | B1 | -87.3 | 82.713 | $R^2 = 0.9791$ |
| | | PW40 | -78.25 | 75.017 | $R^2 = 0.9919$ |
| | | PW60 | -75.2 | 72.727 | $R^2 = 0.9961$ |
| | | PW80 | -78.7 | 74.363 | $R^2 = 0.996$ |
| | | PW100 | -80.8 | 75.443 | $R^2 = 0.9974$ |
| e) | Compressive strength at 90 days and water to cement ratio | B1 | -69.6 | 75.697 | $R^2 = 0.9784$ |
| | | PW40 | -56.35 | 64.16 | $R^2 = 0.9756$ |
| | | PW60 | -52.5 | 61.33 | $R^2 = 0.9837$ |
| | | PW80 | -54.8 | 62.42 | $R^2 = 0.9756$ |
| | | PW100 | -53.65 | 61.653 | $R^2 = 0.9693$ |

## 4. Conclusions

This study allows us to evaluate the impact of the use of soapy wastewater on the strength properties of fresh concrete and hardened concrete. The following conclusions were drawn based on the results of the various tests we performed:

1. The increase in the percentage of polluted water in the soap factory induced a decrease in the cone subsidence of the concrete;
2. Concrete made with a high percentage of polluted soap water has a high fresh unit weight. However, the difference with concrete made from B1 tap water is not very important;
3. The increase in the percentage of polluted water in the soap factory has the effect of delaying the onset of setting of the cement;
4. The increase in the percentage of soap wastewater results in a reduction in the compressive strength of concrete at all ages assessed;
5. Visual observation of concrete specimens made with polluted soap water allows us to notice from the first days of maturation the formation of pores in the concrete matrix;
6. The correlation between the compressive strength as a function of the increase in the water to cement ratio, shows that the increase in the water to cement ratio has the direct impact of reducing the compressive strength of concrete and this at all ages.

## Author contributions

ZGM and TPK conceived the ideas, laboratory analyzes, interpretations and wrote the draft manuscript. NF, GC and MF reorganized all data and revised the manuscript.

## Competing interests

The authors declared no competing Interest.

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