Effects of Treated Sewage Water on the Performance of Concrete

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ABSTRACT

In construction industry concrete is commonly used material worldwide, ever since concrete was invented, it has been mixed with drinking water. It is observed that there is an increase in water scarcity with population growth and urbanization. However some studies show that water that is not safe for human use might be used in concrete for mixing and/or curing purposes.

In this experimental study; the applicability of treated sewage water on concrete production was tested. For this purpose, set of experiments are performed: slump test; setting time; permeability; compressive, splitting tensile and flexural strengths; sulfate attack; pH test; ultrasonic test and corrosion tests. Collected treated sewage water which was provided from Gazimağusa Sewage Treatment Plant was used. Four different concrete mixes were produced by using potable water (PW) and treated sewage water (TSW) either for mixing and/or curing purposes with 0.47 w/c. Utilization of TSW caused little increase on workability, however it is pointed out that there is no adverse effect on workability. The initial setting time of TSW showed an increament 30 minutes when compared with the initial setting time of PW, showing that TSW slows down the hydration rate of concrete which is an advantage for hot countries. It has not been determined that there is a negative effect on the alkali character of concrete in the use of TSW. It is indicated that utilization of either for casting with TSW (CasT) or curing with TSW (CurT) result in a lower permeability of concrete. It is noted that the use of TSW for mixing or curing improves long-term durability and strength. Using TSW either curing or mixing caused reductions in compressive strength as 8-14% at 28 days. However at 150 days the reductions were between 3-9%. The lowest weight loss was observed in (CasT-CurT) mix while the highest was observed in (CasP-CurP, CasP-CurT) mixes for 72-hour exposure time. However, after 168 hours, it is observed that the corrosion rate increased in time for all mixtures. Also the most weight loss was seen in (CasT-CurP) as 55% and nearly 20% weight loss was observed in (CasP-CurT and CasT-CurT) when compared with CasP-CurP after 168 hours.

Keywords: concrete, mixing water, curing water, treated sewage water, mechanical properties, permeability, corrosion

ÖZ

İnşaat sektöründe beton dünya çapında yaygın olarak kullanılan bir malzemedir, beton icat edildiğinden beri içilebilir su ile karıştırılmıştır. Nüfus artışı ve kentleşme ile su kıtlığının arttığı görülmektedir. Ancak bazı araştırmalar, insan kullanımı için güvenli olmayan suyun betonda karıştırma veya kürleme amacıyla kullanılabileceğini göstermektedir.

Bu deneysel çalışmada; arıtılmış kanalizasyon suyunun beton üretiminde uygulanabilirliği test edilmiştir. Bu amaçla, bir dizi deney gerçekleştirilmiştir: çökme testi; priz süresi; geçirgenlik; basınç dayanımı, yarma gerilme ve eğilme mukavemetleri; sülfat deneyi; pH testi; ultrasonik test ve korozyon testleri. Bu testlerde, Gazimağusa Kanalizasyon Arıtma Tesisinden temin edilen arıtılmış kanalizasyon suyu kullanılmıştır. Beton karışım suyu ve kür suyu olarak, musluk suyu ve arıtılmış kanalizasyon suyu değişik kombinasyonlarda kullanılarak dört farklı 0.47 su-çimento oranı ile beton karışımı üretilmiştir. Arıtılmış kanalizasyon suyunun kullanılması işlenebilirlik üzerinde çok az artışa neden oldu, ancak işlenebilirlik üzerinde olumsuz bir etkisinin olmadığı belirtildi. Arıtılmış kanalizasyon suyu ile üretilen çimento pastasının ilk priz süresinin, musluk suyu ile üretilmiş olan pastanın ilk priz süresinden daha yüksek olduğu gözlemlenmiştir. Bu da sıcak ülkeler için bir avantajdır. Arıtılmış atık su kullanımında betonun alkali karakterinde herhangi bir olumsuz etkisi görülmemektedir. Atık suyun karışım suyu veya (CurT) kür suyu olrak kullanımın daha düşük beton geçirimliliği ile sonuçlandığı belirtilmektedir. Karıştırma veya kürleme için arıtılmış kanalizasyon suyunun kullanımının uzun vadeli dayanıklılık ve mukavemet açısından avantajlı olduğu belirtilmektedir. Arıtılmış kanalizasyon suyunun karışım veya kürleme suyu olarak kullanılmasının 28 günlük basınç dayanımlarında %8 ile %14 arasında düşüşlere neden olmuştur. Ancak 150 günlük basınç dayanımında bu düşüşler % 3 ile %9 arasında kalmıştır. Korozyon kaynaklı, en düşük ağırlık kaybı (CasT-CurT) karışımında gözlenirken, en yüksek ağırlık kaybı (CasP-CurP, CasP-CurT) karışımlarında 72 saatlik pozlama süresi için gözlendi. Ancak 168 saat sonra 4 karışımın tümünde korozyon oranının zamanla arttığı gözlemlenmiştir. Ayrıca 168 saat sonra oluşan ağırlık kayıp oranları (CasP-CurP) ile kıyaslandığında en yüksek (CasT-CurP) karışımında % 55 olup, (CasP-CurT) ve (CasT-CurT) karışımlarında yaklaşık %20 olmuştur.

Anahtar Kelimeler: beton , karışım suyu, kür suyu, kanalizasyon suyu, mekanik özellikler, geçirimlilik, korozyon

DEDICATION

To My Family

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CasP	Casted with Potable water
CasT	Casted with Treated water
CurP	Cured with Potable water
CurT	Cured with Treated water
f_c	Compressive Strength
f_f	Flexural Strength
f_t	Splitting Tensile
OPC	Ordinary Portland Cement
PW	Potable Water
TSW	Treated Sewage Water
w/c	Water to Cement ratio

Chapter 1

INTRODUCTION

''We never know the worth of water till the well is dry''

Benjamin Franklin

1.1 General

This is a study that deals with the treated water consumption in the construction industry. Clean water plays an important role in human life which is being used in industrial, domestic, urban needs, agricultural, construction industry etc. Since the available potable water is becoming more precious due to its scarcity, it is believed that, this research will provide awareness especially in construction sector with a cognitive approach of water.

Researches show us that, the fresh water on our planet is not evenly distributed, moreover it is even emphasized that, the consumption is high due to both urbanization and population growth. On the earth, approximately 0.5% of the total water is consumed by the human being. This water volume is obtained mainly from the aquifers and the streams. Note that, nearly 97% of the water on earth is seawater or ground waters that are frozen, and these are named fresh water which is around 2.5%. [Oki et al., (2006); Ilgar et al., (2009)].

Turkish Republic of Northern Cyprus (TRNC), since 1960's facing water scarcity parallel with population growth. Hence, since 2015, through a pipeline system, a potable water of 75 million m^3/year is transferred continuously from Turkey so as to overcome this scarcity. On the other hand, like the other sectors, the concrete production sector is as well using this potable water. So, using the treated water for concrete production industry in TRNC, will be a proper selection, if the expected measures are satisfied.

As a matter of fact, the cost of using potable water and the cost of waste water is definitely different, so a low costly concrete production can be achieved with 2-sided gain. Hence, with the help of this study, it is believed that, replacing the use of potable water with the treated water, will raise not only the awareness but even may contribute to a new perspective especially on the concrete production industry of TRNC, if the required standards are achieved.

1.2 Aim and Objective of the Study

This research aims to investigate the applicability of the treated sewage water for concrete production. For this goal, the treated sewage water from Gazimağusa Sewage treatment plant, that is not used for any purpose and discharged to the nearby lagoon, was used as mixing and curing water requirement of concrete production. To examine the mechanical properties and the performance of the plain and the reinforced concrete samples were casted according to relevant standards.

1.3 Research Questions

- How can we minimize the excessive use of potable water in construction industry?
- How the treated sewage water affects the mechanical properties and the performance of quality in the production of concrete?

1.4 Methodology

This research is mainly on experimental study. The relevant data is collected in Department of Civil Engineering Laboratuaries of Eastern Mediterranean University (EMU). Examinations and observation of the selected experimental results guided us the appropriateness of the treated sewage water usage in this reseach. In this study, the effect of treated water on the mechanical properties and performance of plain and reinforced concrete were examined. Appropriate mechanical and physical tests, such as:

- the compressive strength,
- the tensile strength,
- the slump test,
- the setting time test,
- the corrosion test and
- the ultrasonic pulse velocity test is performed.

In order to achieve the aim of this study, four different concrete samples groups with appropriate number of specimence were casted and utilized. These concrete sample groups are:

1. Casted with Potable water (CasP) and Cured with Potable water (CurP); (this combination will be used to compare the others),
2. Casted with Potable water (CasP) but Cured with Treated water (CurT); (to understand its sole effect on curing),
3. Casted with Treated water (CasT) but Cured with Potable water (CurP); (to understand its sole effect on casting),

4. Casted with Treated water (CasT), and Cured with Treated water (CurT); (to understand its total effect).

1.5 Limitation of the Study

This study examines the effects of treated sewage water of Sewage Treatment Plant of Gazimağusa, North Cyprus.

1.6 Significance of the Study

It is believed that, using the treated water for the concrete production, this study will offer a new milestone in the concrete production industry.

1.7 The Structure of Thesis

This study is structured into six chapters as follow,

Chapter 1 presents the introduction of the study. Chapter 2 includes the literature studies relevant to this study topic. Chapter 3 explains the background of the study in general. Chapter 4 provides the methodology applied during the study. Chapter 5 concludes results and discussions. Chapter 6 summarizes the conclusions.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The development of the cities due to population growth and civilization parallel with the scarcity of potable water increase, the studies on the utilization of non-potable water for different areas of our life being one of the research areas of the investigators. So examining, the use of non-potable water such as sewage water, sea water, mineral water, industrial water, etc. for the concrete production is a part of these studies (Al-Saidy et al., 2011).

According to BS 3148:1980, there are two ways for measuring the questionable water, for the utilization of concrete paste, firstly the initial setting time should be tested for the paste which is mixed with that questionable water and the result should not exceed 30 minutes comparing to the control sample. Another method is by testing the compressive strength, where the result should not be below 90% of the control samples of the strength after 28 days.

2.2 Literature Studies on Different Types of Questionable Water Utilization in Concrete

Kanwal et al., (2018) investigated the effect on compressive strength of concrete using treated waste water for mixing and curing of concrete. The treated sewage water was taken from the plant of Chokera Treatment, Faisalabad, Pakistan. Compressive strength of the treated sewage water compared with the compressive strength of the freshwater (potable water) for 7 and 28 days. They depicted that, the results of the compressive strength of the treated sewage water and the compressive strength of fresh water were almost similar, and, they suggested that, the treated sewage water is suitable for the mixing and the curing since no adverse effect on strength were detected by them.

Al jabri et al., (2011) discussed the effect of the waste water on the properties of high strength concrete. Specimens were obtained from three different car washing station in Muscat, Oman. Chemical composition of the three different waste water were examined and found that, even though the chemical composition of tap water (potable water) is greater than the chemical composition of the waste water, the waste water was still within the acceptable limits of ASTM standards, hence recommended it to be used for concrete production. In their study, they tested the concrete with varying mixing amount of waste water ratios 25%, 50% and 100%. Adopting BS 1881-116, the compression test was done for 7 and 28 days cured concrete samples. The result of the compressive strength for the tap water used samples were higher than the waste water used samples for those two mixing ratios 25% and 100%, on the other hand 50% of waste water replacement mix was almost same with 100% tap water used mix. They also determined that, the flexural strength and the splitting tensile tests have the highest value for 25% of tap water replacement mix.

Hassan et al., (2014) studied the effect of using well water as mixing water in concrete. Ordinary Portland cement and sulphate resisting cement were used. Three different well waters were selected from three different areas in Iraq, and distilled water was selected for comparison where 3, 7, and 28 days cured samples were examined. Results show that, samples which were mixed with Ordinary Portland cement and the distilled water were having the greatest compressive strength respectively for 3, 7, and 28 days.

Tay et al., (1987) studied the applicability of reclaimed water is examined in Indonesia. In this study, they compare the concrete pouring with reclaimed waste water with 25% to 100% samples with the concrete pouring with 100% potable water. According to their results, an increase of the compressive strength was seen in concrete poured with waste water between 8% and 10% compared with potable water. But for ages of three months and beyond, the results of the compressive strength reached nearly the same level for both types of concrete.

Olutoge et al., (2014) studied that, the effect of sea water on the compressive strength of the concrete. Utilizing sea and freshwater concrete, 150 mm cubes specimens were prepared with a mixing ratio of 1:2:4 where for all the samples the water cement ratio (w/c) were the same, which was 0.6 by weight. 140 concrete cubes were casted totally and those cubes were divided for fresh water and sea water equally. Their study indicated that, there is an improvement in the compressive strength of concrete mixed and cured samples poured with sea water. For the corrosion, they suggested that, the embedded steel may be avoided in the case of reinforced or pre-stressed members by painting or covering the steel with cement slurry made with fresh water.

More et al., (2014) studied that, the effect of different types of water on compressive strength of concrete where the concrete cubes of 150 mm sides was casted with different types of water. These water types are the mineral water, the tap water, the well water and the waste water. For long time after pouring, the compressive strength were examined but they found out that they did not vary greatly. The grade of concrete mix was 20 MPa with w/c of 0.5 was used. These cubes after 7 and 28 days were pressed. Similarly, the compressive strength for the ground water, the packed drinking water, the waste water were as well examined for 7 and 28 days of curing after casting. Results were almost the same or very close to 90% of the strength of the samples casted with clean water.

Saricimen et al., (2008) studied the testing of treated effluent for use in mixing and curing of concrete in Saudi Arabia. The solutions extracted from the mortar samples prepared by treated sewage water were tested for alkalinity and for their cloride contents and compared with potable water sample solutions. It is found that, utilizing the treated sewage water is appropriate for any concrete production.

Cebeci & Saatci, (1989) indicated that, the use of treated wastewater did not affect the concrete negatively. However, using raw sewage water caused a drop of 9% for the compressive strength of the concrete for 28 days.

Al-Ghusain et al., (2003) studied the using of treated waste water in Kuwait. For the mixing of concrete, they detected that, the concrete slump and the density have no effect.

Ghorab et al., (1990) have stated that, type of water commonly impacts the setting time of the Ordinary Portland cement. The initial setting time decreased by 4% with the utilization of the Nile River water relative to the tap and by 25% with groundwater.

Ghazaly et al., (1993) stated that river, rain and treated sewage water can be used in mixing cement, but on the other hand raw sewage water is inappropriate for using in cement mixing.

2.3 Effects of Questionable Water on Workability of Concrete

Tsimas et al., (2010) studied the reuse of waste water from ready-mixed concrete plants. The waste water is mixed to produce concrete samples and their workability tests were performed. According to the results, no bad effects were observed. Also, no adverse effects were detected even in the concrete used with admixture and without admixture. In addition, the setting times and water demand for cement pastes indicate no substantial difference between the waste water cement pastes when compared with the control one.

Abdul Razak et al., (2015) investigated experimentally the usage of gray water in concrete production. They determined that, the concrete which is mixed with the primary treated waste water its workability was decreased. But the concrete which is mixed with secondary treated waste showed an acceptable workability level.

2.4 Effect of Questionable Water on Setting Time of Cement

Ghrair et al., (2018) performed a study influence of grey water on physical and mechanical properties of mortar and concrete mixes that contains questionable water. Two different types of questionable water types, the raw and the treated grey water were used that were obtained from the Deir-Alla, in Jordan. The cement type was pozzolanic cement type II. The experiments were performed according to ASTM C94. The initial setting time of the cement paste with raw grey water was 25 minutes more than the control sample. However, cement paste with treated grey water was 20 minutes more than control sample. They concluded that, the large amount of dissolved solid may have been caused for this rising.

Ramkar et al., (2016) conducted a study to determine the effect of treated waste water on the strength of concrete. In this study, domestic waste water, primary and secondary treated waste water types were used and compared with potable water for their initial and final setting time of cement based on IS 4031-4 (1988) . According to Indian standard (IS 456: 2000) the minimum duration for initial setting time should be around half an hour, moreover the duration of final setting time should not exceed 10 hours. This study showed that, the initial setting time of the cement paste with secondary treated waste water was 5.88% higher than potable water. Even the primary waste water had a greater initial setting time than of the secondary treated waste water.

2.5 Effects of Questionable Water on Compressive Strength of Concrete

Vijay et al., (2014) conducted a study on plain concrete, OPC 53 grade was used, and tap water was obtained for mixing concrete from NMAMIT which is located in India. Fine aggregates. Concrete cube sizes with 150 mm were used with 0.45 w/c ratio. For different type of mixes 9 concrete samples were used and they are cured at the age of 3, 7 and 28 days. They concluded that, the strength of the concrete is improved by no adverse impact on concrete when tap water is replaced by treated effluent.

Silva et al., (2010) studied on the recycling of sewage treatment plant water in concrete paste. A sample of sewage treatment plant water was taken from

Milwaukee, Wisconsin, USA. Three batches of sample were prepared with potable water and another one with the treated water using cube sizes 50 mm. The used w/c was 0.485. The mortar mixture test was performed according to ASTM C305 in order to determine the flow of the mortar. After the curing period of 24 hours, the specimens were sunken in a saturated lime water curing tank. The compressive strength calculations were done on different time ranges, 1, 7, 14, 28, 56 and 91 days after casting. The average flow for mortar cubes was clearly different for each mixture type, the average flow of samples paste that was made by of potable water and treated (reclaimed) water were 98.1% and 89.5% respectively. The curing time of 3-28 days was found to be enough to show an increase on the compressive strength of the mortar cubes with treated water.

Kanwal et al., (2018) studied the effect on compressive strength of concrete using treated waste water for both mixing and curing of concrete. It was indicated that, for all the mixes there is an increase for compressive strength with age. The strength of concrete which is mixed with the treated waste water concrete is even higher than the control mix so concluded that, the treated waste water is appropriate for the use of concrete mix.

2.6 Effect of Questionable Water on Splitting Tensile Strength of Concrete

Sushma et al., (2014) studied that impact of water quality on strength properties of concrete. In this study, they used a mix of M 20 Grade concrete to test the impact of potable, non-potable, and waste water usage on the concrete strength production at 7, 14 and 28 days. Cubic beams and were prepared for testing the splitting tensile strength of the casted concrete. According to their results, the splitting tensile strength of the potable water mixed concrete higher by 14.89% when compared with the concrete sample prepared with the treated waste water.

2.7 Effect of Questionable Water on Flexural Strength of Concrete

A research was carried out by Ramkar et al., (2016) to indicate the effect of waste water on concrete where the molds were prepared to measure the flexural strength of these molds having dimensions of 15x15x70 cm. Three types of water were used, the domestic water, the primary treated waste water, and the secondary waste water. The Indian standards IS: 516-1959 and IS: 9399-1979 were used and after 28 days of curing, consequences show that an improvement was seen samples which were casted with secondary waste water flexural strength of concrete by 4.4% more than the samples mixed with potable water.

Giaou et al., (2008) indicated a study on the use of ready mix concrete waste water as curing water. For this reason, the waste water was collected from the ready mix concrete plant just for curing. After 14- and 28-days of curing duration, the flexural test was applied and the results were appropriate as compared with the potable water as curing. Furthermore, results were pleasant for the splitting tensile test and the compressive test too for the same durations.

A study performed by Pritam Patil et al., (2015) investigated the effect of water with untreated algae, the kitchen and garage waste water on the strength characteristics of concrete as curing water. After 28- and 60-days of curing, the flexural test was performed. According to the results, there was an important enhancement for waste water with algae that was used as curing when compared kitchen and garage waste water.

2.8 Effect of Questionable Water on Sulphate Resistance of Concrete

Nirmalkumar et al., (2008) carried out a study to examine durability impact of concrete by using recycled waste water (treated tannery effluent) which was obtained from the tannery industry. Concrete samples were casted in cube size of 15 cm and cured in freshwater tank for 28 days. After drying the concrete cubes, they were weighed and exposed to 3% sulphate solution in a non-porous container for 28 days. Once they taken out from the sulphate solution also cleaned and dried. To examine the difference of weigh they were measured before the compressive test was performed. The results were found by weighing the samples that, the highest with 2.01% increase for the samples mixed with untreated tannery effluent because of the sulphate attack. On the other hand, an increase of 1.46% was observed in the samples mixed with treated tannery effluent and lastly samples simply mixed with the potable water having an insignificant effect. In order to observe the sulphate attack with admixture was added. The dosage was 2%. Based on that, the highest value for weigh was for untreated tannery effluent with 1.74% implying how import the effect of the admixture on sulphate attacks.

2.9 Effect of Clean Water on Alkalinity (pH) of Concrete

Rao et al., (2014) studied that effect of the treated waste water on the properties of hardened concrete. The concrete specimens were cast and the pH test was performed for potable and treated waste water. Potable water pH test results were 7.10, 7.29, and, 7.28 for 7, 14 and 28 days respectively. Also, for treated waste water pH test was carried out and values were 8.03, 8.02, and, 8.08 respectively. According to this study, the result shows that, the treated waste water is suitable for using concrete productions without having any adverse effect on the concrete production.

2.10 Effect of Waste Water Corrosion Attack in Reinforced Concrete

A research was carried out by Al-Ghusain et al., (2003) to observe effect of treated waste water on mechanical tests and durability tests. Four types of water were used for mixing the concrete. These were the tap water, the preliminary treated waste water, the secondary treated waste water and the lastly the tertiary treated waste water. The waste water was taken from the municipality of Kuwait City. The concrete specimens were prepared with covers of 1.0 cm and 2.5 cm separately and then reinforcing steel corrosion was tested after 12 and 18 months. The test was done based on half-cell potential method. Outcomes of the corrosion potential show that, the water which is used for mixing, affects the results of corrosion because when the quality is high, leads less corrosion occurrence probability. Concrete mixed with tap water and tertiary treated waste water have lowest corrosion on the other hand with respect to preliminary treated waste water mixed, having the highest corrosion probability. In addition, samples having covers of 1.0 cm corroded more than the 2.5 cm ones.

Nirmalkumar et al., (2008) investigated the corrosion attack by utilizing the recycled waste water collected from the tannery industry. 30 MPa of concrete was produced and cylindrical mold was used 15 cm in diameter with a length of 30 cm. 20 mm in diameter of reinforcing steel was used with the length of 30 cm. The samples were cured for 28 days and then embedded into 6% NaCI solution where a copper plate was used as cathode. The samples were left untouched for 15 days. The color of the solution changed to reddish brown due to the occurrence of the rust. After that, samples were taken from solution, they dried and the corroded steel bars were extracted. As a result of corrosion there is weight loss occurred which is equal to 6.01% when concrete is mixed with tannery effluent, however for potable water mixed concrete caused less corrosion which equal 2.94 %. Furthermore, they concluded that when an admixture is added to the concrete mixed with any water type, the weight loss decreases within a range of 0.09% and 0.13% respectively.

Chapter 3

THEORETICAL BACKGROUND OF THE STUDY

3.1 Background to the Study

Concrete is popular and durable material, which is utilized worldwide for construction. The use of Portland cement could be traced back to 19^{th} century. English bricklayer named as Joseph Aspdin was first reveals the cementitious material in the island of Portland in England when he pastes this material it hardened similar to stones (Davidovits et al., 1987). Concrete generally represents the coarse aggregates, the fine aggregates, the Portland cement and water. Aggregate as a component of concrete is a chemically inert and makes up the body of the concrete that decreases its shrinkage and even affects the economy. In concrete, the aggregates constitute 70-80% of the volume. Cement which is a binding material for concrete occupies nearly 12% of concrete by weight (Dubey et al., 2014). Fresh water, has an important role in concrete. Shekarchi et al., (2012), specified that, the consumption of fresh water for mixing and curing of concrete is approximately 1 billion tones in construction industry. The growth of the population and the rising of the economic activities would cause the enhancement of consumption of the fresh water. In addition, distribution of the fresh water on the earth is not in balance. For that reason, fresh water may not be available at the desired place and time due mainly economic issues (Maden et al., 2013). The quality of water affects the performance of the concrete. Impurities in water could effect the setting time of cement and even may have a negative influence on durability and strength (Kucche et al., 2015). Even has effects on efflorescence staining, corrosion of reinforcing and the durability reduction. So, alkalis, chloride, sulphates and solid particles may be available in the mixing water and thatis why it is recommended to use fresh water to mix the concrete mixture. (Kosmatka et al., 1995). However, fresh water is precious and must be consumed carefully (Al-Jabri et al., 2011). By consuming fresh water for our daily needs, for the agriculture, for various industrial uses and even urban needs causes the shortage of fresh (potable) water (Hawken et al., 1995). According to Mujahed (1989) and Olugbenga (2014) a quite a lot studies have examined the impact of different types of water on the concrete use, including the sea water, the alkaline water, the mineral water, the treated and untreated sewage water, the industrial waste water, the water with many chemical contaminants, and the black water of oil wells.

3.2 Properties of Concrete

Concrete is an artifial material, which is a mixture of cement, coarse aggregate, fine aggregate, water and air. In addition, concrete which is a brittle material having a high compressive strentgh but low tensile strength. Cement is one of the components of concrete and is a binder material. Aggregate is a filler which is inert. On the other hand, water reacts with the cement and cause the concrete to attain its strength in water (Li et al., 2011). Fresh water is an anavoidable material for concrete both for mixing and curing (Mane et al., 2019). Puspalatha et al., (2019) mentioned that, normally to make 1 cubic meter of concrete a 150 liter of fresh water is need. So water is an important ingredient of concrete. When water interferes with cementitious materials, then composes the cement paste by asissting the hydration process of the cement. The aggregates stick with cement paste with the help of water by filling the spaces and pores. Meanwhile water can flow eaisly. When there is less water amount in the cement paste in fact it gives a better yield and better durability. But having more water amount makes more flowable concrete with higher slump (Olugbenga et al., 2014).

3.3 Workability of Concrete

Workability is defined as; to give the desired shape to the concrete when it is in fresh state (plastic state) without losing its quality. Workable of concrete can easily take the shape and can compact rapidly. To have more workable concrete more water is required. So, by adding more water one can obtain a higher workability. In this case, even the fluidity will be higher besides the water content and workability. On the other hand, a reduction in the strength of the concrete as well as the segregation occurs. Segregation of concrete is the seperation of coarse aggregates from one another especially when the concrete is in its fresh state. Note that, having excess amount of water, or due to poor compaction or over vibration saggregation occurs. In order to avoid the segregation, the compaction should be done properly, no excessive water than desired should be added to the suggested design mix requirement. Some of the some factors affecting the workability of the fresh concrete are:

- the water cement ratio,
- the admixture,
- the cementitious content,
- the size of the aggregates,
- the shape of aggregates,
- the texture of aggregates,
- the temperature and
- the time.

In order to measure workability of concrete, the widely used tests are slump test and the Ve-Be consistometer test.

3.4 Setting Time of Cement

The description of the cement setting can be explained as the stiffening of the cement paste. In this process the cement (concrete) paste slurry changes from fluid to rigid phase. When water and cement is mixed, the cement paste is formed, so one can give a desired shape to it. If the cement paste does not lose its plasticity and, if it is still softness, this phase is named 'the dormant period'. If the cement paste cannot be shaped if it is not softness any more, however stiffening get, this phase is named as the initial set. Once the initial set time is completed, this time period is named as initial setting time. When the cement paste lose its plasticity completely and even hardened completely, this time period is called the final setting time where the concrete paste is called either the cement (concrete) stone or hardened cement (concrete) paste (Soroka et al., 1979). Several factors affecting setting time are:

- the w/c ratio,
- the temperature,
- the fineness of cement and
- the relative humidity (Tan et al., 2004).

3.5 Permeability of Concrete

One of the most important durability problems of concrete is its long term permeability. Concrete permeability is defined as the allowing of water, aggressive species such as chloride ions, oxygen sulphate ions, etc. to enter the concrete (Jackson, 1978). Concrete is naturally a porous material. There are different features that influences like the curing method, the water/cement, etc. When the w/c ratio increases, the concrete permeability increases. High w/c ratio will cause a high permeability in concrete that leads to a higher pore in the concrete mass. Thus, water can infiltrate through the concrete easily (Mindess et al., 2003).

3.6 Compressive Strength of Concrete

Compressive strength is one of the mechanical properties of the concrete which determines the grade of the concrete. In order to determine the quality of the concrete, the compressive strength test is conducted. This test is crucial for the strength of tension and shear. Due to that, the compressive strength is the major feature of any concrete mix. Concrete compressive strength is tested by using molds in cubic or in cylindrical shapes. The cement paste is quite important for the strength of concrete, because inappropriate cement paste can cause voids or bleeding of concrete occurs. Note that, as the w/c ratio is increased, the strength of the concrete decreases (Shetty et al., 2019).

3.7 Splitting Tensile Strength of Concrete

One of the important mechanical properties of concrete is its tensile strength. As the concrete is determined as a brittle material, it is considered to be weak in tension. Note that, the brittle materials get compacted under tensile strength whereas the ductile materials elongate under the effect of tensile strength. Although the tensile strength of the concrete is low, its compressive strength is reasonably high. In order to find out the tensile strength of the concrete, the well know standard test is the splitting tensile test. According to the standards, the maximum tensile stress is applied when failure is occurred. In fact, when the compressive load is applied on the concrete sample, it splits into two parts.

3.8 Sulphate Resistance of Concrete

One of the significant durability issues of concrete is the sulphate attack. The sulphate attack occurs through a sequence of chemical and physical reactions between the hardened cement paste and the sulphates [(Collepardi, (2003); Taylor et al., (2001)]. The consequences of sulphate attack on concrete are the disintegration, the spalling, the cracking and the lead to decrease in strength. According to the macroscopic research, it is indicated that, the expansion, the cracking or the spalling are due to the chemical sulphate attacks. Physical sulphate attack is not associated with any reaction with hydrates. The reduction in strength, the mass loss, softening, and de-cohesion would observed due to internal changes of micro-structure of the concrete paste (Whittaker et al., 2015).

Sulphate attack can be either external or internal depending on the source of sulphate ions. In the event of an external attack, the sulphate ions penetrate to the concrete to commence the reaction. The external sulphate attack is due to the penetration of the water or soil from the environment into the concrete paste. The sulphate ions which are found in the ground water are mostly due to the minerals that are available in soils. These are mainly, potassium, magnesium, calcium, and sodium sulphate. The internal sulphate attack occurs at sulphate-free surroundings, if there is sulphate source within the concrete like the gypsum-contaminated aggregates or cement with high sulphate content (Collepardi et al., 2003). Generally, sulphate salts are found in nature as $MgSO_4$, and Na_2SO_4, and these salts lead to external attack causing the expansion of concrete ingredients like the ettringite and the gypsum (Skalny et al., 2002). To avoid the sulphate attack there are some important remarks to be considered. The w/c ratio, and the calcium hydroxide, and the amount of C_3A

(tricalcium alimunate) content should be kept low (Young et al., 1998). As the w/c ratio increases, the permeability increases. Sulphate sources are present in the sewage, in the waste water, and within the fertilizers. As the industry grows, many structures are get destroyed by the sulphate attacks. One of the reasons is due to the loss of material useful lifetime (Costa et al., 2018).

3.9 Alkalinity (pH) of Concrete

In chemistry, the concentration of acid ions which is in solution are specified by measuring its pH degree. The range pH is 0 to 14. If the pH is below 7, it implies an acidic substance, if it is above 7, implying basic (alkaline) substance, on the other hand pH 7 is defined as neutral. The pH value of fresh concrete is between 12 and 13 implying an alkaline substance.

3.10 Corrosion Attack

Corrosion of embedded steel bar reinforcement in the concrete could occur if it has been subjected to oxygen or water or an electrolyte. This process is also called rusting. Both oxygen and the moisture are essential for the rust to happen. The water droplet would reach to iron, where the Reduction Oxidation process which is known as 'Redox' starts. When the iron releases its ions in a moisture medium, the oxidation process take place, thus the iron loses its electron. Then these electrons react with dissolved oxygen in order to form hydroxyl ion, hence, the iron ions then react with hydroxyl ion to form ferrous hydroxide. Corrosion can be described by the electro-chemical process. There are active and passive layers of steel, when the passive layer is destroyed, the corrosion starts to occur. Note that, the passive layer is the layer that surrounds the surface area of the iron bar with corrosion inhibitors like calcium nitrite. The anodic and the cathodic reactions that takes place are simply detailed by the following chemical formulas:

$$Fe \rightarrow Fe^{2+} + 2e^{-} \qquad \text{(anodic reaction)}$$

$$4e^{-} + O_2 + 2H_2O \rightarrow 4(OH)^{-} \qquad \text{(cathodic reaction)}$$

$$Fe^{2+} + 2(OH)^{-} \rightarrow Fe(OH)_2 \qquad \text{(ferrous hydroxide)}$$

$$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3 \qquad \text{(ferric hydroxide)}$$

The occurrence of corrosion due to the destroyed passive layer of steel bar is illustrated in Figure 3.1 (Delikanlı et al., 2001).

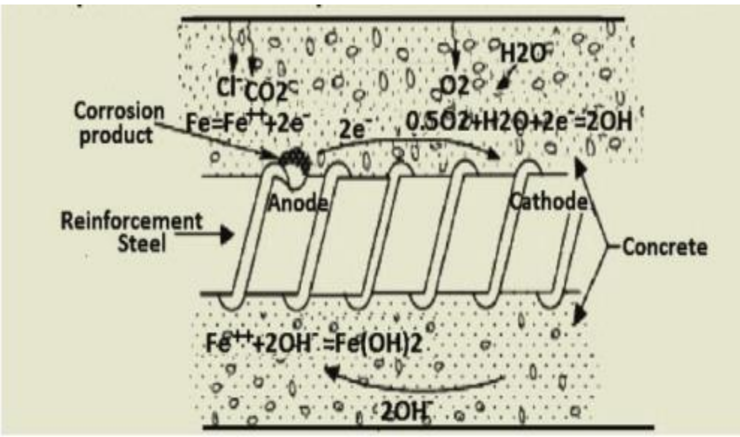

Figure 3.1: Corrosion Process of the Steel Bar in Reinforced Concrete Paste

There are some other occasions that causes the corrosion, these may be due to aggressive substances that are causing the corruption on the passive layer on embedded bar like carbonation, ingress of chlorides etc. Even the location and situation of the steel bar within the concrete paste also affects the corrosion, although it is mostly depends on concrete properties. The obvious sign of corrosion of steel bars within the concrete paste are the cracks of the concrete cover (Hansson et al., 2007).

3.11 Effect of Water Quality and Quantity on the Mechanical Properties of Concrete

Water is an important component of concrete ingredients. There are several reasons why water should be used. Among them;

1. for better adhesion to drench surface of aggregate with water. Therefore, cement paste will stick with the drenched aggregates easily and quickly,
2. the fresh water is required for the ease of placement of workable concrete,
3. the strength is affected by quality of water with the mix,
4. for the curing it has to be used,
5. the chemical reaction takes place between the cement and the fresh water (Nikhil et al., 2014).

Neville et al., (1996) mentioned that, if the water is ideal for drinking, then it can be used for concrete but it is not applicable for all situations, because some water cannot be suitable for drinking but can be used in concrete especially in arid areas (Steinour et al., 1960). The pH range of water that is between 6.0 and 8.0 is accepted to be suitable for concreting (Gupta et al., 2012). According to Obi et al., (2016) there may be effect worst effect on the strength, hardening and the setting time of concrete due to the by quality of mixing water (Wachira et., 2016).

3.12 Broad Classification of Water Types

Tap Water:

Tap water fulfills the requirements of people need such as drinking, washing fruits, for personal grooming and washing [(Bos et al., (2016) and De Zuane et al., (1997)].

Raw Water:

Raw water is the water that has not been processed by human (Schutte et al., 2006). On the other hand, if raw water is processed can be used for drinking as required standard (Moayedi et al., 2011)

Waste water:

The waste water is that water which is gathered after the domestic, commercial or industrial use. Sometimes it is named as 'the used water'. According to the World Health Organization (WHO), any water containing dissolved and suspended matter is waste water.

Domestic (Municipal) water:

Municipal water refers the water within the network system. It is consumed for drinking depends on quality of water or for showering, for washing laundries and dishes, for irrigation and for any other purposes which are appropriate (Kohli et al., 2010).

Raw Sewage Water:

Sewage waste consists of 99.9% water and 0.1% of impurities which may be found as settle down, or as in suspension or as in dissolved manner. In raw sewage water, there are harmful substances that are named micro-organisms which may threat the human health. It comes from the sinks, the showers and from the toilets. With the help of processes like biological treatment and disinfection one can remove most of these detrimental substances (Feigin et al., 2012).

Reuse Water:

It is the treated water and recyled so as to be used for any other than human consumption like farming, toilets flush and cooling applications. Mainly the municipal waste water is used for various aims like to conform certain water quality standards after a certain treatment. Reuse water is also known as 'reclaimed water' (EPA, 2012).

Gray Water:

Wastewater, which is produced by the domestic users referred as grey water, including the bathroom, kitchen sinks etc. Mostly the grey water has been found in the residential and commercial buildings effluents (Khediya, 2016).

Sewage (Black) Water:

Sewage water mainly contains urine and feces. Its black color is due to the existence of the organic substances and the manganese, in fact this water is gathered from the toilets. It is also called 'black water' (Team et al., 2004).

Tannary (Yellow) Water:

The waste water of the tannary industry contains some organic substances causing the water color to be yellowish. It is also referred as 'yellow water' (Team et al., 2004).

3.13 Treated Sewage Water

Sewage treatment is the method of purifying pollutants from urban waste water mostly domestic sewage which includes toilets, showers etc. and the industrial waste water. There are processes, by which purifying the pollutants of to generate treated sewage water. These process are physical, chemical, and biological. A standard method for handling the sewage water has three steps, the primary treatment, the secondary treatment and the tertiary treatment and then the disinfection. To remove raw particles from the waste water screens and grates are used as the first step of the treatment, where the sand, the dirt, and the larger items are separated. In the second stage of treatment, the amount of micro-organisms are reduced. Eventually, water pass through disinfection, where the bacteria are destroyed by chemical compounds. These chemical compounds are separated only before the water-body discharges water.

3.14 Characteristics of Treated Sewage Water

There are fecal pathogenic microorganisms, suspended impurities, and soluble organic compounds in sewage water. However, sewage water does not consist of just fecal components and water, it also contains solvents, pesticides, trace elements, heavy metal, and some eccentric matters such as antibiotics, hormones etc.

Physical Characterization of Treated Sewage Water:

To determine of physical characteristics of water, it should be examined by its turbidity, with its odor, with its temperature, its color, and its taste.

Turbidity:

Turbidity is occurred whenever a significant amount of suspended impurities exists in sewage water such as fecal particles, soap, etc. Therefore, sewage water becomes either cloudy or muddy. Turbidity meter or nephelo turbidity meter are used for measuring the turbidity.

Odor:

Anaerobic decomposition of hydrogen sulfide (H_2S) spreads the sharp bad smell.

Temperature:

Temperature affects biologic activities within the sewage water.

Color:

Sewage water is generally quite dark in color, common color is black. The color of sewage water can be identified even with the naked eye. Variation of organic impurities causes the changes of this color.

Chemical Characterization of Treated Sewage Water:

Chemical characteristic of sewage water consists of gases, organic and inorganic impurities. Mainly, these are:

- Nitrogen content,
- Chloride content,
- Total solid, suspended and dissolve solids,
- Oxygen Demand (DO)
- Biological Oxygen Demand (BOD)
- pH
- Conductivity,
- Sulphate ion concentration, and
- Hardness.

Chapter 4

MATERIALS IN USE AND THE ADOPTED EXPERIMENTAL PROCEDURES

4.1 Introduction

This chapter details both the materials used and the adopted experimental procedures with the applied tests using relevant equipments, devices, and machines for this study. To perform the required experiments their relevant BS/ASTM standards and other appropriate methods were adopted.

4.2 Materials Used

The materials used for this analysis are mentioned and defined as follows;

Cement (C): CEM II/B-S Portland slag cement of 42, 5 N was used. In North Cyprus, it is commonly used for the structure to prevent acid, sulphate or some chemicals attacks that may cause corrosion. The chemical component of this cement is shown in Table 4.1.

Table 4.1: Chemical Composition of Portland Slag Cement

Oxide	Cement (%)
CaO	60.88
SiO_2	19.00
Al_2O_3	2.19
Fe_2O_3	2.89
MgO	2.27
SO_3	2.55
CaO free	1.00

CO_2	-
Na_2O	-
SrO	-
P_2O_5	-
K_20	-
Loss on ignition	0.98
Insoluble residue	0.02

Fine Aggregate (FA): Fine aggregates used in this study crushed limestone aggregate from Besparmak Mountains with a maximum diameter of 5 mm. Furthermore, sieve analysis was done by following ASTM standard C136M-14, and is checked by ASTM C33-1. Sieve Analysis of FA is shown in Figure 4.1.

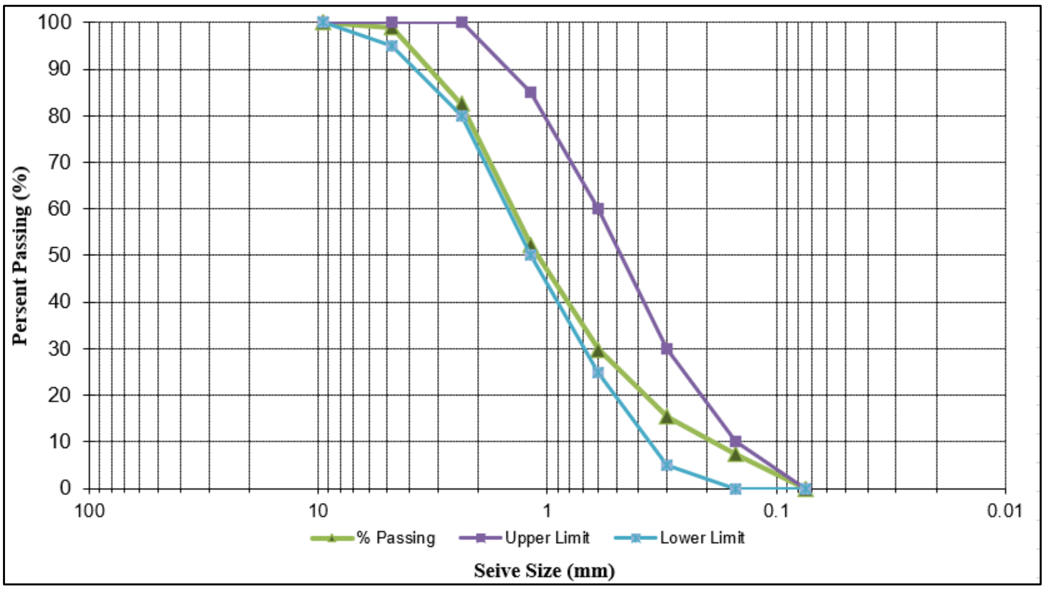

Figure 4.1: Sieve Analysis of Fine Aggregate

Coarse Aggregate (CA): Coarse aggregates used in this study were crushed limestone from Besparmak Mountains with various diameters (10 mm - 20 mm) as well . Sieve analysis of the coarse aggregates were done according to ASTM C136M-14 standard and checked by ASTM C33-16. Sieve analysis of the CA is shown in Figure 4.2.

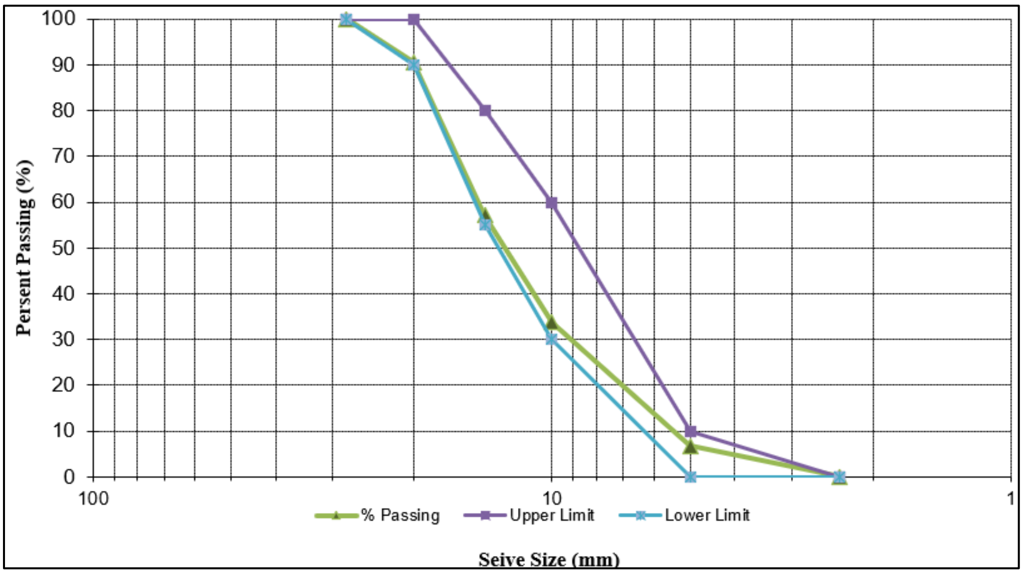

Figure 4.2: Sieve Analysis of Coarse Aggregates

Mixing and Curing Water

Two types of water were used both for mixing and curing procedures.

1. the tap (potable) water; provided for consumption in the laboratory of having no hazardous contaminants like organic impurities, unwanted oils etc.,
2. the treated sewage water; the chemically controlled discharged water obtained from the Famagusta Sewage Treatment plant. Before it is exposed to the atmosphere the treated water was chemically controlled according to the relevant standards so as not to harm the environment. The chemical analysis of the treated sewage water which was obtained from Famagusta Sewage Treatment Plant was shown in Table 4.2.

Table 4.2: Famagusta Sewage Treatment Plant Outflow Water Analysis

Chemical Oxygen Demand (COD)	30 mg/lt
Biological Oxygen Demand (BOD)	5 mg/lt
Total Nitrogen (TN)	13.2 mg/lt

Total Phosphate (TP)	1.2 mg/lt
Conductivity	2300 µS/cm

Note that, 1 µS/cm = 0.64 mg NaCl/kg, therefore it is 1.5 g/kg = 1.5 ppt = 1500 ppm. On the other hand, the NaCl content of the potable water is between 400 – 1000 ppm, of the sea water is 35000 ppm and of the rivers 50 ppm.

The Reinforcement Bars: Non-corroded reinforcement steel bars were used for purpose of electro-chemical method which has the diameter of 14 mm; the length of each bar was 30 cm.

4.3 Mix design of Concrete

Mix design is completed according to (BRE 331, 1988) by adding treated sewage water as seen in Table 4.3. Treated Sewage water was used instead of tap water at the same ratio. In order to see influence of treated sewage water on concrete productions 4 different combinations are generated.

Table 4.3: Concrete Specimens: Mix Proportions (w/c = 0.47) and Curing Conditions

Tested Specimen Names	Cement ‘C’	Fine Aggregate ‘FA’	Course Aggregate ‘CA’	Mixing Water		Curing Conditions
				PW	TSW	
	kg/m^3					
CasP-CurP	480 with w/c=0.47	770	904	225	-	Potable Water ‘PW’
CasP-CurT						Treated Sewage Water ‘TSW’
CasT-CurP				-	225	Potable Water ‘PW’
CasT-CurT	480 with w/c=0.47	770	904	-	225	Treated Sewage Water ‘TSW’

4.4 Experimental Procedures

4.4.1 Setting time of Cement

Initial setting time test was done accordance with ASTM C191 standard.

4.4.2 Concrete Mixing Procedures

Concrete mixes are carried out by using the mixer which is available in the laboratory of Civil Engineering Department.

4.4.3 Workability of the Concrete

The slump test was carried out based on ASTM C143/C143M 15a standard.

4.4.4 Specimens Preparation and the Curing

As mentioned earlier different types of samples were prepared for different testing purposes. To be able to test the required properties of concrete 3 samples for each set was casted and cured. For this reason, a total of 168 cubes (150x150x150 mm), 36 beams (100x100x500 mm) and 40 cubes (100 mm) were casted. In order to start casting, the molds were cleaned and their inner faces were oiled so as to reduce the friction between the specimen and the contact surface of the mold so as to remove the specimens from their molds easily without damaging it as shown in Figure 4.3. Once the samples poured into the molds they were put on the vibration machine so as to be compacted. Figure 4.4 shows the samples during vibration. After that, the samples were ready to be kept in the curing room for 24 hours at 99% relative humidity as shown in Figure 4.5. After the curing procedure, the samples were put in water tanks for 9, 28, 56, 120 and 150 days until tests were carried as shown in Figure 4.6. Two different water tanks were used for the curing, one of the tank was containing the tap (potable) water and the other one was containing the treated sewage water. The reason for checking strength of concrete at 9 days is due to laboratory's work hours. Because one of the groups which was casted on weekend, but on weekend there is no access all the time to enter laboratory.

Figure 4.3: Oiling Molds

Figure 4.4: Vibrating the Samples

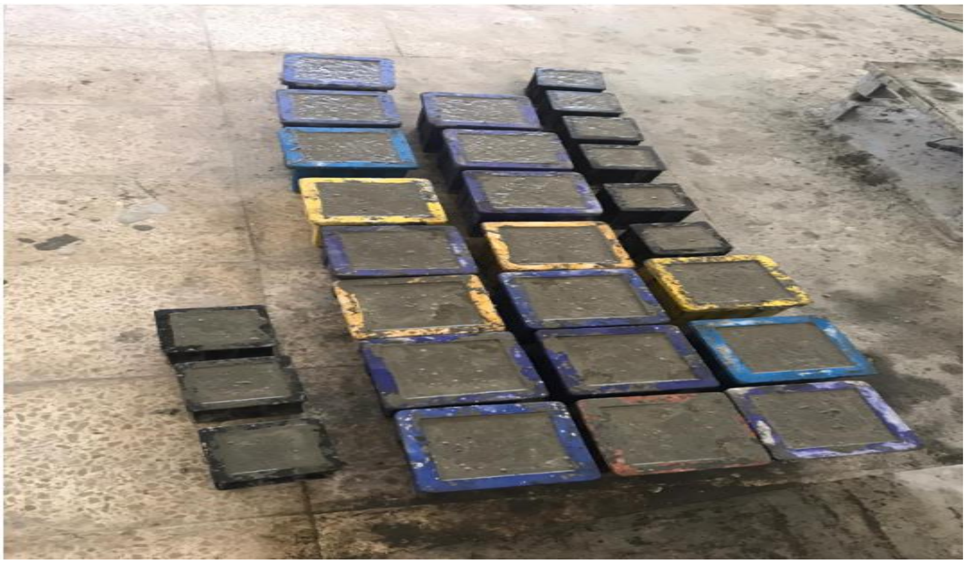

Figure 4.5: Ready Samples before Curing

Figure 4.6: The Curing Tank

4.5 Permeability Test

Cubes of 150 mm dimensions were used for the permeability test. This test was performed based on BS EN 12390. Samples in penetration cell were shown in Figure 4.7. The depth of penetrated water was measured as shown in Figure 4.8.

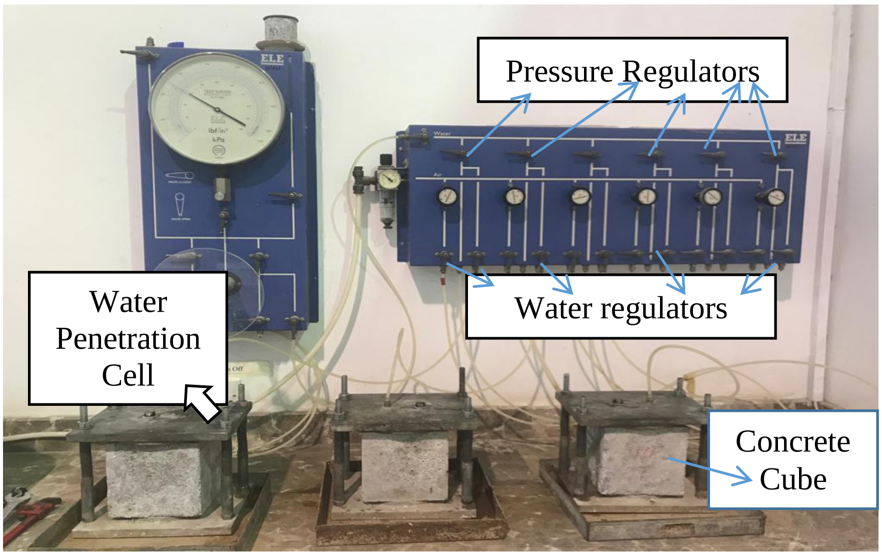

Figure 4.7: Samples in Penetration Cells


Figure 4.8: Marked Depth of Water

4.6 Ultrasonic Pulse Velocity Testing of Concrete

The cubes of 100 mm sized were tested based on ASTM C597. The used device for this experiment is shown Figure 4.9. The grading intervals of the concrete quality based on ultrasonic test are given Table 4.4.

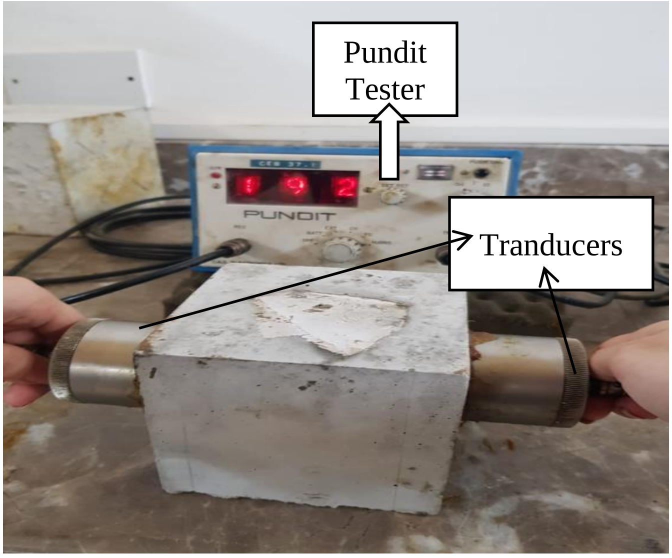

Figure 4.9: The Ultrasonic Pulse Velocity Test Apparatus

Table 4.4: The Concrete Quality Grading Based on Ultrasonic Pulse Velocity Test

Pulse Velocity (km/s)	Concrete Quality Grading
> 4.5	Excellent
3.5 – 4.5	Good
3 – 3.5	Fair
2 – 3	Poor
< 2	Very Poor

4.7 Compressive Strength, Splitting Tensile Strength and Flexural Strength

The test was carried out based on BS EN 12390-3:2009 standard. Three (3) samples from each specimen group of the cubes of 150 mm dimensions were used. In order to define the compressive strength of any sample group, the simple averaging was used.

Splitting tensile strength was done according to ASTM C496/C496M-17.3. Dimension of cubes 150 mm. Similarly, 3 specimens in each group were used and their results were simple averaged.

The flexural strength test was conducted in accordance with ASTM C78/C78M–16. Four (4) set of beams that were prepared for 100x100x500 mm dimensions and cured for 28- and 56-days were used for this test.

4.8 Sulphate Resistance

Cubic moulds of 100 mm dimension were casted to conduct this test. After the specimens kept 28-days under usual curing procedure, they were cured for another 28-day within the sodium sulphate solution. To obtain this solution 5% of Na_2SO_4 was added in water by weight of water.

4.9 Concrete pH

To examine pH test, crushing hammer was used to crush specimens, then crushed specimens are put inside grinding machine to grind. 30 g of powder used for each sample. Then, 15 g of crushed concrete powder and 15 g of distilled water are mixed around 5 minutes. Then, 15 g of suspension used for pH test additionally, test is done by utilizing pH meter, it is demonstrated in Figure 4.10.

Figure 4.10: The pH Meter

4.10 Accelerated Corrosion Test

4.10.1 Accelerated Corrosion Test Procedure

An electro-chemical analysis was performed on the corroded steel bars so as to detect the influence of the treated sewage water on reinforced concrete samples. First, surface of the reinforcement steel bars was brushed and cleaned in order to assure the definite weight of the bars as shown in Figure 4.11. Once, each of them was weighted as well labelled. For this test, one sample cube (150x150x150 mm) having 10 cm of steel bar that was immersed into the concrete paste for each specimen type was used. In order to do this, a piece of metal was prepared in the workshop and each steel bar was connected to it so as to prevent the complete penteration of the bar while casting. Also, in order to avoid these concrete moulds to contact with the steel bar while in they were in the curing tanks, a 10 cm PVC pipes were used of which 5 cm embeded into the mold and the ther 5 cm kept above the concrete as shown in Figure 4.12. After the formwork was prepared the steel bars were immersed into mould as desired.

Figure 4.11: Brushing Process of the Steel Bars

Figure 4.12: Designed Formwork of Steel Bars

After this process, the samples were taken to the curing room for 24 hours then immensed into water tank for 28-days. For the accelarated corrosion test, these samples were kept immensed in 3,5% NaCI by weight for 4 days. Then for performing electro-chemical test they were immersed in 5 % NaCI solution. Before the test was applied a copper plate was as well placed within the salty solution tank so as to accelarate the corrosion as shown in Figure 4.13. This copper plate will act as a cathode and the steel bar will act as an anode by this way a close circuit will be established that will allow the electrical current.

4.11 Accelerated Corrosion Test Calculations

Faraday Law's equation will be used for finding the definite loss of the steel bar. According to this equation at any point, the corroded steel bar's mass loss due to effect of electrical current can be measured. After the electro-chemical test was caried out for exposed to electro-chemical method at different hours, the corroded steel bars were washed with 12 % HCI acid for cleaning as shown in Figure 4.14. The cleaned steel bars after HCI acid wash is shown in Figure 4.15.

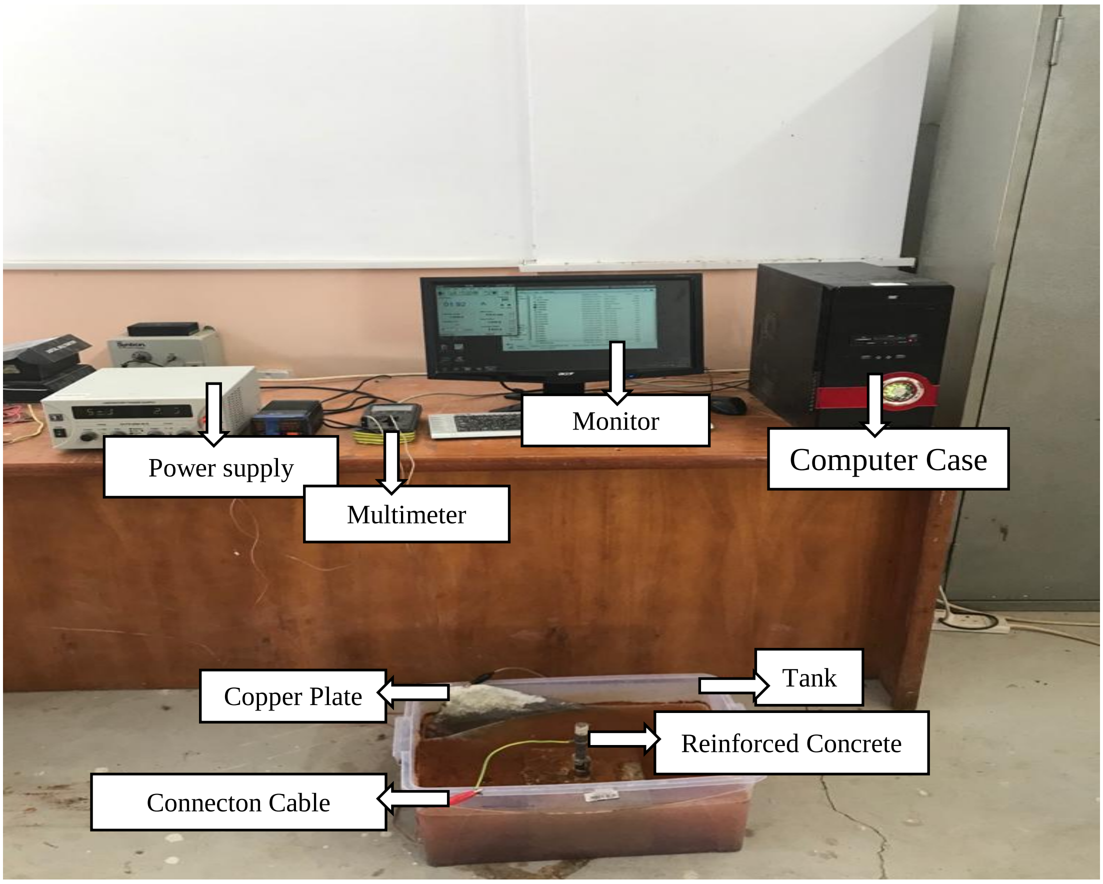

Figure 4.13: The Electro-Chemical Corrosion Apparatus with Power Supply

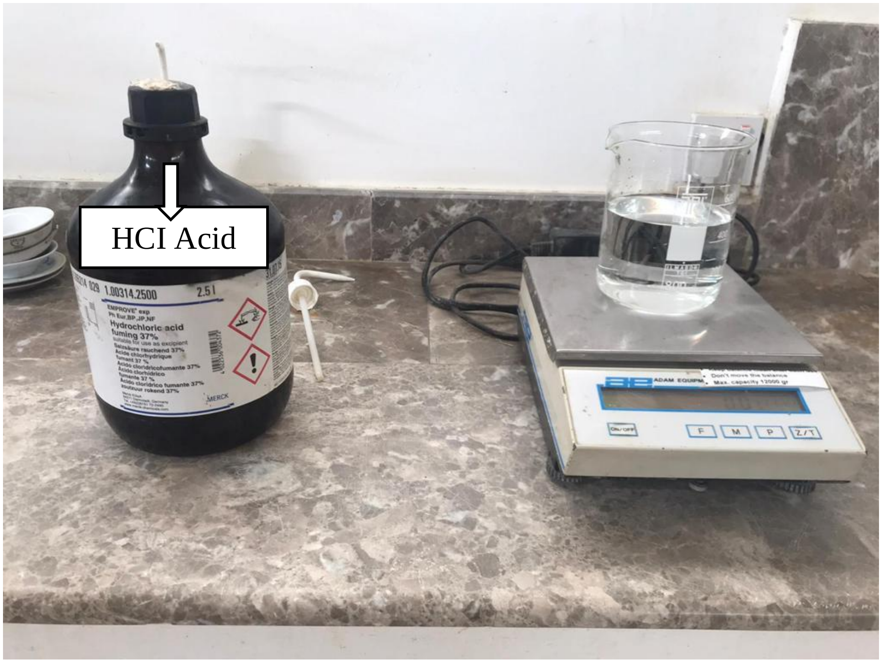

Figure 4.14: HCI Acid Used for Cleaning the Corroded Steel Bars

Figure 4.15: Cleaned Steel Bars after HCI Acid Wash

Theorotical weight lossess can be found by using Faraday Law's due to corrosion. In his model when the reinforced bars were directly submerged in a water-filled tank the corrosion would begin when the electric power is subjected. The suggested Faraday's Law equation is given below:

$$\text{Weight loss} = \frac{I(A)*t(s)*AM(g)}{V*F} \quad (1)$$

where,

I(A) is the current in Amper,

t(s) is the time used in second,

AM is the atomic mass of 1 mole of he used metal, which is 55.547 g for the steel,

V is the chemical valency of the used metal, which is 2 for the steel,

F is the Faraday constant which is 96487.

In order to determine the reduction of thickness in mm per year over the corroded surface, the below given equation should be used. Corrosion rate was found according to the ASTM G1-03.

$$\text{Corrosion rate (mm/yr)} = \frac{K*WL}{SA*T*D} \quad (2)$$

where,

K is a constant that is equal $8x10^4$

WL is the weight loss in grams,

SA is the initial surface area of the steel bar (cm^2),

T is the time passed in hours,

D is the density of the metal g/cm^3 which is 7.75 g/cm^3 for the steel bar.

Chapter 5

RESULTS AND DISCUSSIONS

5.1 Introduction

In this chapter; experimental results of four different concrete mixes produced with the usage of PW and TSW as mixing and/or curing water are tabulated in tables and drawn in figures as shown in below sections. In order to investigate the effects of TSW on concrete mechanical properties and durability; four different concrete mixes including the different combinations of PW and TSW as a mixing and/or curing water were produced and list of experiments are performed. Tests performed are: slump test; setting time; permeability; compressive, splitting tensile and flexural strengths; sulphate attack; pH test; ultrasonic test and corrosion tests. Results, presented in tables and graphs are compared and discussed in details. Also, samples average was taken and their standard deviation was given.

5.2 Effect of Potable and Treated Sewage Water on Concrete Workability

In this study, slump test was applied to two different mixes produced either using PW or TSW. Obtained workability (slump) values are presented and in Figure 5.1.

It is clear from Figure 5.1 that there is a little increase in the slump in case of using TSW. The observed higher slump value of TSW was believed to be due to the existing dissolved solids (impurities) within the treated sewage water sample. Hence, it is concluded that, there is no adverse effect of the TSW on workability. In other words; the concrete slump is not affected severely by TSW.

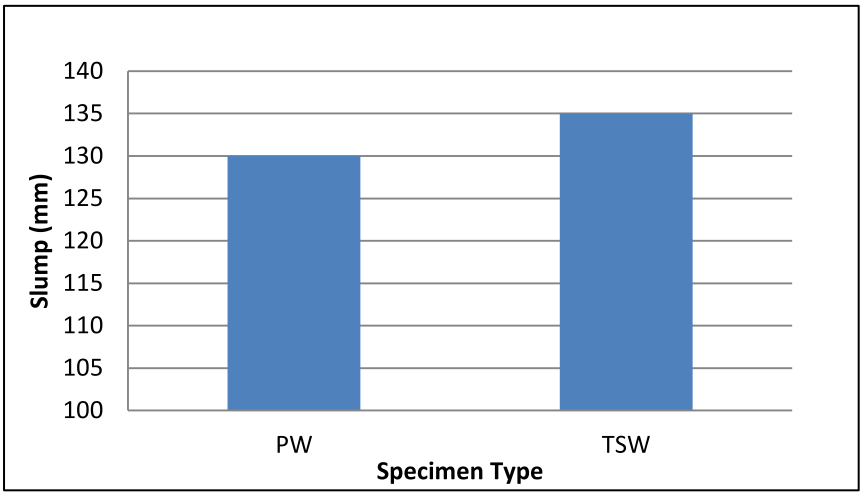

Figure 5.1: Effect of Potable and Treated Sewage Water on Workability

5.3 Effect of Potable and Treated Sewage Water on Setting Time

In order to assess the effect of PW on initial setting time, test is performed on two different types of cement pastes produced either with PW or TSW. As seen in Figure 5.2, initial setting of TSW is higher than PW. It is believed that, the existing impurities in TSW causes the delayed of the initial setting time of cement paste. ASTM C94 specified that, initial setting time of cement paste which is mixed questionable water should not be 1 hour earlier than initial setting time of distilled water and should not exceed 1 and half hour than initial setting time of distilled water. At the end, according to the setting time results it can be stated that; TSW slows down the hydration process of the concrete mixes.

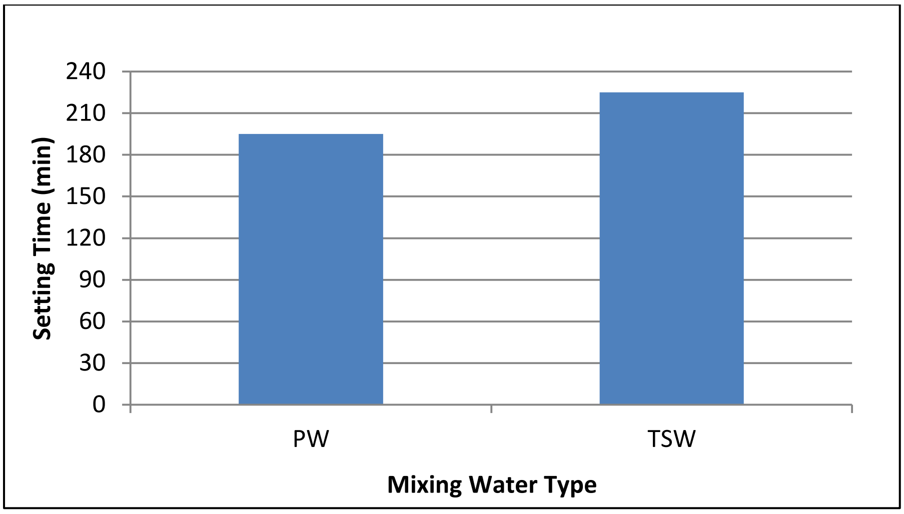

Figure 5.2: Effect of Potable and Treated Sewage Water on Initial Setting Time

5.4 Effect of Potable and Treated Sewage Water on Permeability

Permeability test was conducted on the four different types of combinations. Results of depth of water penetration were given in Table 5.1 from highest to the lowest respectively. As can be seen from the Table 5.1 the type of curing water affects the permeability. Therefore, concrete with low permeability will prevent intrusion of some aggressive agents into a concrete that might be the cause of corrosion. Using TSW as curing and mixing caused densification of the pore structure by blocking the pores and causing low permeability in CasT-CurT concrete mix. Therefore, corrosion will be less or will be prevented.

Table 5.1: Effect of Potable and Treated Sewage Water on Permeability

Specimen Type	Depth of penetration (mm)	
	Arithmetic mean of 3 samples	Standard deviation of 3 samples
CasP-CurP	17.20	1.87
CasP-CurT	13.11	2.85
CasT-CurP	22.89	2.93
CasT-CurT	13.78	2.79

5.5 Ultrasonic Pulse Velocity Test Results

The results of ultrasonic test are illustrated Table 5.2.

Table 5.2: Ultrasonic Test Results

Specimen Type	Pulse Velocity (km/s)	Quality	Standard Deviation of 3 samples
CasP-CurP	5.00	Excellent	0.42
CasP-CurT	4.85	Excellent	0.21
CasT-CurP	4.97	Excellent	0.14
CasT-CurT	4.72	Excellent	0.63

As it can be seen from Table 5.2; the pulse velocity of all the mixtures tested in this study are higher than 4.5 km/s and very close to each other. According to the standard, all our samples are excellent in quality. Since it contains less impurities in potable water compared to treated sewage water, in CasP-CurP may have resulted in higher pulse velocity. Therefore, their elastic modulus's, and densities will be high due to less void and crack occurrence in the matrix. At the end, it can be stated that; there is no adverse effect of TSW on pulse velocity readings.

5.6 Effect of Potable and Treated Sewage Water on Compressive Strength of Concrete

To investigate the influence of potable and treated sewage water on compressive strength, 9, 28, 56, 120 and 150 days compressive strengths were measured for four concrete mixes. Results are illustrated in Table 5.3 and Figure 5.3.

Table 5.3: Effect of Potable and Treated Sewage Water on Compressive Strength

Specimen Type		9 days f_c (MPa)	28 days f_c (MPa)	56 days f_c (MPa)	120 days f_c (MPa)	150 days f_c (MPa)
CasP-CurP	Average	50.20	58.70	63.76	67.80	68.52
	Standard Deviation	2.00	0.25	1.94	2.48	3.00
CasP-CurT	Average	46.00	54.20	62.50	64.10	65.37
	Standard Deviation	0.43	3.66	0.29	1.46	2.85
CasT-CurP	Average	42.10	50.70	56.90	62.80	66.23
	Standard Deviation	2.55	0.21	0.14	0.34	2.11
CasT-CurT	Average	42.70	51.80	59.00	61.50	62.10
	Standard Deviation	3.18	1.65	0.78	1.49	2.21

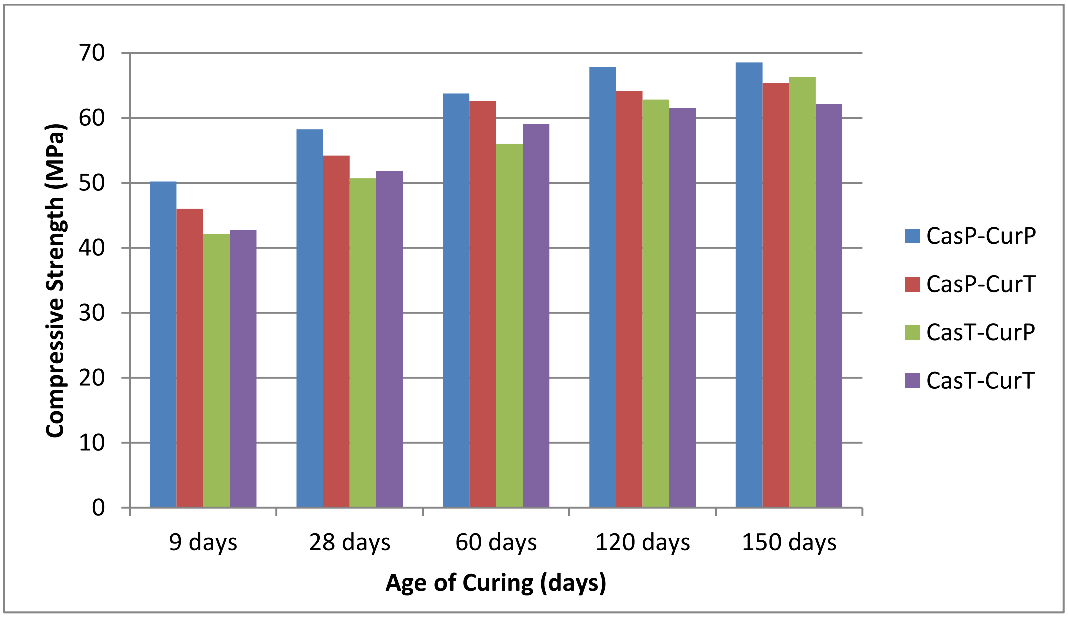

Figure 5.3: Effect of Potable and Treated Sewage Water on Compressive Strength

From Table 5.3 and Figure 5.3, it can be observed that; compressive strength (f_c) of the control mixture (CasP-CurP) was the highest for all tested ages (9, 28, 56, 120 and 150 days). Second highest one is the specimen which is mixed with PW but cured with TSW (CasP-CurT) again for all tested ages except 150 days age in which the f_c value of CasT-CurP became the second highest surprisingly. In the third order is the CasT-CurT which is mixed with TSW and cured with TSW, showed the same trend with the CasP-CurT. CasT-CurP is in the last order but very close to the CasT-CurT up to 60 days of curing. However, beyond that point its strength gain rate has increased and rose nearly up to CasP-CurP which is the first one in terms of strength development. In general, strength gain with the curing age is high and linear up to 60 days of curing. However, beyond 60 days curves bend to horizontal due to decreased hydration rate and became more close to each other.

If total strength gain from 28 days to 150 days are analyzed for four different mixes (CasP-CurP, CasP-CurT, CasT-CurP, CasT-CurT) separately, it can be stated that; the least increment (17%) belongs to CasP-CurP which is the control specimen, while the most increment happened in CasT-CurP (31%), 21% and 20% increments with CasP-CurT and CasT-CurT respectively. Use of TSW either for mixing or curing water purposes increases the long term strength and durability properties.

At 28 days age, decrement in f_c is 8% in CasP-CurT, 14% in CasT-CurP and 12% in CasT-CurT relative to control (CasP-CurP). This shows that incorporation of TSW (particularly as a CasT) reduces f_c value. This reduction is believed to be due to:

- The occurrence of the chemical reactions between the impurities of TSW and the cement paste which may cause the reduction of the bindness (stickiness) characteristic of the cement material,

- The existing impurities within TSW may surround the surface of the crushed aggregates by not only reducing their contact surfaces areas and even may form a layer that may prevent the cement to bind them properly.

Moreover, it is possible to say that when TSW is used as a mixing water that's better to cure the specimen with TSW instead of PW. When 150 days age f_c reductions are analyzed; it is possible to say that decrements are much lower (3%- 9%) because of the TSW effect which has decreased the rate of hydration.

When fc development is analyzed from another point of view (strength changes in each specimen from 28 days to 150 days). CasP-CurP concrete mix showed the least development (17%), the other two concretes mixed with PW or TSW but cured with TSW (CasP-CurT and CasT-CurT) showed nearly 20% f_c development. The strength development in CasT-CurP is the maximum (%31) and nearly two times better than control (CasP-CurP).

5.7 Effect of Potable and Treated Sewage Water on Tensile Strength of Concrete

Tensile strength test results of four concrete mixes at 9, 28, 120 and 150 days are presented in Figure 5.4 and Table 5.4.

Table 5.4: Potable and Treated Sewage Water on Splitting Tensile Strength

Specimen Type		9 days f_t (MPa)	28 days f_t (MPa)	120 days f_t (MPa)	150 days f_t (MPa)
CasP-CurP	Average	2.74	3.13	3.50	4.03
	Standard Deviation	0.18	0.65	0.74	0.35
CasP-CurT	Average	2.94	3.35	3.57	4.42
	Standard Deviation	0.17	0.84	0.58	0.19

CasT-CurP	Average	2.91	3.26	3.79	4.02
	Standard Deviation	0.14	0.16	0.87	0.18
CasT-CurT	Average	2.98	3.29	3.72	4.00
	Standard Deviation	0.20	0.89	0.83	0.34

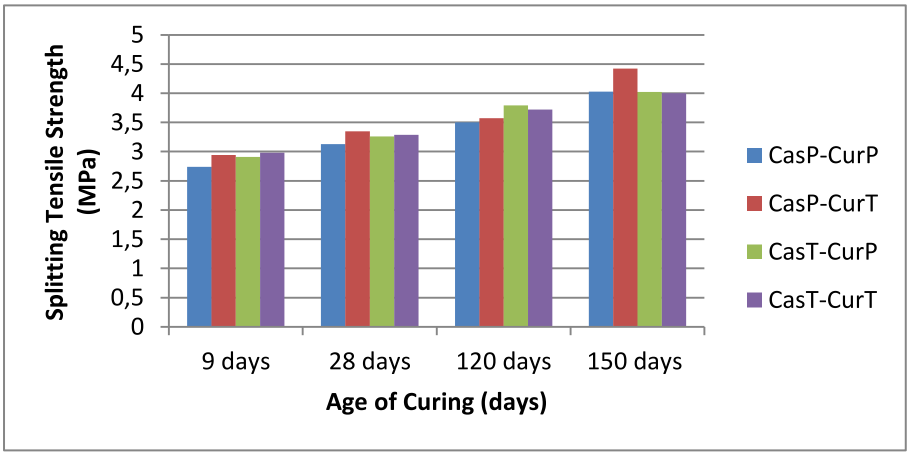

Figure 5.4: Potable and Treated Sewage Water on Splitting Tensile Strength

The results of splitting tensile strength (f_t) showed that f_t of the control specimen (CasP-CurP) is the lowest one up to 150 days of curing age. At 150 days of curing all reached to the same strength value except CasP-CurT. It showed a sharp increment at 150 days of curing. In other words, at 150 days age f_t values of the specimens mixed with TSW and cured either with PW or TSW are very close to each other and also to the control specimen (CasP-CurP).

If total split tensile strength gain from 28 days to 150 days is analyzed for four different mixes (CasP-CurP, CasP-CurT, CasT-CurP, CasT-CurT) separately, it can be stated that; the least increment belongs to CasT-CurT (22%), while the most increment happened in CasP-CurT (32%), 23% and 29% belongs to CasT-CurP and CasP-CurP specimens respectively. Usage of TSW either for mixing water or curing water purposes does not have an adverse effect on f_t development particularly with the passing time. This is due to the improved hydration process and increased positive effect of TSW on hydration products.

The tensile strength of the produced concretes increase linearly for all ages, except CasP-CurT specimen which showed a linear increase up to 120 days of curing but beyond that point it showed a sharp increment and became the most strength gain mixture at 150 days among the others. Here, it is worth to say that; using TSW either for mixing or curing water purposes enhances f_t values for all curing ages (9, 28, 120, 150 days).

5.8 Effect of Potable and Treated Sewage Water on Flexural Strength of Concrete

In this section, the effect of PW and TSW on flexural strength of the concrete mixes were investigated. According to the results illustrated in Table 5.5 and Figure 5.5; there is no significant difference between the f_f results of CasP-CurP and CasT-CurT concretes for the both of the curing ages (28 days). When f_f values of CasP-CurP, CasP-CurT are compared, it is possible to say that, using TSW as a curing material decreases 28 days strength.

Table 5.5: Effect of Potable and Sewage Water on Flexural Strength of Concrete

Specimen Type	Flexural Strength after 28 days (MPa)	
	Arithmetic mean of 3 samples	Standard Deviation of three samples
CasP-CurP	6.52	0.43
CasP-CurT	6.37	0.26
CasT-CurP	6.30	0.33
CasT-CurT	6.48	0.34

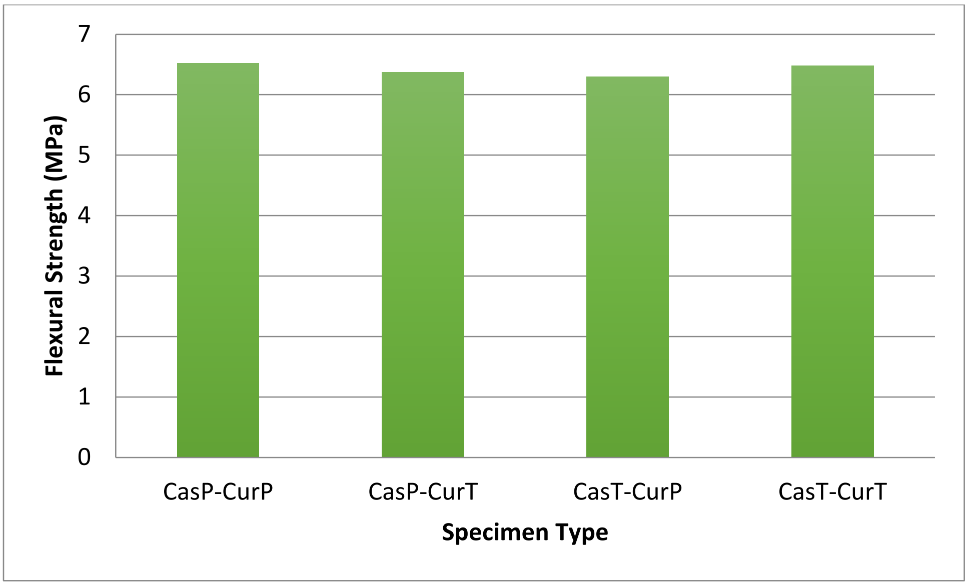

Figure 5.5: Effect of Potable and Treated Sewage Water on Flexural Strength of Concrete

Effect of TSW on flexural strength development is negligible. f_f values of all mixes including the control are very close to each other for the two tested ages (28 days).

5.9 Effect of Potable and Treated Sewage Water on Sulphate Resistance of Concrete

In case of cracks happened in concrete, ingress of aggressive water will flow easily that will accelerate the deterioration process. Due to the weakening in the cohesion of cement hydration products, sulphate attack may also take place. In this research, in order to examine the effect of treated sewage water and clean water on concrete sulphate resistance, strength loss method was used. Samples were immersed in Na_2SO_4 solution by weight of water for 56 days. As shown in Figure 5.6 and Table 5.6 the strength of the samples cured in normal water are larger than the strength of the samples cured in sulphate solution. According to the results, the most resistant to the sulphate are CasP-CurT, CasP-CurT, CasT-CurP and CasT-CurT respectively. Moreover, sulphate resistance of the concretes (CasP-CurT, CasT-CurP) produced with different type of water for mixing and curing are very similar. On the other hand, using different mixing water but same curing water (CasP-CurT, CasT-CurT), (CasP, CurT) result in decrement of the sulphate resistant. The lowest sulphate resistant belongs to CasT-CurT concrete mix among the produced mixes. Both mixing and curing with TSW reduces the sulphate resistance considerably. This reduction in compressive strength can be explained due to the dissolved solids within TSW degraded the calcium silicate hydrate (C-S-H) within the concrete paste hence, causes weakening of the concrete resistance.

If permeability of the concrete is high non sulphate chemical will reach products of hydrated cement and this reaction will give some products unhydrous calcium sulphoaluminate which is mostly known as ettringite and another gypsum which is called sulphate hydrate. These products will cause more expansion than solid reactants when stresses are occurred deterioration will happen in the concrete.

Table 5.6: Effect of Potable and Treated Sewage Water on Sulphate Resistance of Concrete

Compressive Strength after 56 days					
Samples	Potable Water	Standard Deviation	5% Na_2SO_4	Standard Deviation	Strength loss (%)
CasP-CurP	63,76	1,94	62,89	2,68	1,40
CasP-CurT	62,50	0,29	61,26	0,49	2,00
CasT-CurP	56,90	0,14	55,77	0,87	2,00
CasT-CurT	59,00	0,78	57,29	2,31	3,00

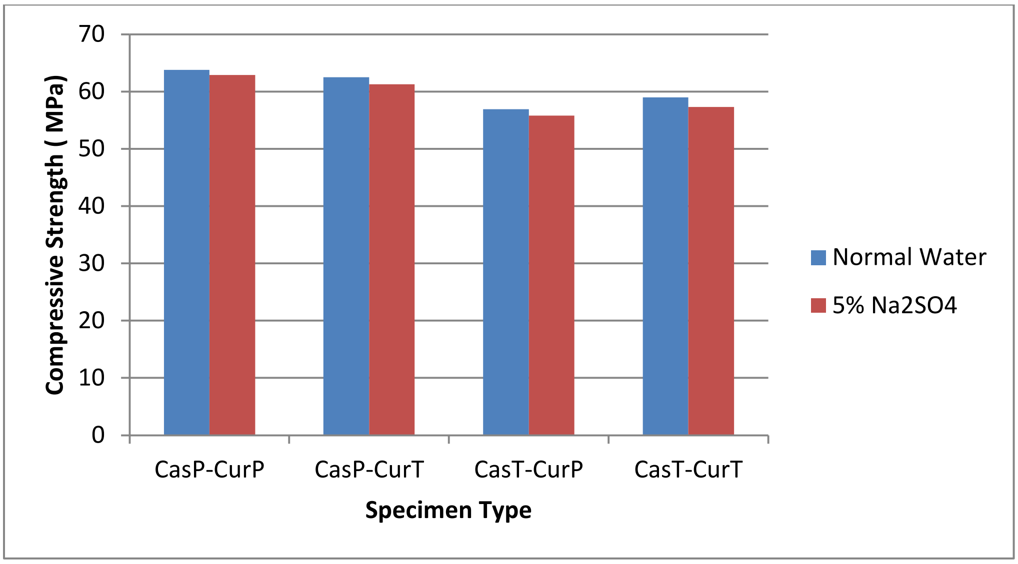

Figure 5.6: Effect of Potable and treated Sewage Water on Sulphate Resistance of Concrete

5.10 Effect of Potable and Treated Sewage Water on Alkalinity (pH) of Concrete

The pH values obtained from the alkalinity test on various specimens are presented in Table 5.7.

Table 5.7: Effect of Potable and Treated Sewage Water on Alkalinity (pH) of Concrete

Specimen Type	pH Value	
	Arithmetic mean of 3 samples	Standard Deviation of 3 samples
CasP-CurP	11.58	0.014
CasP-CurT	11.56	0.022
CasT-CurP	11.50	0.014
CasT-CurT	11.53	0.01

The results of alkalinity test (concrete pH) on four different concrete specimens are presented in Table 5.7. It is clear from Table 5.7 that the pH values of the produced concretes were found to be between 11.5 and 11.6. Hence, the utilization of TSW was not found to affect the alkaline character of the concrete. The pH values of the mixtures mixed with PW. Moreover, it might be better to cure the mixtures mixed with TSW with TSW again in terms of reinforcement corrosion. It is well known that; pH value which is around 12 is good to protect reinforcement from corrosion. Therefore, pH value or the alkalinity degree of the mixtures incorporated with TSW creates negligible negative effects on steel reinforcement and make the concrete having resistance to corrosion similar with the control (CasP-CurP).

5.11 Accelerated Corrosion Method on Different Types of Concrete

In order to examine the effect of PW and TSW on corrosion, accelerated corrosion method was used by applying electro-chemical method on the steel bars. By obtaining the actual weight loss and the time exposure to corrosion, the corrosion rates were calculated. To determine the reduction of thickness on the corroded steel surface, the theoretical corrosion values were also calculated and compared.

As it is seen in Figure 5.8; concrete specimens mixed with PW and cured with PW or TSW (CasP–CurP and CasP-CurT), interestingly have the same weight losses due to 72-hours of exposure to corrosion. On the other hand, concrete specimens mixed with TSW and cured with PW or TSW (CasT–CurP and CasT-CurT) had very little weight loss at the end of 72-hours of exposure to corrosion, compared with the other two types. This result implies that, the use of TSW either for mixing or curing purposes up to a certain age is less harmful than PW in terms of steel bar corrosion. However, once a long period of exposure time (168-hours) were examined, the results were completely different. So, when 168-hours exposure corrosion time is examined; CasP-CurP showed the lowest weight loss. CasP-CurT and CasT-CurT showed about 20% more weight loss than CasP-CurP, and CasT-CurP %55 more weight loss than CasP-CurP. The reason for this changed is believed that, the use of TSW as a curing water (CurT) in particular, in fact, by providing a corrosion resistance layer that protects the steel bar due the existence of chemicals within TSW. However, this protective effect of TSW decreases and the corrosion process accelerates as the concrete age progresses as detailed in Table 5.8. Due to chemical composition of TSW, it is believed that, the impurities may cause both the increase of the corrosion rate and the weight loss of the reinforcement bars as detailed in Table 5.8.

Table 5.8: Corrosion rates on Different Type of Concrete

Specimen Type	Exposure to corrosion time (hr)	Weight loss (g)	Corrosion rate (mm/yr)
CasP-CurP	72	12	73.6
	168	96	194.6
CasP-CurT	72	12	73.6
	168	102	228.7
CasT-CurP	72	5	30.6
	171	175	297
CasT-CurT	72	2	12.3
	168	125	236.6

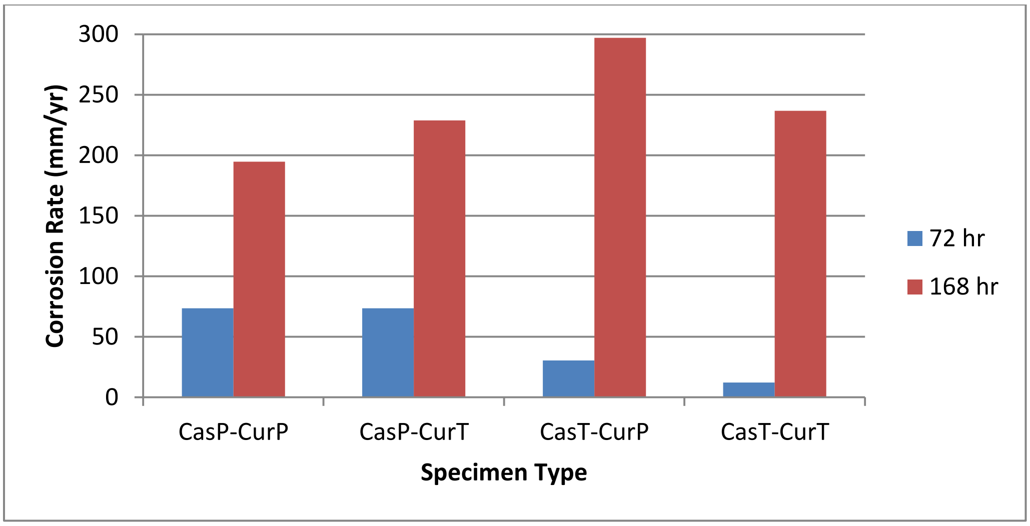

Figure 5.7: Corrosion rates on Different Type of Reinforcement Concrete

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In this experimental study; set of experiments are performed on four different concrete mixes produced by using potable water (PW) and treated sewage water (TSW) either for mixing and/or curing purposes to be able to evaluate the applicability of the TSW (provided from Gazimağusa Sewage Treatment Plant) in concrete production. Results of the experiments related to workability, permeability, alkalinity, ultrasonic pulse velocity, strengths (compressive, tensile and flexural) and corrosion led us to express the following conclusions:

1. Utilization of TSW caused little increase on workability. Usage of TSW in mixing concrete will not have an adverse effect on the workability.
2. The initial setting time of TSW showed an increment when compared with the initial setting time of PW. This indicates that TSW slows down the hydration rate of concrete which is an advantage for hot countries.
3. Usage of TSW as a mixing (CasT) or curing (CurT) purposes, reduced the permeability of concrete. It could be noted that, the usege of TSW improves long-term durability.
4. All concrete specimens produced are excellent in quality since their pulse velocities are higher than 4.5 km/s.
5. Usage of TSW either for mixing or curing purposes does not have an adverse effect on f_c, f_t and f_f development in total. This is due to the improved

hydration process and increased positive effect of TSW on hydration products with the passing time. Most affected strength in an adverse manner due to TSW incorporation is f_c with maximum 9% reduction relative to control (CasP-CurP) at 150 days age.

6. Using TSW either for mixing or curing water purposes enhances strength values and makes them to become very close to the control with the passing time. Therefore, usage of TSW either for mixing or curing water purposes increases the long term strength and durability properties.
7. The pH values for the concrete mixes ranged between 11.5 and 11.6. Thus, the utilization of TSW was not found to affect the alkaline character of concrete. Therefore, the use of TSW in concrete mixes will not have negative effects on steel reinforcement in terms of corrosion.
8. There is no negative effect of TSW incorporation on sulphate resistance of the produced mixes. The maximum compressive strength loss is found to be only 3% in CasT-CurT.
9. When weight losses up to 72 hr exposure corrosion time is examined; the use of TSW as CasT or CurT purposes is less harmful than the usage of PW in terms of steel bar corrosion. However, when the subsequent weight reductions of 168 hr exposure corrosion time are examined, it is seen that, the results are completely different: CasP-CurP showed the lowest weight loss, CasP-CurT and CasT-CurT showed 20% and CasT-CurP 55% weight loss compared to CasP-CurP. Thus, implying that, the use of TSW as a curing water (CurT) in particular, provides a corrosion resistance through a protective layer on the steel bar due the chemical content of the TSW up to a

certain age. However, this protective effect of TSW decreases, as the concrete age increases since the corrosion continues to progress.

6.2 Recommendations for Future Studies

1. It is advisable to carry out researches especially on the type of chemical reactions that may occur within the concrete mix and cured with treated sewage water.
2. It might be a good trial to test this treated sewage water, especially for clay brick productions.
3. Investigating the effect of this treated sewage water for the compaction of soil especially for the sub-base of roads during construction, might be a quite interesting attempt.

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