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Experimental Study on Wastewater Application for Cement Mixing in Concrete

Mohammad Pordel Nezami[1], Mohamad Aslalinezhad Fard[2], Mahdi Aslalinezhad Fard*[3]

[1]*Department of Civil Engineering, Maragheh Branch, Islamic Azad University, Maragheh, Iran*
[2]*Department of Civil Engineering, Power and Water University of Technology, Tehran, Iran*
[3]*Department of Civil Engineering, Maragheh University of Technology, Maragheh, Iran*

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ABSTRACT

Water content is a very important part of concrete which has an important impact on strength of the concrete. The water condition in concrete is mostly located in drinking level which by shortcoming on the waters is required to reconsider the usage water in concrete. The presented study attempted to provide the experimental study on wastewater application for cement mixing in high-strength concrete. In this regard, the experimental assessment was conducted on 2 types of concrete mix named Mix 1 and Mix 2 (for 7 and 28 days) which is indicated of drinking water, and treated wastewater-based concrete. The main evaluation index is UCS which is performed on 10 samples. According to the results of the study, using treated wastewater provides the 12 to 18 MPa strength regarding UCS which is near to the freshwater (14 to 20 MPa). So, the application of treated wastewater can be considered as an alternative for fresh water in concrete.

1. Introduction

Concrete is one of the most basic and important materials that plays a role in human life to the extent that some consider it the most important material in engineering (Nguyen-Sy et al., 2020). Every day around the world, different development plans are designed and built with different goals and applications. Concrete is one of the most widely used building materials, which is widely used in construction due to its cheapness and availability of raw materials. Because the volume of concrete used in construction projects is very large and sometimes reaches millions of cubic meters, this brings a lot of costs for the executors of various projects. On the other hand, different designs require concrete with different strengths and characteristics; meeting such requirements requires the application of new approaches in concrete engineering (Cao et al., 2020). Researchers have conducted various experiments to produce concrete with the required properties at a lower cost, and this effort continues today (Arachchige et al., 2014). In this way, various materials are used in concrete compositions and are tested in different procedures. If the relevant standards are met and the costs are reasonable which they are used in appropriate designs that have been used in concrete technology in recent years and the desired results are impressive (Zacoeb and Ishibashi, 2009). Concrete has different mechanical properties such as compressive strength, durability, performance and permeability (Zhang et al., 2019), each of which has its own importance and depending on the type of work can be recognized as the key factor required in the

*** Corresponding author.**
E-mail address: Aslalinezhad@gmail.com
M.Sc., Research Assistant.

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usage of concrete (Zhou et al., 2019; Mohammadinia et al., 2019). But, compressive strength is generally considered as most important characteristic of any concrete (Arulrajah et al., 2015). This index is used to evaluate the mechanical properties of concrete, especially durability and shear under axial loading (Wong et al., 2020). An increase in uniaxial compressive strength (UCS) is an indicator for measuring the improvement in quality and stability of concrete (Azarafza et al., 2017). Thus, a set of activities to improve the quality of concrete, such as the addition of artificial and natural materials, the use of fibers and textiles, synthetics, additives such as microsilica, nanosilica, etc. (Fisonga et al., 2019). Different mixing designs for different conditions and application of materials in concrete in order to increase UCS. In all these stages, the use of water, especially drinking water, in mixing projects has been a common case. But a key point about this basic foundation of concrete derivatives is the application and control in the nature of the fluid used. Use of recycled water or treated wastewater instead of drinking water, which can be used to return fresh water to the utilization cycle for more important uses. Also, the use of treated effluent can improve and control environmental damage (Song et al., 2020).

Water recycling is one of the important factors in the water sector. Reuse of water leads to environmental protection, sustainable development, increasing the welfare level, increases the construction trend. So, the concrete industry has been recognized as the most important building material in the last century, and its economic and environmental aspects must be monitored (Poltue et al., 2020; Ma et al., 2021). In most countries, the ratio of concrete to steel consumption has exceeded about 10 to 1 (Shivanath et al., 2011). About 180 liters of water is needed for each m^2 of concrete, so in countries like Iran with huge concrete buildings, sometimes up to 3000 m^2 of water is used to make concrete, due to the water shortage crisis, this amount of water supply and cost (Ivšić-Bajčeta et al., 2013) which considered as one of the main problems for developers of development and construction projects, especially concrete buildings (Esmaeili and Heidarzadeh, 2021).

Water used in concrete should be drinking water. According to Clause 9-3-4-1/Section 9 of the Building Instructions in Iran Code (Esmaeili and Heidarzadeh, 2021), drinking water that does not have a specific taste or smell and is clean and smooth can be used in concrete. Water that does not meet the specifications of 9-3-4-1 (non-drinking water) can be used in concrete under the conditions set out in full in 9-3-4-2/Section 9. One of the conditions is that the pH of water used in concrete should not be less than 5 or more than 8.5. This is a very sensitive issue that has a profound effect on other characteristics as well. So that the change in the nature of water causes many problems in concrete, including cracking of concrete, hollow concrete, white phenomenon, etc. This issue raises various concerns in the construction industry. The amount of water consumed inside the concrete is very important. In order to complete the process of cement reaction with water, a certain amount of water is required. If more than the required amount of water is added to the concrete mix, after completing the reaction, some water remains freely inside the concrete, which after hardening of the concrete will cause it to become hollow and consequently reduce the strength. For this reason, it is necessary to be careful not to consume too much water inside the concrete in order to achieve high strength (Esmaeili and Heidarzadeh, 2021).

2. Related Works

The minimum amount of water required to complete the reaction is defined as the water-to-cement ratio parameter. This ratio is about 25% for ordinary Portland cement. With this amount of water, concrete will not have the necessary efficiency and usually the ratio of water to cement used in construction workshops is more than this amount. In determining the mixing ratio of concrete, a parameter is considered that also takes into account the moisture content of the aggregates before adding water to the concrete, which is important in determining the amount of water required (Poltue et al., 2020). This excess moisture is the amount of excess moisture of the aggregates from the saturated state with the dry surface of the Saturated Surface Dry (SSD). In general, different approaches to water to concrete ratio have been proposed and extensive work has been done to optimally estimate this ratio. Many researchers have conducted extensive studies on the properties of materials and additives, the type of cement used and the new technologies used in the concrete industry. However, studies on the nature of the water used are very limited and are generally considered national building standards (Esmaeili and Heidarzadeh, 2021). Severe shortage of fresh water resources, especially due to successive droughts in most regions, including Iran, the need for fresh water resources and more has already been considered. One of these sources is the use of treated effluents. So, here is a review and study of some numerous researches and researches that have been done in this field in relation to the reuse of treated wastewater in concrete in a number of different countries by different researchers (Radovanović et al., 2016).

Franzoni and Sandrolini (2001) studied on production of concrete and mortar using effluent, and showed that concrete produced with effluent has a compressive strength above 90% of the UCS of the control concrete sample. Lee et al. (2001) in Malaysia using compaction effluent as mixing water in the preparation of concrete to perform UCS and compared it with drinking water which showed the use of effluent in the preparation of UCS concrete more than 90% of the resistance of the sample prepared with drinking water shows that it meets the ASTM C94 and increases the setting time of cement compared to drinking water. Terro and Al-Ghusian (2003) used water recycled from concrete truck wash effluent in the preparation of concrete. Taking pH is very important for the durability of concrete in corrosive environments. Meyer (2005) stated that in order to reduce the negative effects of cement and concrete production, replacement of fly ash as a percentage of cement, recycled materials instead of recycled aggregates, worn rubber, glass and industrial waste and recycled water in the production of concrete instead. Drinking water should be used to achieve a sustainable environment. Chatveera and Lertwattanaruk (2009) used the effluent water of concrete plants and concrete trucks with ash as additives in the production of new concrete. They concluded that the use of solids less than 1% in concrete water would have acceptable strength and durability and that there was a limit to the use of return sludge, in addition that concrete to which the additive was added did not meet ASTM C94 standard. Alenezi (2010) prepared concrete using supplemental treated effluent. The result of this study is that the use of supplemental treated effluent in concrete production has no effect on UCS strength. Noruzman et al. (2012), in their studies on treated effluent in concrete construction, observed that the compressive strength of samples made of effluent was higher than the compressive strength of conventional concrete samples. At the end of the processing period, they observed a percentage increase in resistance. Ghrair et al. (2016) evaluated the potential of using untreated gray water and treated gray water in concrete construction. Using this method, more water can be stored with less drinking water. Both types of effluents increased the initial setting time and decreased the slump. Compressive strength of the samples at 7 days of age also showed a significant increase. At 28, 120 and 200 days of age, purified wastewater had no significant effect on compressive strength.

3. High Strength Concrete

3.1. Concrete Properties

Over the years, the definition of high-strength concrete has changed due to the increased strength of concrete used in the workshop. High strength concrete is considered to be concrete that has a significantly higher strength than ordinary concretes (Rani et al., 2020). CSA A23 standard defines high strength concrete as concrete with a compressive strength higher than 70 MPa (Esmaeili and Heidarzadeh, 2021). Due to the ignorance of concrete operators about the properties of high strength concrete, the use of this type of concrete is very limited. It should be noted that the implementation of high-strength concrete requires higher knowledge and technical skills than ordinary concrete. It is necessary to try to make the implementation of this concrete common with the training of skilled technical force and take advantage of its desirable properties. By using additives such as pozzolans, lubricants, etc., the desired resistance can be achieved (Shang et al., 2017).

3.2. Concrete Mixing Design

Although most concrete regulations still limit the strength of concrete used in structures to 60 MPa, new regulations of Iran have recently set a limit higher than 105 MPa (Güllü and Girisken, 2013). Table 1 shows the mixing ratios of four types of concrete with a 56-day strength between 66 and 76 MPa, which during standard mixing without additives. One of the important factors in achieving such resistances is the use of resistant aggregates and the reduction of the maximum aggregate in the concrete mix for greater homogeneity and with very low porosity, which will have the highest specific gravity. In high-strength concretes, the water-to-cement ratio (W/C) should be reduced as much as possible, in which case some non-hydrated cement aggregates, increase the density and thus increase the strength. In the manufacture of such concretes, hardened methods under pressure and temperature are used to process the concrete and provide high initial strength (Ekolu and Dawneerangen, 2010). Table 2 presents the mixing ratios of concrete with strength of 56 days equal to 124 MPa which has additives. The main advantage of high-strength concretes is the reduction of building weight due to the application of fine stresses and thinner parts, major savings in the amount of concrete and steel used, shortening of the construction period, less time-dependent deformation in concrete. The advantages of using lightweight concrete can be divided into two general categories (Shang et al., 2017):

- Higher insulation properties than ordinary concrete, including thermal insulation and fire and frost resistance,
- Less statical loading.

Table 1. High strength concrete mixing design without additives

No.	Materials	Unit	Value
1	Water	Kg/m^3	200
2	Cement	Kg/m^3	552
3	Fly ash	Kg/m^3	-
4	Coarse to fine grain ratio	%	0.4
5	Ultra-lubricant	-	-
6	W/C	-	0.34
7	UCS in 56 day	MPa	65

Table 2. High strength concrete mixing design with additives

No.	Materials	Unit	Value
1	Water	Kg/m^3	130
2	Cement (Type II)	Kg/m^3	530
3	Fly ash	Kg/m^3	50
4	Silica fume	Kg/m^3	40
5	Coarse grain (maximum size to 1 cm)	Kg/m^3	1050
6	Fine grains	Kg/m^3	600
7	Water reducer I	L/m^3	1.70
8	Water reducer II	L/m^3	7.71
9	W/C	-	0.22
10	UCS in 56 day	MPa	127

3.3. Geotechnical Properties of Concrete

Concrete, requires the definition and estimation of geotechnical properties in terms of use in the construction or implementation of engineering projects. Conceptually, concrete is a synthetic material whose properties can be changed and defined by experts. These materials are any material or compound that is composed of a cementitious adhesive. Concrete can be made from different types of cement as well as pozzolans, kiln slag, sulfur, additives, polymers, fibers, heat, water vapor; vacuum, hydraulic pressures and various compressors may also be used in its construction (Tang and Nordfors, 2020). Sometimes to change some of the properties of concrete, when mixing materials, the amount of additives is added to it. Freshly made concrete has a pasty shape and after being poured into the mold, it takes the shape of the specified mold and after a certain period, it hardens and acquires the required strengths (Xiu et al., 2021).

Compressive strength (UCS) indicates the quality of concrete. Its amount is determined by compression test on cylindrical, cubic and rectangular specimens after a period of time. The compressive force is vertical and is applied to the upper and lower surfaces, which are perfectly flat and smooth. The limit of resistance is when the sample is crushed and disintegrated. Concrete strength is usually calculated after 28, 32 or 90 days of construction. What is certain is that the compressive strength increases with age. This strength is the most important parameter of concrete strength, which indicates the degree of strength, stability and durability in concrete. The second strength parameter proposed in concrete is related to shear strength and stress, which evaluates the concrete against shear. This parameter evaluates the ability of concrete against non-parallel, dynamic and discrete loads. The third strength parameter is related to the tensile strength of concrete, which is not considered much in engineering designs (Panda et al., 2013).

3.4. Concrete Uniaxial Compressive Strength

Compressive strength (UCS) is the bearing capacity of an object, building material or structure against the direct axial compressive forces applied to it. The concrete used in many structures is capable of withstanding pressures above 50 MPa (concrete is a material with high compressive strength); However, soft materials such as soil have a compressive strength of less than 1 MPa (Panda et al., 201). Compressive strength is usually measured by a universal test machine (UTM) or uniaxial compressive test machine (UCS). Measurement of compressive strength is subject to test methods and special conditions. UCS warping is commonly reported in the form of special standard techniques that may or may not be used during operation (Tang and Nordfors, 2020). By definition, the compressive strength is equal to the amount of UCS when the element in question is completely failure (Xiu et al., 2021).

4. Material and Methods

In this article, 2 types of mixing designs were studied and compared. In all mixing designs, the amount of changes in concrete constituents and fixed construction factors have been considered. In all designs, the ratio of water to cement (W/C) is constant and equal to 0.35 and the amount of lubricant is considered constant. The only variable is the nature of the water used, which has changed in all designs. For this purpose, in this study, by sampling 2 different types of water under the titles of Mix1 and Mix2 which are related to drinking water, and treated wastewater, respectively. On the other hand, the UCS has been selected as the index test for evaluating the strength properties of concrete, which has been tested by various effluents after making the concrete. For this purpose, 20 uniaxial and chemical tests have been performed, which are classified into different categories. Prior to performing the resistance tests, the fabricated samples were placed in a saturation pool for 24 hours.

4.1. Materials Used in Concrete Preparation

The materials used to prepare the concrete samples in this study are cement, aggregate, microsilica additive, water and superplasticizer, the characteristics of which are described below:

Pozzalani Cement: Cement used for testing is Portland pozzolanic cement of Sufian cement factory in east azerbaijan province, which has a specific weight of 3130 kg/m^3 (according to the factory catalog). Portland pozzolanic cement is obtained from a combination of clinker (OPC) with 15 to 35% of pozzolanic material. A pozzolanic substance is essentially a siliceous or aluminate material which, while itself having no cementitious properties, reacts with calcium hydroxide in a very fine form in the presence of water, decomposing at normal temperatures by hydration to compounds having cementitious properties. It reduces calcium hydroxide hydrogenation when used in aqueous structures, especially in offshore and hydraulic structures and other bulk concrete structures.

Aggregates or aggregates: Aggregates are aggregates such as sand, gravel, crushed stone, and blast furnace slag that are used with a cementitious interface to form concrete or hydraulic cement mortar. Aggregates are the main components of concrete that reduce shrinkage and have an economic effect. The fact that aggregates occupy 80-70% of the volume of concrete, no doubt their impact on the various properties and characteristics of concrete is considerable. The aggregate used in this project is a type of aggregate with normal and natural weight, which has been prepared from Tabriz Sram mine. Large aggregates are known as crushed sand with a maximum size of 12.5 mm and fine aggregates are known as Leica, the granulation of which is presented. The aggregation of aggregates is done according to the method stated in ASTM C136 standard. The sand is angular in appearance. Coarse aggregates are fully compliant with ASTM C33 aggregates. The properties of concrete aggregates are stated in ASTM C33 standards. It should be noted that of the total coarse aggregates, 65% of almonds and 35% of chickpeas are within the permissible granulation range and have been used in the mixing design. The light grain consumption in this study is domestically produced lyca with a grain size range of 0-5 mm and a specific weight of 400 kg/m^3 with a 24-hour water absorption percentage of 30%, which replaces sand.

Plugins: Among pozzolanic additives, microsilica is very suitable for the production of high strength concrete due to its very fine and separate particles and also the high percentage (about 90%) of amorphous (non-crystalline) silica. Concretes with microsilica are not as porous as ordinary concretes, and all the spaces around the aggregates are uniformly occupied by calcium silicate hydrates. In general, silica foam will increase compressive strength and flexural strength, reduce permeability, improve concrete and cement paste infrastructure, reduce heat due to cement hydration in concrete and improve the size distribution of cavities under cement paste and concrete structure.

Super lubricant additive: The superplasticizer enhances the lubricating properties of water without affecting the surface tension of the water. For this reason, excess air does not enter the concrete and water mixed with super plasticizer creates a lubricating layer on cement particles and aggregates, reduces friction between the concrete solid components and at the same time improves the adhesion of the particles. The major agent in most of these double solutions is hydmalamine formaldehyde or naphthalene sulfate formaldehyde. Super plasticizers are made according to the requirements of ASTM-C494 types A & F standard and also according to Iranian standard No. 2930.

4.2. Mixing Water

According to the executive instructions in making concrete, drinking water is the most suitable water for preparing concrete. The use of drinking water in the construction of concrete, in addition to the issue of reducing water resources, reduces the level of capability in industry and metropolitan management. Considering this issue, this study tries to reduce the use and dependence of concrete on drinking water by applying a different approach in the concrete industry. This operation has been done in order to enable the use of treated effluent instead of drinking water in the concrete and construction industry.

4.3. Exampling and Process

Examples of each mixing design for testing the mechanical properties of lightweight concrete include 10 cubic specimens (10×10×10 cm) for the compressive strength test at the ages of 7 and 28 days. Before concreting inside the formwork, they are lubricated so that there is no adhesion between the formwork and the concrete.

4.4. Mixing Plan of Experiments Stages

In order to determine the mixing ratios of concrete mix components from concrete materials and properties, the absolute volume method of ACI 211 standard has been used. With this value, the general formula of the mixing scheme is obtained. Table 3 shows the amount of consumables as well as all mixing plans, including reference mixing plans and other mixing plans for one cubic meter of concrete. After making the mixture, the concrete is poured into the molds and after 24 hours of making the samples, the molds are opened and placed in ordinary water at 20°C for processing. After the processing time (7 and 28 days), the solids were removed from the water and weighed, then placed in an oven at 105°C to dry completely for 24 hours. After drying, the samples are brought to normal temperature in normal air for several hours to be prepared for testing. Cubic specimens have been used for resistance tests.

Table 3. Mixing plan specifications

No.	Qty	W/C	Water (Kg/m^3)	Cement (Kg/m^3)	Coarse (Kg/m^3)	Fine (Kg/m^3)	Lubricant ratio
1	1	0.35	170	500	850	120	0
2	1	0.35	170	480	850	120	0
3	1	0.35	170	460	850	120	1
4	1	0.35	170	440	850	120	1
5	1	0.35	170	420	850	120	1

5. Results and Discussions

Taking into account the information related to the design of the mixing performed for this stage of construction, which will also be used as a reference in the evaluations, the other items related to the changes made are compared to this stage and the results are interpreted. This is a test phase called Mix1 for drinking water. UCS tests for this stage of evaluations are given in Fig. 1 which shows the trend of compressive strength changes in the mixing with different ages. The study of compressive strength of the mentioned samples shows a relative increase in compressive strength by considering the constant rate of water to cement during days 7 to 28 days. Also, in order to evaluate the chemical properties of the water used, a series of chemical tests have been performed on the water samples taken, which are given in Table 4.

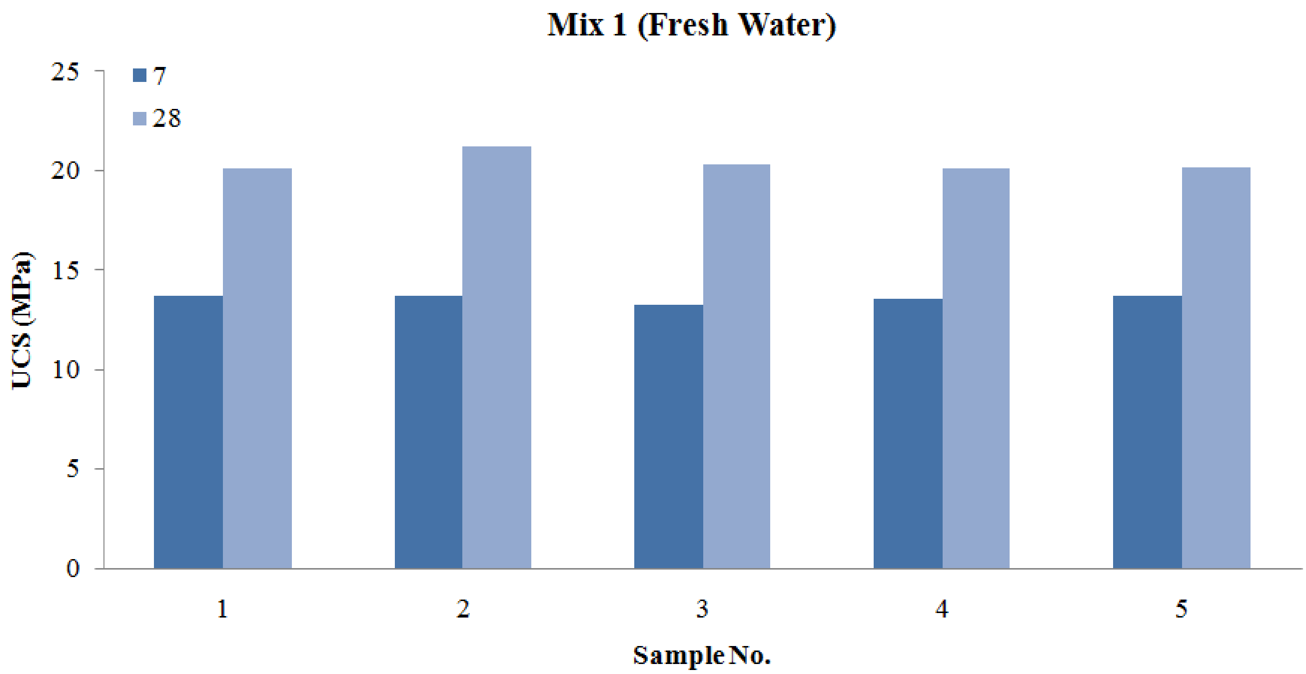

Figure 1. The variation of the UCS for Mix1(fresh water)

Table 4. Results of chemical assessments for Mix1(fresh water)

Mix No.	Temperature (^{o}C)	pH	Turbidity (NTU)	Chlorides (ppm)	Sulphates (ppm)	Conductivity (µs)	Total Solids (ppm)	Slump Value (mm)
1	15.3	7.5	-	-	-	0.53	320	52
2	18.2	7.7	65	40	60	0.66	322	57
3	20.1	7.5	71	38	57	0.61	307	50
4	18.0	7.5	-	-	-	0.60	324	52
5	15.7	7.5	99	42	60	0.61	320	52

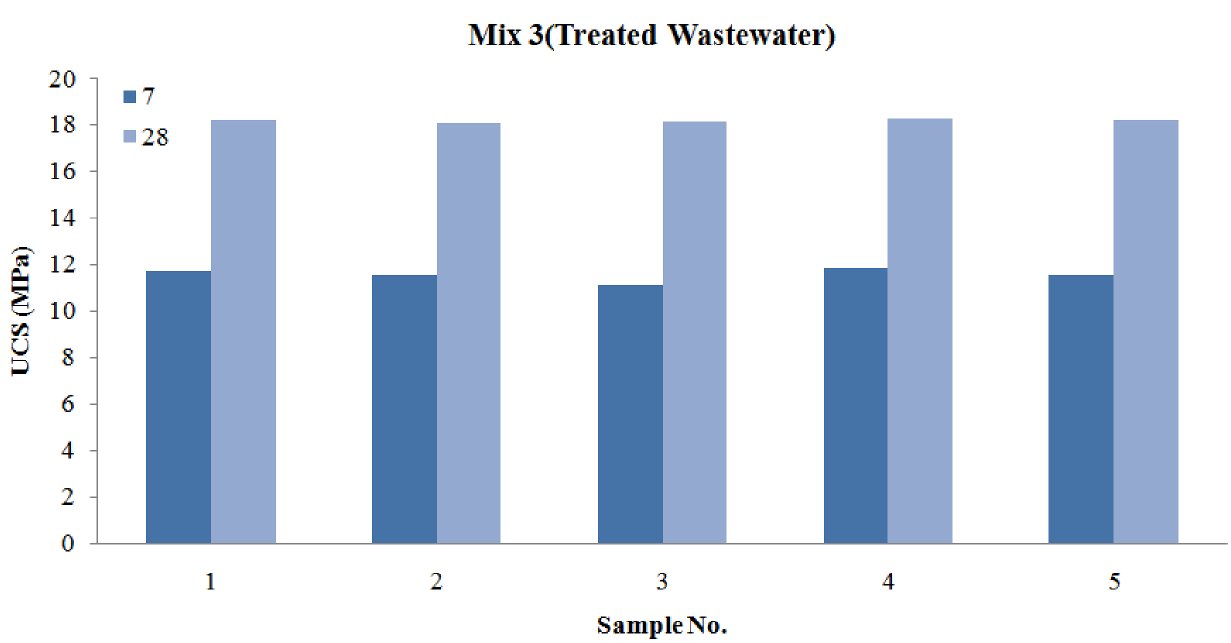

Figure 2. The variation of the UCS for Mix2 (treated wastewater)

Table 5. Results of chemical assessments for Mix2 (treated wastewater)

Mix No.	Temperature (°C)	pH	Turbidity (NTU)	Chlorides (ppm)	Sulphates (ppm)	Conductivity (µs)	Total Solids (ppm)	Slump Value (mm)
1	18.3	7.5	47.0	57	63	0.68	556	45
2	18.0	7.5	56.3	55	55	0.77	530	47
3	20.4	7.7	68.7	52	56	0.71	552	47
4	20.4	7.7	65.3	-	55	0.71	530	45
5	18.5	7.5	71.6	52	63	0.73	552	47

After performing tests to evaluate the strength of concrete by drinking water, in the next stage, mixing plans equal to the effluent have been prepared. The difference is that in this stage of the mixtures, effluent has been used instead of drinking water. Fig. 2 is provided the results of the UCS testing on concrete samples and Table 5 is provided the information about chemical tests for this type of concrete. According to the results of the study, it was indicated that using the using treated wastewater provide the 12 to 18 MPa strength regarding UCS which is near to the fresh water (14 to 20). The results confirmed that using the recycled waters can be used as alternative for the freshwater in concrete as well.

6. Conclusion

The present study investigated the potential for the use of alternative such as wastewater in concrete as to allow for the use of these waters instead of the drinking freshwater. In this regard, different properties of concrete are evaluated and compared in two different steps. These steps are based on the effect of increasing the type of water on the strength of the reinforcement and the mechanical strength of the concrete concrete. In the first step, the concrete is made by water treatment by the operating instructions specified in the ABA and ASTM standards, and the pressure resistance or UCS resistance, which is considered to be the most important precondition for the geotechnical specifications. In the second step of concrete by treated wastewater has been tested. Experimental results based on the design of concrete mixing plan with drinking water (Mix 1) and wastewater (Mix 2). In order to accurately evaluate the effects of fluids on the uniaxial strength of concrete, in all mixing designs, the ratio of cement and water is equal to 0.35 and the values of other variables are considered constant. This issue has caused the change in the nature of water consumption to appear directly on the strength results of concrete. The following results were obtained from the data obtained from UCS resistance tests:

A) The use of drinking water as the main fluid in concrete is generally considered in the construction of concrete and the construction industry, which is a very significant consumption of drinking water.

B) Generally, concrete effluent prepared by drinking water is not usable and is discharged. This issue itself is the cause of environmental degradation and creating negative effects on the workshop area.

C) According to the results of the experiments, the use of treated effluents and treated wastewater in the concrete industry and the manufacture of concrete with suitable strength, is possible and has good results.

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