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CONCRETE BEHAVIOR USING RECYCLED WASTEWATER

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ABSTRACT: Concrete is one of the world's most essential and most widely used civil engineering applications, making it the reason to continue the need for development by implementing more sustainable methods. Water is one of the fundamental pillars in its manufacture and its acquisition of the required mechanical and physical properties through the applicable mixing ratios. So far, tap water is mainly used in this process, whether in preparing components, mixing, or even after hardening during the curing treatment process. However, this may become a burden in the future due to the increasing scarcity of fresh water, where regions suffer due to population growth, climatic changes, and poor management of water systems. This paper deals with the use of tertiary treated wastewater (recycled water) treated by the Jebel Ali sewage treatment plant in Dubai-UAE as an alternative in the concrete industry during the mixing and curing treatment phase by testing the extent of this effect on the mechanical properties of concrete, such as compressive, flexural, and tensile strength from a general perspective. The results show a significant improvement in the compressive strength observed according to the cubes crushing test, reaching 33% after seven days, 70% after 14 days, 56% after 21 days, and the endurance tensile strength test improved by 4% after 28 days in comparison with the normal concrete. The results show that the recycled wastewater concrete performed closer to, if not better than, the normal concrete in mechanical and physical properties.

Keywords: Concrete Behavior, Tertiary Treated Wastewater, Mechanical Properties of Concrete.

1. INTRODUCTION

The construction sector is blamed for being the largest natural resources consumer [1,2]. Concrete is the most widely used in this industry, a product of gathered materials mixed with cement, sand, gravel, and fresh water. Unfortunately, it is considered one of the largest fresh water-consuming during its different process stages. One cubic meter of concrete requires about 150 litres of fresh water, increasing to 500 litres if counting the washing materials, curing, transportation losses and equipment preparation [3,4,5]. Nearly one trillion cubic meters annually is reserved for concrete production [5,6]. It accounts for around 9% of the extraction of fresh water for industrial use, accounting for up to 1.7% of the total extraction of freshwater [2,7,8].

Undoubtedly, the stress of global population growth, urbanization, industrialization, climate change, poor management of water systems, surface and groundwater contamination, and global warming are the most challenging environmental freshwater scarcity [6,7,9]. The concrete industry, in general, is not environmentally friendly; it is responsible for the emission of more than 1.4 billion tons of CO_2 through the cement process production only, equal to 7% of the CO_2 of worldwide output. In addition to the high energy requirement and the excessive use of freshwater in its production processes, they are not attuned to sustainability development [10].

Sustainable solutions shall take place in the concrete manufacturing field, as it is strongly needed. The aims were to minimize the freshwater use in the concrete industry, eliminate the continued expanding need for it, and reserve it for drinking purposes only [2,10]. The freshwater was targeted to be replaced by another alternative to utilize its functionality in concrete manufacturing. Many types of disposed water were suggested to be investigated by the researchers, for example, treated and untreated wastewater (WW), fertilizer factory WW, textile factory WW, sugar factory WW, service station WW (preliminary, secondary, and tertiary treated) WW, salty water, seawater [11], oily water, stone slurry WW, sludge WW, car wash station WW, and many other types [3,4,12].

From the above short list of different water types, the treated wastewater types are the most convenient, sustainably achievable, and globally can be afforded both technically and financially. Moreover, many researchers have achieved progression in studying the differences in mechanical and physical aspects of concrete when using fresh, tap, or potable water compared with wastewater, and it was found to have very similar properties, thus promoting the idea of replacement in the near future [2,4,12,13]. This research is unique from others as it is based in the United Arab Emirates, precisely Dubai, using the locally treated wastewater from the Jebel Ali sewage treatment plant in studying the concrete.

In this study, an investigation was attempted to focus on using tertiary recycled wastewater as a replacement for tap water in the concrete mixing and curing stages by studying its impact on mechanical properties such as compressive, tensile, and flexural strength and physical properties such as workability.

2. RESEARCH SIGNIFICANCE

This research signifies a wide step toward a global concrete manufacturing industry to be more sustainable by using tertiary treated wastewater (the sewage wastewater plant's final stage output water before discharging in water streams) to replace tap water usage in the concrete mixing and curing process. Consequently, tap water savings will be obtained; the tertiary treated wastewater or recycled water will be globally technically and financially affordable. In addition, the concrete physical and mechanical properties' behaviour comparison using recycled water results were near, if not better, than those made using tap water.

3. MATERIAL AND METHODS

3.1 Concrete Component

Concrete consists of three main components: cement, with a sharing rate of 16.5%, water of 8.5%, and aggregate, whether coarse or fine, with a sharing rate of 75% from the mixer [14].

3.1.1 Cement

An ordinary Portland cement of CEMI type and 42.5N class was used under the BS-EN-197-1:2011 speciation [15].

3.1.2 Water

Tap water: Normal tap water is distributed by the DEWA authority (Dubai Electric and Water Authority) [16]. Tertiary Treated Wastewater: Obtained from Jebel Ali sewage treatment plant located south of Dubai emirate [17].

Table 1 Water quality test comparison between tap water and recycled wastewater

Parameter	Symbol	Unit	Water type	
			Tap Water	Recycled WW
Total suspended solids	TSS	mg/l	4	50
Total dissolved solids	TDS	mg/l	100 to 450	1500
PH	PH	---	7.9 to 8.5	6 to 9
Turbidity	-	NTU	<5.0	75
Biochemical Oxygen demand	BOD	mg/l	0	50
Chemical Oxygen demand	COD	---	0	100
Fecal Coliform bacteria	-	cells/ 100ml	null	1000
Total Coliform	-	MPN/ 100ml	null	1000

3.1.3 Aggregates

Fine: black sand graded medium size from 0.4mm to 2mm.

Coarse: two sizes, 10 mm and 20 mm.

3.2 Concrete Mixing Design

The Concrete mix design used in experiments is proportional between its components (1 cement: 1.5 fine aggregates: 3 coarse aggregates) mixed by a water-cement ratio of 0.5 to produce a concrete characteristic compressive strength of 40 $N/mm^{2,}$ which is known as concrete grade M40.

Table 2 Concrete mixing design ratios and quantity

Material	Cement	Aggregates			Tap Water / Recycled WW
		Fine	Coarse		
			20 mm	10 mm	
Ratio	1	1.5	2	1	0.5
Quantity (kg/m^3)	436.4	654.6	872.7	436.4	218.2

3.3 Concrete Testing Preparations

3.3.1 Physical properties

Workability (slump test): Metallic mold with a cone shape filled with concrete in layers and rod taped 25 times each, then mold pulled up, leaving the concrete to deform under the influence of its gravity flow.

3.3.2 Mechanical properties

Testing machines:

1. Compressive strength test (Cubes crushing test).
2. Tensile strength test (Splitting cylinder test).
3. Flexural strength test (Beam test).

3.4 Concrete Specimens' Preparation

The testing replaced fresh or tap water with treated or recycled wastewater. Both types of water were used interchangeably in the two stages, so the first testing option was to use only tap water in the mixing and curing stages. It was denoted by (control specimen or MC), while the second testing option was to keep the tap water in the mixing, whereas the curing with recycled wastewater was denoted by (MC1) specimen. The third testing option comes by replacing the tap water with recycled wastewater; as for the curing stage, tap water is used (MC2), and then the fourth and last testing option is using recycled wastewater in mixing and curing (MC3) (Fig.1).

The recycled water used was the output of the tertiary wastewater treatment. The concrete mixtures were arranged to produce a total of 16 concrete specimens classified into 12 concrete cubes of 150 mm length, two concrete cylinders of 150 mm diameter and 300 mm height, in addition to 2 concrete beams with dimensions of 100 mm for width and height and 500 mm for length.

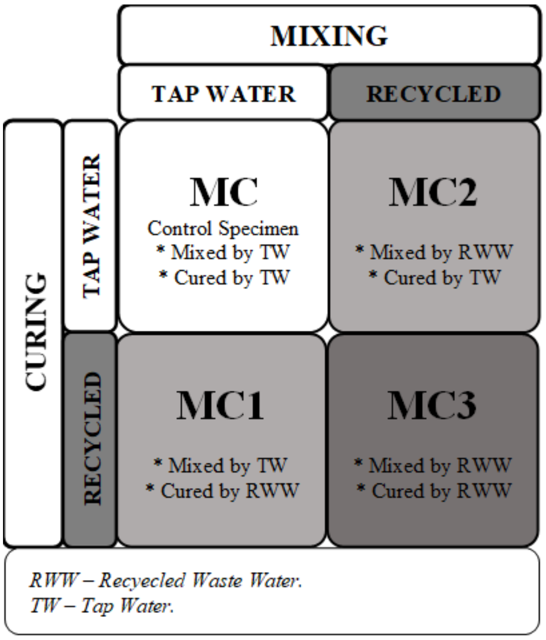


Fig. 1 Arrangement of using the two types of water interchangeably in the mixing and curing stages

The 12 concrete cubes were conducted to test the concrete compressive strength behaviour. Tests were performed at ages 7, 14, and 21 days, with four cubes every time after drying from the curing stage and four cubes that comply with four different water combination options covering the two mixing stages and curing. At the same time, the two concrete cylinders were conducted for the concrete tensile strength that was tested at 28 days using two different water options, which were either fully mixed and cured by tap water or recycled wastewater. Finally, the two concrete beams were conducted to test the concrete flexural tensile strength behaviour at 28 days with the same two different water options in the previous test (Fig. 2).

In fact, recycled tertiary treated wastewater contains dissolved solid particles with a high absorption property, decreasing the water content quality. That leads to lowering the slump value as agreed with [1,18,19,20]. In other words, the high content of fine particles in the recycled wastewater reduces the effective W/C ratio in the mix, and therefore the workability goes down. However, it is still in the acceptance range.

4. RESULTS AND DISCUSSION

4.1 Physical Properties

4.1.1 Workability (Slump Test)

The concrete control specimen produced by mixing the components with tap water was observed to have a higher value than that of recycled tertiary treated wastewater. The control specimen slump was 65 mm in height, while the recycled wastewater was 46 mm, reflecting a 29% decrease in the control specimen values.

According to the findings of [18], the slump was decreased by 25% when using tertiary treated wastewater, giving a difference of only 4% away from our values, while a decrease of 50% when using secondary treated wastewater.

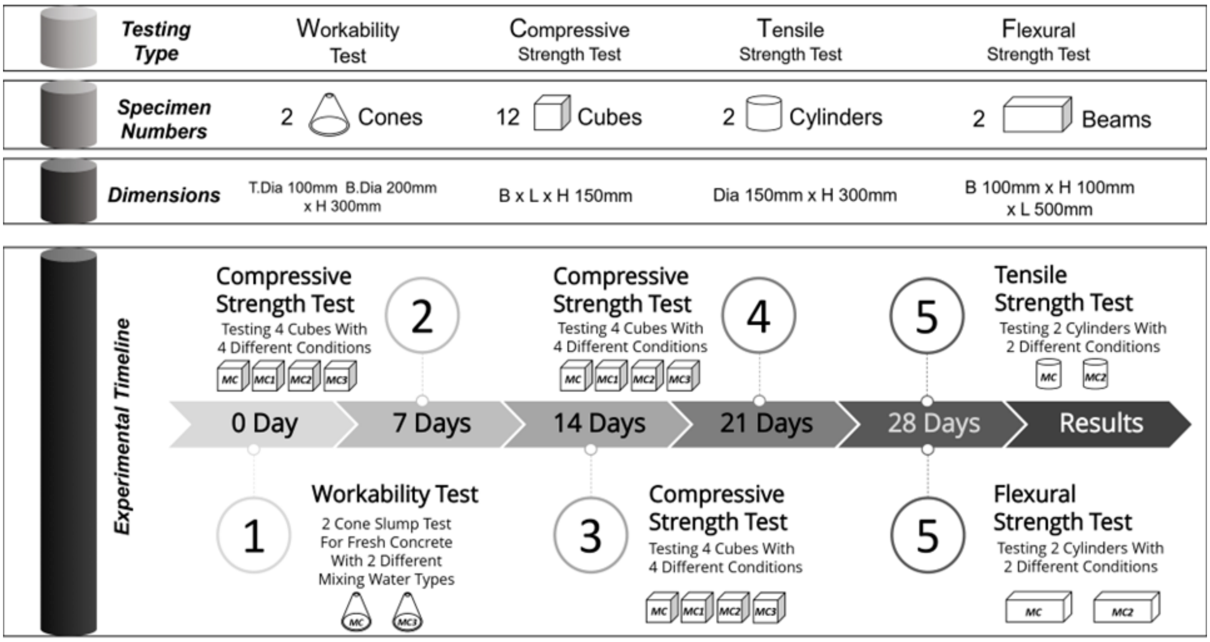


Fig. 2 Sequence of the testing procedure, including the curing period

4.2 Mechanical Properties

4.2.1 Compressive Strength Test (Cubes Crushing Test)

Tests were maintained over intervals of up to 21 days; for every seven days, four different cubes were required to obtain their compressive strength value.

4.2.1.1 At Seven Days Interval

The results were compared with the control specimen and were found to be higher when tap water mixing and recycled wastewater in curing (MC1) were used, as it got 24.62 MPa. The control specimen got 18.5 MPa, which is 33.1% higher than the control specimen. The other two specimens got lower values as the specimen using recycled wastewater in mixing and tap water in curing (MC2) got 16.66 MPa, as low as 8.9 % from the control specimen value. Also, the specimen using recycled wastewater in both stages of mixing and curing (MC3) got 10.99 MPa, as low as 40.4% from the control specimen value (Fig. 3).

That was contrary to [1,14,21,22] findings, in which the concrete with treated wastewater exhibited a greater compressive strength than the concrete with tap water. The reason that may arise for lowering the strength of the concrete at an early age when using recycled treated wastewater in concrete mixing is that it may contain an organic matter that lowers the pH, which deteriorates the concrete [3].

4.2.1.2 At 14 Days Interval

It was observed that all the results were significantly higher than the control specimen, where it was found that the specimen made by using recycled wastewater in mixing and tap water in curing (MC2) had 37.3 MPa. In comparison, the control specimen got 22 MPa only, which is 69.5% higher than the control specimen. Also, the other two specimens got higher values as the specimen made using recycled wastewater in both stages of mixing and curing (MC3) got 35.31 MPa, with a 60.5 % increase from the control specimen value. In contrast, the specimen made using tap water in mixing and recycled wastewater in curing (MC1) got 27.46 MPa, a 24.8% increase from the control specimen value (Fig. 3). That was also agreed by [14] and [21] findings that the increase of compressive strength in the concrete mixed with treated wastewater is most significant during the early concrete ages of 7, 14 and 28 days.

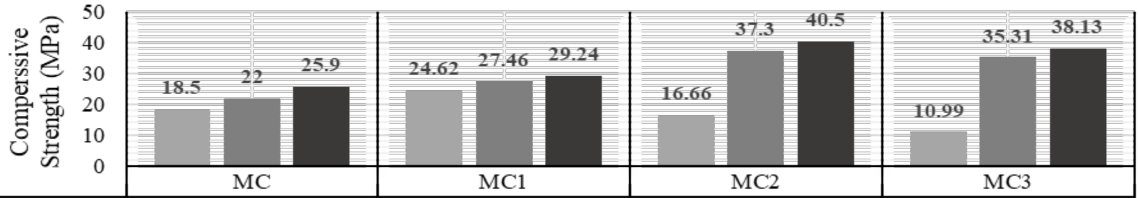
4.2.1.3 At 21 Days Interval

It was also observed that all the results were significantly higher than the control specimen, where it was found that the specimen made by using recycled wastewater in mixing and tap water in curing (MC2) had 40.5 MPa. In comparison, the control specimen got 25.9 MPa only, which is 56.4% higher than the control specimen. Also, the other two specimens got higher values as the specimen made using recycled wastewater in both stages of mixing and curing (MC3) got 38.13 MPa, reflecting 47.2% higher than the control specimen value. In contrast, the specimen made using tap water in mixing and recycled wastewater in curing (MC1) got 29.24 MPa, with a 12.9% increase from the control specimen value (Fig. 3).

Finding by reference [14] notes that when the concrete is both mixed and cured using treated wastewater, an increase of 17% in compressive strength is obtained; according to this experiment, an increase of 47.2% was found when the concrete was mixed and cured with the treated wastewater (MC3).

4.2.1.4 Results Commentary

When comparing the result curves between the different mixing and curing combinations, the curves expressing the combinations using the tap water in mixing as MC and MC1 have very similar patterns as both grew linearly and almost turned into parallel lines. Also, the increase in concrete strength was almost gradual and small throughout the time intervals.



	MC	MC1	MC2	MC3
7 DAYS	18.5	24.62	16.66	10.99
14 DAYS	22	27.46	37.3	35.31
21 DAYS	25.9	29.24	40.5	38.13

7 DAYS   14 DAYS   21 DAYS

Fig. 3 Shows the compressive strength values for all concrete mixing combinations (MC, MC1, MC2, and MC3) for 7, 14, and 21 days period

In comparison, the other two curves present the use of recycled wastewater mixing combination as MC2 and MC3 had nonlinear behaviour. They began lower than those mixed with tap water in strength values as in the seven days test, then significantly increased at the 14 days test and became higher than the tap water mixing curves, then continuing to slightly increase at a rate nearly matching with that in the tap water mixing curves values.

MC2 gains more strength as values than MC3, but practically, MC3 gains more strength since the start was significantly low compared to MC2, as it gained 23.84 MPa more during the testing period from 7 to 21 days. MC3 gains a higher value of 27.14 MPa for the same period, which confirms the advantage of using recycled wastewater in curing (Fig. 4).

Building codes like ACI [23] permit the use of non-potable water in concrete mixing to provide at least 90% of the strength gained by potable water specimen values on both seven and 28 days of testing [14]. By applying the ACI code to the result, it was found that the two mixing combinations that use non-potable water (MC2) and (MC3) were 90.05% and 59.40%, respectively, for the 7-day test, which means one of them passed (MC2), and the other failed (MC3). However, the experimental values exceeded those of potable water (MC and MC1) at 14 and 21 days. Although no testing was conducted during the 28 days, it was obvious that the mixing using the non-potable water (MC2 and MC3) values would be higher than the potable water (MC and MC1) values, if not at least equal to them (Fig. 4).

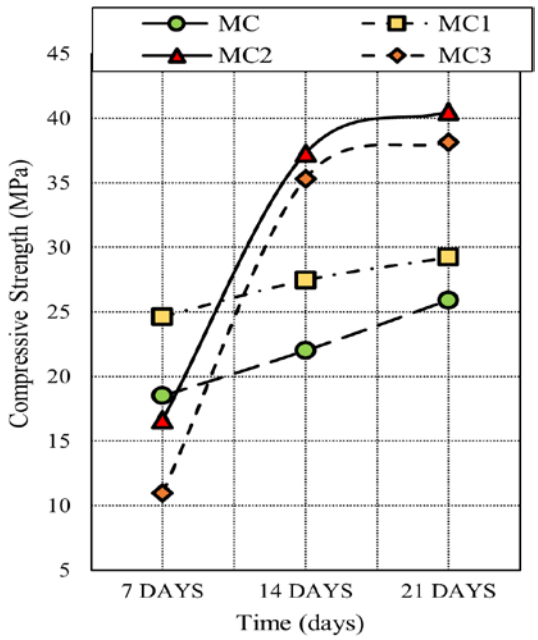


Fig. 4 Compressive strength of concrete specimens

Gaining more compressive strength in specimens mixed with recycled wastewater has been illustrated by [24], which mentions that the pore-filling provided by the deposition of dissolved and suspended solids existing in the recycled water was responsible for the strength increase, and similarly, when using recycled wastewater in the curing process, as the efficiency of cement hydration increased under the pore filling effect.

In other words, pore-clogging exists by settling dissolved solid particles, reducing the porosity and enhancing the strength [25]. Even though the concrete mix water was tap water, it may be why compressive strength differences were found between the results for specimen mixing by tap water and that cured by tap water MC and by recycled water MC1.

The differences between control specimen MC and MC1 reached 33% extra in strength on day 7, then reduced to 24.8% on day 14, and finally reached 12.9% extra on day 21; eventually, the two curves of MC and MC1 are likely to meet at day 28 (Fig. 2).

On the contrary, the findings of [26] concerning a study of sharing different proportions between the tap water to treated domestic wastewater of ratios (0, 50, 75 and 100%) using cylinder concrete specimens tested at the age of 28 days.

Results revealed that the specimens with a sharing ratio of 50% and 75% of treated wastewater have no significant differences from tap water. In comparison, the 100% treated wastewater share gains a 17.7% increment in compressive strength.

4.2.2 Tensile Strength Test (Splitting Cylinder Test)

A tensile strength test was done at 28 days of concrete age for two cylinders; one of them was the control specimen, and the other was selected based on the superior results obtained from the compressive strength test at day 21 and using the same corresponding concrete combination for water in mixing and curing, as it was the use of the recycled wastewater in mixing and tap water in curing (MC2).

As a result, a slight increase in the results was observed compared with the control specimen, as it got a tensile strength of 2.93 MPa to 2.83 MPa for the control specimen, representing a 4.2% relative increment (Fig. 5).

Similarly, [9] found that the tensile strengths of the concrete specimens with 50% wastewater sharing gained a higher value than the control mix. Some researchers pointed out that the reduction or increase in the tensile strength was related to the level of organic matter content in the water, particularly the existence of the BOD and COD values [3].

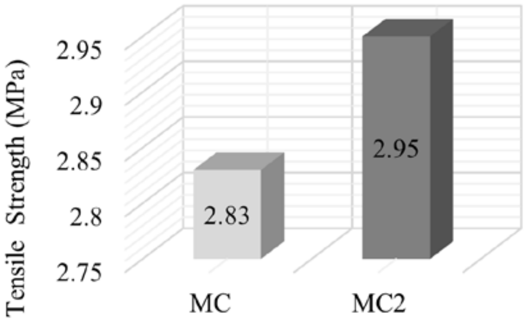


Fig. 5 Tensile strength of the concrete specimens for 28 days of curing

4.2.3 Flexural Strength Test (Beam Test)

A flexural strength test for two beams was done on day 28 of concrete age. One of them was the control specimen, and the other was selected based on the superior results obtained from the compressive strength test at 21 days of age and using the same corresponding concrete combination for water in mixing and curing as it was selected previously in the tensile strength test. It was made using recycled wastewater in mixing and tap water in curing (MC2). A decrease in the results was observed compared with the control specimen, as it got a strength of 3.8 MPa to 4.2 MPa for the control specimen, representing an 8 % relative decrement (Fig. 6).

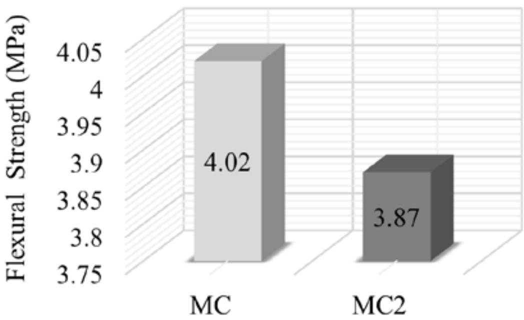


Fig. 6 Flexural strength of the concrete specimens for 28 days of curing

According to [18], using secondary and tertiary treated wastewater in the concrete mix reduced the flexural strength of the concrete at its early age, then slowly increased its strength at the later stage, as it was found to be 7.71% at 28 days and further decreased at its later ages of 90 days by 25.73%. Compared with this experiment, the figures were so close in values that MC2 reveals a decrease in strength of 8% at 21 days.

Despite the compressive and tensile strength testing results for the MC2 specimen, which were relatively high in comparison with the control specimen MC results, the flexural strength result was less, which proves that there is no relationship between the compressive strength and flexural strength; nevertheless, it was noticed that the use of the recycled treated wastewater in concrete mixing affects the concrete bonding strength between the cement pastry and aggregate [3]. Similarly, what was revealed by [18] was that the main contributor to flexural strength reduction was the tertiary treated wastewater that has a high alkalinity content, which forms a layer between the cement paste and aggregates in the interfacial transition zone.

5. CONCLUSIONS

It was noticed that the excellent benefit of using recycled wastewater in mixing and curing concrete is choosing the water-cement ratio that enhances the workability, which is reduced by the large content of suspended and dissolved solid particles that absorb the water in the mixer.

Nevertheless, these dissolved solids play a significant role in filling the pores initiated and reducing the porosity in the produced concrete during the mixing stage, which increases its strength in the early developing ages. Besides, it has the same effect when using recycled wastewater in the curing stage. The more there are dissolved solid particles and the longer the curing time, the faster the remaining pores in the concrete are blocked due to percolation and filling, which eventually increases the concrete strength.

The main achievement pursued by the experiment is as follows:

1- Concrete performed using recycled tertiary wastewater has such near-performance mechanical and physical characteristic properties relative to that performed using tap water.
2- Using recycled tertiary wastewater in the concrete curing stage has an advanced strength compared to tap water use.
3- Using recycled tertiary wastewater in concrete is an excellent achievement toward sustainability in preserving freshwater and concrete manufacturing.

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