# Comparison of compressive strength of concrete made with drinking water and wastewater treated by reverse osmosis in areas affected by water scarcity

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***Abstract*—Water is a vital resource for the production of concrete in the construction industry. However, in regions where potable water is scarce, it is important to find sustainable alternatives. In this study, it is proposed to use wastewater treated by osmosis, a process that eliminates contaminants and makes it suitable for various uses, to produce concrete as a solution to this problem. An exhaustive comparative analysis of the compressive strength properties of concrete made with these 2 types of water was carried out, based on previous studies that analyze the effect of wastewater on concrete properties, such as compressive strength. The research proposal proposes to use treated wastewater from the WWTP of the company Esmeralda Corp. in the preparation of concrete, following the ACI method. The necessary tools and materials are mentioned, as well as the tests that will be carried out, including the compression test at 7, 14 and 28 days. The compressive strength results obtained indicate that the manufactured concrete that used treated wastewater showed a 4.6% increase in design strength in the first 7 days of curing, and after 28 days it improved by 24.6%. This demonstrates better behavior and greater resistance compared to concrete made with drinking water.***

***Keywords*—treated wastewater, compressive strength, concrete, reverse osmosis, water scarcity.**

## I. INTRODUCTION

Population growth and economic progress demand more and more water, which leads to an increase in shortages and a crisis in the supply of this fundamental resource. In the world, more than one hundred million people do not have access to water for consumption and 40% of people lack adequate sanitation facilities.

In Peru, between 7 and 8 million people lack the essential element of water, while, in Metropolitan Lima, one and a half million residents experience daily the lack of both drinking water and sewerage services. Lima is a vulnerable city, since it is the second city settled in a desert and it only rains 9 mm a year, Municipality of Miraflores [1]. That is why, today at the time of construction, it is sought to reduce the waste of drinking water destined for the elaboration of concrete.

### *A. State of the art*

According to Ganesh et al [2] it focuses on the elaboration of concrete mixtures using reverse osmosis wastewater for its preparation and curing. The experimental process comprises four proportions of mixing with different amounts of water and cement. Workability and fluidity tests were carried out on the fresh concrete. Cubes were manufactured and the compressive strength of the concrete was evaluated. The results of the tests were compared between concrete prepared with drinking water and concrete made with reverse osmosis wastewater. The results reveal that the workability of both types of concrete is similar. However, in terms of compressive strength, concrete with reverse osmosis wastewater shows a lower resistance at 28 days compared to conventional concrete. They have a difference of no more than 3kN.

In their research, Se-Jin et al [3] sought to increase the recycling rate of steel slag and reduce pollution in the construction industry. To achieve this, they applied fine aggregate of blast furnace slag (BSFA) and recycled water (RW) to the cement mortar. They evaluate several properties of the mortar, including fluidity, compressive strength, tensile strength, drying shrinkage, carbonation depth and chloride penetration resistance, using RW and BSFA. The compressive resistances of the samples that used RW and BSFA were higher than those of the control group. In general, all samples that used RW and BSFA showed compressive resistances higher than those of the control group after 28 days.

The study carried out by Jamuna et al [4] investigated the effects of the use of treated gray water in the production of concrete. Wastewater samples were collected from the secondary treatment tank of a school and analyzed in the laboratory to determine their suitability in the concrete mixture. Chemical parameters such as pH, Total Solids, BOD and COD were evaluated. Then tests of setting time, workability and compressive strength were carried out using drinking water and treated gray water to pour the concrete. The results showed that the use of treated gray water in concrete improved both workability and resistance compared to concrete with drinking water, with an increase of 20%.

Tamashiro et al [5] evaluated the compressive strength of concrete made with vinasse and aggregates of recycled concrete (RCA) as substitutes for water (100%) and sand (50% and 100%) respectively. Since both residues proved to be viable in the composition of the concrete, they were used in the manufacture of a prefabricated concrete panel that showed satisfactory results, which allows its use as a non-structural wall. In conclusion, the use of sugar cane vinaza with recycled concrete aggregate (RCA) is an appropriate solution to achieve a better reuse of construction and agro-industry waste as new composite construction materials.

Monkman & Meyer [6] carried out research on the use of carbon dioxide to treat washing water with high solids content and use it as mixing water in concrete production. They made seven batches of concrete: one as a reference, two with untreated washing water and four with CO2-treated washing water. The treatment with carbon dioxide managed to mineralize 28% of the treated solids. It was possible to obtain acceptable concrete by adjusting the additives to improve their workability. The compressive strength of CO2-treated concrete improved compared to the mixture of standard concrete and that produced with untreated washing water, in the periods of 1, 7, 28 and 56 days. CO2-treated suspended solids served as a viable replacement for cement. In addition, the combination of cement and carbon dioxide helped reduce the environmental impact of concrete by approximately 14%. This approach allowed the reuse of three waste streams (CO2, washing water and washing water solids) to produce a more sustainable concrete.

### *B. Contribution*

This study contributes to the efforts to counteract the water shortage in Metropolitan Lima by providing a viable alternative for drinking water in concrete production. It also contributes to the existing literature in several ways. It offers a comparative evaluation of the compressive strength of concrete made with drinking water and treated wastewater, a topic that has received limited attention in previous research. Finally, it provides a rigorous analysis of the influence of the type of water on the properties of concrete, which is critical to inform the practices of the construction industry.

## II. MATERIALS AND METHODS

### *A. Materials*

The following materials were used in this work: fine and coarse aggregates, cement and treated waste water.

The treated wastewater was extracted from the company Esmeralda Corp. The activity of the company is the food category. That is why they have a wastewater treatment plant (PTAR) to recycle the water that has already been used in other processes. They carry out the treatment using the ultrafiltration method and the reverse osmosis method. The aggregates were extracted from a quarry near the UPC Concrete Technology laboratory. The cement used is Portland Type I.

**Fig. 1.** Collection of wastewater treated by reverse osmosis

### *B. Methodology*

The methodology of this study consists of a combination of laboratory experiments and statistical analysis. Laboratory experiments involve the production of concrete samples with drinking water and treated wastewater, followed by compressive strength tests after different curing periods.

The experimental data are used to perform a statistical analysis of the difference in compressive strength between the two water conditions. This analysis provides a rigorous evaluation of the influence of the type of water on the compressive strength of the concrete.

### *C. Chemical tests on treated waste water*

The water was taken to the ALAB laboratory and has tests accredited by INACAL to perform the following chemical tests: chlorides, sulfates, pH, organic matter, amount of solids and total alkalinity. The values of each assay are compared with the NTP standard 339.088 for the limits of chlorine, sulfate, alkalinity and total solids. The pH limit was compared according to the author Rivera and organic matter according to the Mexican standard NOM C-122.

*D. Essays to the aggregates*

The use of aggregates is essential in the preparation of concrete. Because these materials make up most of the total volume of the mixture, their quality significantly influences the physical and mechanical properties of the concrete under study. Consequently, aggregate tests were carried out in accordance with current standards to ensure that they meet high quality standards and are suitable for the pattern design. These tests are: granulometric analysis of fine and coarse aggregates (NTP 400.012), moisture content (NTP 339.185), specific weight and absorption of the fine and coarse aggregate (NTP 400.022/NTP 400.021) and unit and compacted weight of the fine and coarse aggregate (NTP 400.017).

*E. ACI Method*

The design method provided by the ACI was chosen, which is the most used and has standardized procedures to achieve a final mixing provision. This design is for a volume of 1m3 of concrete, a settlement of 3" to 4" and resistance of 210 kg/cm2 at 28 days.

*F. Elaboration of concrete specimens*

Once the design of the final mixture with the adjusted weights has been obtained, it is possible to prepare batches of concrete to fill the molds of the test samples. These samples will be used to carry out compressive strength tests. The molds used for these samples have standardized dimensions according to NTP 339,033 and molds of 4"x8" (100 mm in diameter and 200 mm in height) have been selected. In total, 18 concrete specimens were made, 9 using drinking water and 9 using treated wastewater.

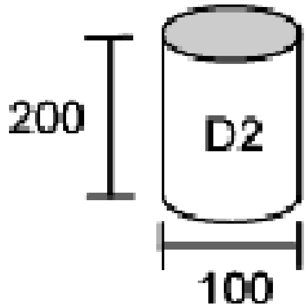


**Fig. 2.** Diagram of the concrete specimen used

*G. Compressive strength test*

The compressive strength test was carried out at each batch of mixture at 7, 14 and 28 days, with the test machine of the UPC laboratory and following the recommendations of the NTP standard 339.034. The data obtained were recorded in an Excel table prepared by the researchers to then make the comparison of the resistances.

**Fig. 3.** Compression test of cylindrical specimens

## III. Results and discussion

*A. Water-based chemical tests*

Table I shows the results of the tests carried out on treated wastewater.

TABLE I. RESULT OF CHEMICAL TESTS OF WASTEWATER TREATED BY OSMOSIS

| Rehearsal | Unit | Results | Maximum limit |
|---|---|---|---|
| pH | pH unit | 6,69 | 6 - 8 |
| Total solids | ppm | 1104 | 50000 |
| Total Alkalinity | ppm | 41.96 | 600 |
| Organic material | ppm | <5 | 150 |
| Chloride | ppm | 429 | 1000 |
| Sulfate | ppm | 7.9 | 3000 |

Note: Own elaboration

### *B. Tests on aggregates*

Table II shows the characteristics of the aggregates obtained from the tests carried out.

TABLE II. CHARACTERISTICS OF THE AGGREGATES

| Properties/Aggregates | Fine | Thick |
|---|---|---|
| Profile | | angular |
| Loose unit weight (kg/m3) | 1273,1 | 1431,2 |
| Compacted unit weight (kg/m3) | 1565,4 | 1535,3 |
| Specific weight (kg/m3) | 2604,2 | 2653,3 |
| fineness modulus | 3,2 | 6,9 |
| TMN | | 1/2" |
| %abs | 1,05% | 1,16% |
| %w | 3,33% | 0,41% |

Note: Own elaboration

Figures 4 and 5 show the granulometric curves of the fine and coarse aggregates.

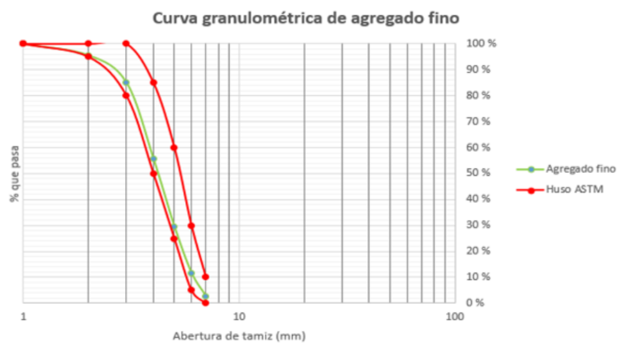


**Fig. 4.** Grading curve of fine aggregates.


**Fig. 5.** Grading curve of coarse aggregate

### *C. Resistance reached at 7, 14 and 28 days*

Table III shows the results of compression tests of cylindrical concrete specimens according to the water used for the preparation of the concrete mix design.

TABLE III. RESULTS OF COMPRESSIVE STRENGTH TESTS BY TYPE OF WATER

| Water Type | Average resistance (kg/cm2) | | |
|---|---|---|---|
| | 7 days | 14 days | 28 days |
| Drinking water | 124.84 | 159.22 | 211.74 |
| Treated Wastewater (Osmosis) | 219.61 | 229.53 | 261.65 |

Note: Own elaboration

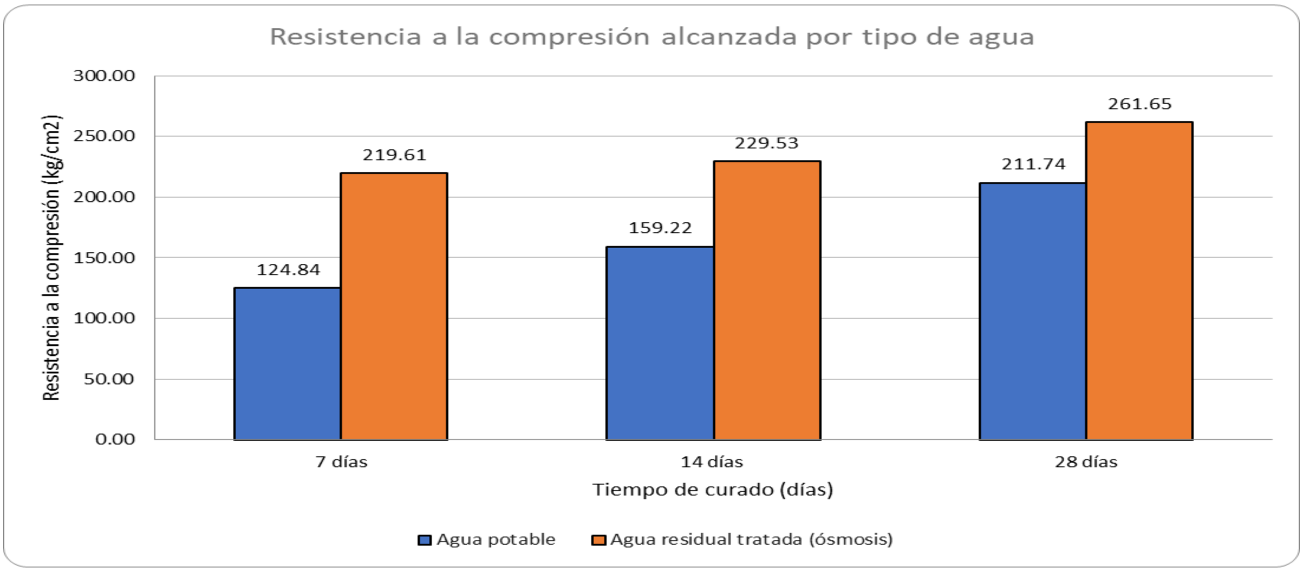


**Fig. 6.** Comparative graph between resistors

Figure 6 shows a summary bar graph with the results of compression tests of cylindrical concrete specimens according to the water used for the preparation of the concrete mix design.

### D. Interpretation

The granulometric curve of the fine aggregate is within the limits as indicated in the NTP 400.037 standard. However, the fineness modulus was 3.2 and is 0.1 outside the range of 2.3 to 3.1 that the standard indicates, but it is acceptable since it is indicated right there that the fineness modulus cannot vary more than 0.2.

The granulometric curve of the coarse aggregate is within the limit indicated by the NTP 400.037 standard for a spindle 67.

The tests of the treated wastewater are within the limits established by the mentioned standards. This means that this type of water is suitable for the preparation of concrete mixtures.

The results obtained reveal that the use of osmosis-treated wastewater in the concrete mix design has proven to be more effective in terms of compressive strength compared to drinking water. After 7 days, the concrete made with treated wastewater reached an average resistance of 219.61 kg/cm2, while the concrete made with drinking water obtained a resistance of 124.84 kg/cm2. After 14 days, the concrete with treated residual water reached an average resistance of 229.53 kg/cm2, in contrast to the 159.22 kg/cm2 obtained with potable water. At 28 days, the concrete with treated residual water reached an average resistance of 261.65 kg/cm2, while the concrete with potable water registered a resistance of 211.74 kg/cm2. These findings suggest a significant improvement in concrete performance at an early stage when using osmosis-treated wastewater.

### E. Analysis

As the results of the tests on the aggregates and the treated wastewater show, these materials are suitable for the design of concrete under the standards of both the ACI method and technical regulations.

Analyzing the results obtained from the compression tests of the concrete made with drinking water versus treated wastewater, it can be observed that the design made with the treated wastewater has a better axial behavior. This means that it is more resistant to compression and reaches a design resistance of 210 kg/cm2 7 days after the test tubes were made.

### F. Validation

According to the results obtained, it can be affirmed that the use of treated wastewater is favorable for the elaboration of concrete mixtures, without significantly varying the compressive strength, as various authors have demonstrated in the consulted investigations. In the investigation carried out by Ganesh et al [2], a difference in compressive strengths was observed between concrete made with reverse osmosis wastewater and conventional concrete at 28 days. Specifically, concrete with reverse osmosis wastewater was found to have lower strength compared to conventional concrete in this time period. However, he mentions that the difference is minimal and it is possible to make concrete with this type of water. Se-Jin et al [3] also found that the addition of recycled water and fine aggregate of blast furnace slag improves the compressive strength of cement mortar. In addition, the study carried out by Jamuna et al [4] indicates that the use of treated gray water in the production of concrete improves both workability and resistance, with an increase of 20%. Tamashiro et al [5] demonstrated that the use of stillage and recycled concrete aggregates in the preparation of concrete shows satisfactory results, allowing its use as a non-structural wall. Finally, Monkman & Meyer [6] explored the use of carbon dioxide to treat wash water and found that concrete produced with $CO_2$-treated wash water exhibits higher compressive strength compared to conventional and concrete produced with untreated wash water.

## IV. Conclusions

The manufactured concrete that used treated wastewater showed a 4.6% increase in design strength in the first 7 days of curing, and after 28 days it improved by 24.6%. These results indicate that the incorporation of treated wastewater into the concrete mix has promising potential to improve compressive strength in the early stages.

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