SUSTAINABLE PRODUCTION OF CONCRETE USING WASTE WATER

A Thesis Submitted in Fulfillment of the Requirements
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MASTER OF ENGINEERING

IN

STRUCTURAL ENGINEERING

Submitted by

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DECLARATION

I, Shivani Bansal hereby declare that the work presented in this thesis entitled, **"SUSTAINABLE PRODUCTION OF CONCRETE USING WASTE WATER"**, in fulfillment of the requirement for the award of degree of **Master of Engineering** in **Structural engineering** submitted at Department of Civil Engineering, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala is an authentic record work carried out under the supervision of **Dr. Shweta Goyal, Associate Professor and Dr. Rafat Siddique, Senior Professor**, Department of Civil Engineering, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala from July 2018 to July, 2019. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

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CERTIFICATE

It is certified that the above statement made by student is correct to the best of my knowledge and belief.

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ABSTRACT

Availability of clean water and disposal of wastewater has become a major environment issue. One common solution to both the problems is the recycled use of water. Here the reuse potential of waste effluent from different sources in mixing and curing of concrete has been investigated. In this study, wastewater from four different sources was collected and used in mixing as well as curing of concrete.

One of the main objectives of this study is to evaluate utilization of wastewater in mixing and curing of concrete. Wastewater was collected from sewage treatment plant of Verka industry (food-based industry), aluminium industry containing acid, aluminium industry without acid and wastewater from Thapar sewage treatment plant. For control samples, normal tap water was taken.

The concrete mixes were casted and cured with the same water whether it is wastewater or tap water (control mix). Performance of concrete mixes was judged by evaluating compressive strength, split tensile strength, water absorption and corrosion current density. The microstructure of the mixes was analyzed by Scanning electron microscopy (SEM) and XRD. Properties of different waters were also compared.

It was observed that compressive strength of concrete mixed and cured with wastewater was less as compared to the compressive strength of control mix. In addition, water absorption was greater for these wastewater samples as compared to control samples that were mixed and cured using tap water.

Keywords: waste water, concrete, compressive strength, corrosion.

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ABBREVATIONS

Units	**Word(s)**
Kg	Kilogram
G	Gram
Mg	Milligram
°C	Degree Celsius
%	Percent
M	Meter
Cm	Centimeter
Mm	Millimeter
µm	Micrometer
N	Newton
MPa	Mega Pascal
kg/m^3	Kilogram per cubic meter
N/mm^2	Newton per square millimeter
kN	Kilo Newton
hr.	Hour
min	Minute
sec	Second
l	Liter
ml	Milliliter

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Seventy percent of the earth's surface is covered with water, but out of this seventy percent only one percent is easily accessible to us. Water is the most important resource and with more and more news of water shortage and droughts, saving water and using it more efficiently has become a necessity.

It was realized with the passage of time that environment and growth are simultaneously important. The importance of environment cannot be ignored. With the growing science and technology, construction industries are increasing rapidly with time, and hence demand of resources is increasing rapidly. Concrete is the second highly consumed substance after water (Asadollahfardi et al., 2016). For one cubic meter of concrete about 186 liters of water is required (Meena and Luhar. 2019). In addition, construction industry is the largest consumer of water (Meena and Luhar. 2019). About one trillion gallon of water is used for the purpose of making and curing of matrix worldwide (Meena and Luhar. 2019). So if are able to find substitute of the fresh water in construction industry we will be able to save large amount of water. Water is one of the majorly important resource available to us but its inefficient usage has led to scarcity of water. In this research, an attempt is made to reuse the wastewater from different sources, in concrete. Concrete was mixed and cured using waste effluents and this waste effluent concrete is checked for various properties.

1.2 ROLE OF WATER IN CONCRETE

Water is most important constitute of concrete with having minimum cost. Its role is very important in mixing, laying, and compaction, setting and hardening of matrix. Matrix is produced by mixing of binding materials (cement, fly ash etc.) and inert materials (aggregates, sand etc.) with water. Cement and water are major active ingredients of concrete. Generally, for hydration of cement, quantity of water required is about three tenth of its mass. Hence, w/c ratio of miniumum value required is 0.3. But the matrix produced by adding this amount of water will be of rough nature and will be difficult to place so more water is necessary to mix the matrix for its proper lubrication, which makes the matrix workable. The functions of water in the concrete mix are as following:

1. It serve the purpose of lubrication for the aggregates and gives workability property to the mixture. It makes the surface of aggregates wet to develop adhesive quality as the cement paste binds quickly and in better way to the aggregates having wet surface as compared to the aggregated having dry surface. It facilitates the spreading of aggregate. It also damps the aggregate surface to prevent them from absorbing water vitally necessary for chemical action.

2. It forms binding paste by chemically acting with cement. Water is also necessary to impart plasticity property to various ingredients of concrete mix to attain proper workability of concrete to facilitate its transportation, handling and placing it at the desired position. It enables the easy flow of concrete mix in to moulds.

Ultimately, by chemically reacting with cement, water helps to produce the desired properties of the concrete.

1.3 QUALITY OF MIXING WATER IN CONCRETE

The quality and quantity of water plays very significant role in determining the properties of concrete. The strength of concrete is greatly dependent on the properties of water used in the mix. Generally, quality of water to be used in construction works is same as drinking water. This ensure that the water does not contain impurities such as suspended solids, organic matter and dissolved salts. These impurities may have adverse effect on fresh, hardened and durability properties of concrete.

It is a commonly accepted that any potable water can be suitably used for concrete making. However, when potable water is not available, it is always better to test the water to find out contents present in it and take suitable steps to minimize the adverse effects of these contents if present in excess. If proper attention is not paid to the water quality used for concrete mixing and water of bad quality is used, then it may have detrimental effects on the structural properties like strength and durability of concrete.

It is reported that presence of salts in excess adversely affect the early age strength and can cause corrosion of reinforced bars in RCC structures. Presence of oils like vegetable oil, linseed oil, or mineral oil in water above 2 % decreases the strength of matrix about 25 %. Though slightly acidic water has no serious effects on the concrete but highly acidic or alkaline water should be avoided as it adversely affect the hardening of concrete. Water mixed with algae should be avoided as this water causes entrainments, which in turn results in loss of strength. It is found that seawater reduces the long-term strength of concrete, though reduction in strength is limited to 15%. Water containing chlorides in larger amounts tends to have persistent dampness and surface efflorescence and cause corrosion of steel used in RCC structures.

The water used for preparing the concrete should fulfill the requirements such that it should be fresh and clean, it should not contain organic impurities, higher amounts of acids or salts, hygroscopic, greasy and oily substance. The pH value shall generally be between 6 and 8. Thus, the presence of chemical compounds in water may participate in the chemical activities and thus affect the fresh, hardened and durability properties of concrete. Thus, it is always better to check water quality for ensuring good quality concrete. For plain and reinforced cement concrete, permissible limits for solids as per IS 456:2000 shall be as described in Table 1.1

Table 1. 1 Permissible limits for different elements in water (IS 456:2000)

Type of Solid in water	Permissible Limits for Construction
Organic matter	200 mg/l
Inorganic matter	3000 mg/l
Sulphates (SO_4)	500 mg/l
Chlorides (Cl)	a) 1000 mg/l for RCC work b) 2000 mg/l for PCC work
Suspended matter	2000 mg/l

1.4 ADVANTAGES OF USING WASTE WATER IN CONCRETE

The consumption of potable water in concrete can be reduced by addition of water reducing admixtures or by the reuse of water. By reusing the water, two problems will be solved by one method that is the disposal of water and at the same time decrease in demand of fresh water. Therefore, by reusing wastewater in concrete production and curing, huge amount of fresh water can be saved which can be used for other purposes.

1.5 OBJECTIVES OF PRESENT WORK

In this research, experiments were performed to check the potential of using industrial and domestic effluent in production of concrete. Effluent water was collected from four different sources and control samples were made using normal tap water from lab. Water collected can be broadly classified into two categories: sewage treatment plant effluent and industrial effluent. Two samples of sewage treatment plant effluent were collected, one from the Thapar sewage treatment plant and second from the Verka sewage treatment plant. At the same time two samples of industrial effluent were collected from aluminium manufacturing industry. These effluents were tested for their chemical properties and used in the casting and curing of concrete. To check its efficiency to be used as concrete water, various tests were performed to check properties of the resultant mixes.

1.6 FORMAT OF THESIS

Research work presented in the thesis is divided into five chapters followed by references

First chapter deals with basic introduction about the role of water in concrete, its quality and requirement for using wastewater in concrete.

Second chapter deals with the detailed review of published literature on use of waste effluents in concrete.

Third chapter describes the scheme of material used, experiments and techniques adopted for testing.

Fourth chapter deals with the test outcomes, properties of fresh mortar and concrete, durability and mechanical properties of hardened concrete. Along with these micro structural properties of the mix were also investigated with Scanning Electron Micrograph (SEM) and X-Ray diffractogram.

Finally, results and conclusion are presented in fifth chapter followed by the list of references.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Construction industry is the largest consumer of fresh water and various researchers have done investigations on the utilization of effluents in concrete. Research regarding use of waste effluent in concrete from 2001 onwards have been discussed in this chapter.

2.2 EFFECT OF DOMESTIC AND INDUSTRIAL WASTE WATER ON FRESH PROPERTIES OF CONCRETE

Various researchers have done investigations to find the influence of waste effluent on fresh properties of cement setting time and fresh properties of concrete i.e. slump. Some of the results of their findings are represented in the following section

2.2.1 Properties of Effluents

In this research work, waste effluents of sewage treatment plant and waste effluents of aluminium industry (heavy industry) were used for concrete mixing and curing. Researchers in past have also used different effluent from different sources and used it for the concrete production. Effluents used by the researchers were different so their properties were also studied different. Therefore, they as represented in Table 2.1 also studied the properties of the effluents

Lee et al. (2001) used the sewage water collected from STP of Malaysia for concrete mixing and curing. The properties of the effluent used are represented in table 2.1. **Noruzman et al. (2012)** used the treated effluent from domestic sewage treatment plant, heavy industry and palm oil mill and it was observed that the solid content of the heavy industry effluent was much more than the solid content of other sources. The waste water used by **Al-Jabri et al. 2011** was collected from the car wash stations that’s why its composition was little different as this water was free from organic impurities.

Table 2. 1 Properties of effluents used by different researchers

parameter	unit	Lee et. al. 2001	Noruzman et al. 2012		
			TEHI	TEDS	TEPM
pH	-	7.48	8.6	7.21	8.14
Total solids	mg/l	89.5	3445	1121	240
Sulfate	mg/l	10.4	56.7	22.6	25.4
Chloride	mg/l	11.9	225	7.5	5.2
Lead	mg/l	-	0.18	0.007	0.003
Copper	mg/l	0.0817	0.39	-	-
Manganese	mg/l	0.124	0.756	0.011	0.028
Zinc	mg/l	0.0460	0.44	0.21	0.13
Calcium	mg/l	46	28	0.5	0.9
Magnesium	mg/l	6.9	1.7	0.2	0.1
Iron	mg/l	29.033	1.52	-	-
Sodium	mg/l	0.490	2	3.9	3.1
nitrate	mg/l	2.1	113	7.5	45

2.2.2 Setting time

Lee et al. (2001) studied the potential of utilization of treated water from sewage treatment plants of Malaysia when used in mixing of concrete. Researcher studied the effect of waste effluent on setting time and observed that setting time increases for waste effluent concrete as compared to potable water concrete. Increase of 10 minutes and 5 minutes was reported for initial and final setting time respectively. According to author, this delay was due to the presence of zinc and copper as these salts act as retarder.

Table 2. 2 Setting time results (Lee et al., (2001)

Type of water	Water content (%)	Setting time (min)	
		Initial	final
Potable water	32	145	165
Treated effluent	32	155	170

Noruzman et al. (2012) used the waste water from three sources that were the effluent of sewage treatment plant, effluent from palm oil mill and effluent from heavy industry. In addition, he reported an increase in setting time for all types of mixes as shown in Table 2.3. He concluded that setting time of mix made using palm oil treated effluent was maximum and this was due to the organic impurities of the effluent. Other two mixes were made with treated effluent of heavy industry and domestic sewage which also shown an enhancement in the setting time as compared to the setting time of potable water mix.

Table 2. 3 Setting time resulted by Noruzman et al. (2012)

Type of mixing water	Initial setting time (min)	Difference in setting time (min)
PW	117	0
TEHI	110	-7
TEDS	108	-9
TEPM	149	+32

Assadolahfardi et al., 2016 used treated domestic sewage effluent for producing of concrete and concluded that setting time of this effluent mix was 165 minutes, which was 15 minutes higher as compared to setting time of control mix made using drinking water. In addition, final setting time follows the same trend i.e. final setting time was also higher for effluent mix as shown in Figure 2.1. The reason for this delay in setting was reported as the presence of solid impurities in the effluent

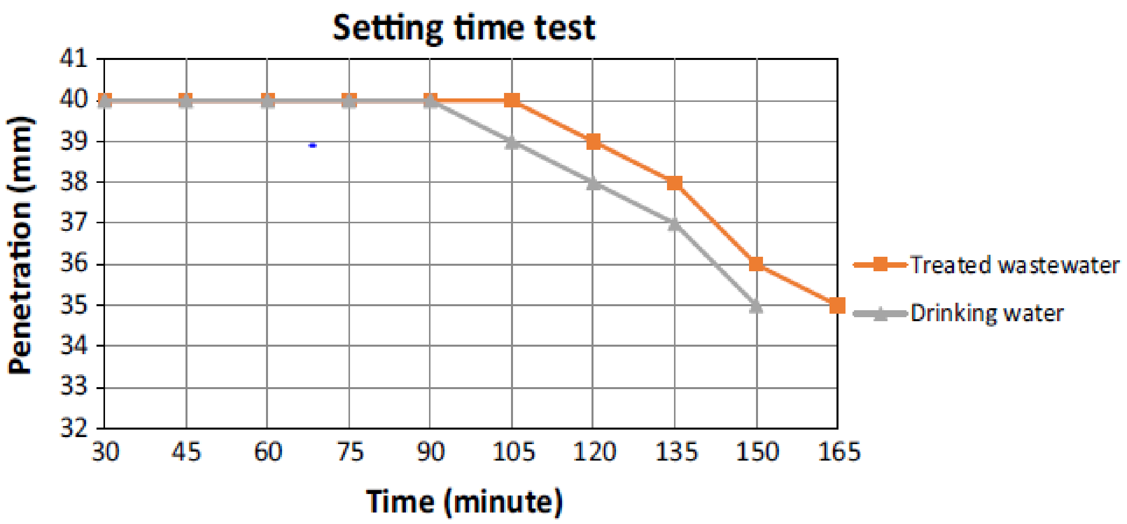

Figure 2.1 Setting time results by Assadolahfardi et al. 2016

Ghrair et al., 2016 use the primary treated and secondary treated waste effluent in concrete. Results of setting time shows an increased setting time of the matrix. An increase of 30 minutes and 5 minutes was noticed when primarily treated and secondary treated effluents were used respectively, as compared to that of the potable water concrete. Presence of sulfates also retard the hydration process of C_3S that also delays the initial setting of the cement.

2.2.3 Workability

Noruzman et al. 2012 used the effluent of three treatment plants for mixing of concrete that are treated effluent from domestic sewage treatment plant, effluent form palm oil mill and treated effluent of heavy industry. The values of slump varies between 25-50 mm but the slump of portable water was 50mm as shown in Table 2.3. The reason behind this decrease in slump was reported as the presence of solid particles. Workability of the palm oil mill effluent concrete was minimum among all mixes and the higher solid content of this effluent was said to be responsible for this decrease in slump as less water is available for concrete.

Table 2.3 Slump test results by Noruzman et al. 2012

Type of mixing water	Slump(mm)
PW	50
TEHI	35
TEDS	30
TEPM	25

Asadollahfardi et al., 2016 used the treated domestic effluent to mix and cure the concrete samples. Two different amount of cement was used i.e. 300Kg and 400 Kg cement per meter cube. Workability was checked using the slump method. and it was reported that slump value of control mix 110mm and that of the effluent sample was 99mm when 300 kg per meter cube of cement was used and the slump value for potable water concrete was 90 mm and that of effluent water concrete was 82 mm 400 kg per meter of cement was used. There was decrease in the slump value when wastewater was used.

Meena and Luhar. 2019 used three types of waste effluents for mixing and curing purpose of matrix. These were effluents of tertiary treated waste effluent (TTWE), secondary treated waste effluent (STWE) and third was the normal tap water (TW). Slump test was performed in accordance with IS 1199-1959 and it was observed that slump value was lesser for the concrete casted with waste effluent as compared to conventional tap water matrix as shown in Figure 2. Where CC stands for control samples, TWW stands for tertiary treated water and SWW stands for secondarily treated water. This decrease in workability was due to the presence of solid content, which are spongy in nature and are highly absorbing in nature.

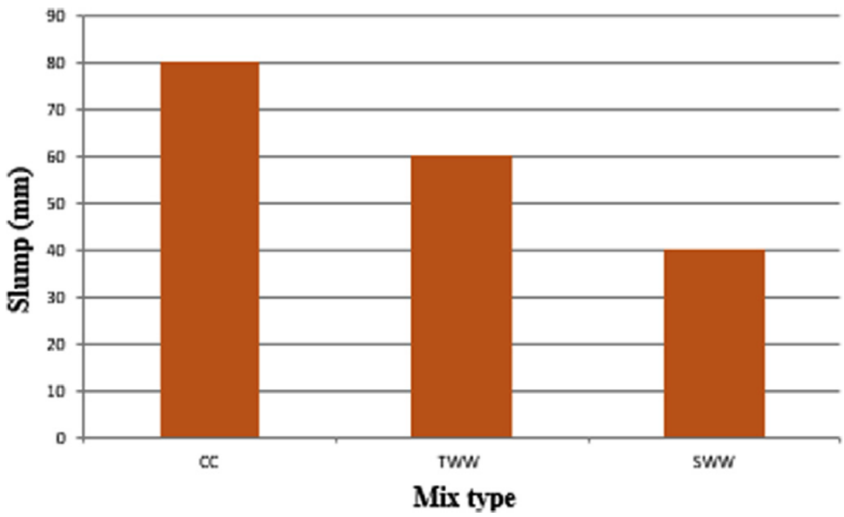

Figure 2. 2 Slump test results by Meena and Luhar (2019)

Ghrair et al., 2016 use the primary treated and secondary treated wastewater in mix. Slump test was conducted for checking the workability of concrete and a decrease in slump value was noticed when wastewater was used for concrete production. There was decrease of 25 mm and 15 mm for primary treated wastewater and secondary treated wastewater respectively. Higher Total solid content in effluent was reported as the cause if thus decrease in workability.

2.3 EFFECT OF DOMESTIC AND INDUSTRIAL WASTE EFFLUENT ON HARDENED PROPERTIES OF CONCRETE

Use of waste effluent in concrete directly effects the quality of concrete as it contain impurities and other elemts in excess. strength in compression is the most significant property of concrete and effect of effluent on hardened properties like compressive strength and tensile strength were investigated by various researchers which are reviewed here.

2.3.1 Compressive strength

Lee et al., (2001) collected the waste effluent from sewage treatment of Malaysia and used this water for the production of matrix. Two grades of concrete were made and effects of waste effluent on the compression strength was tested by comparing the results with that of the potable water concrete. The concrete cube of 150mm casted using sewage water were tested for strength in compression after curing period of 7, 28 and 90 days. Compression strength results of the research are shown in table 2.--. He observed that 7-day strength of treated effluent concrete was 26.22 N/mm^2 which was greater than that of the potable water concrete that was 24.46 N/mm^2 for grade 30 concrete. Similarly, 28 days strength of treated effluent concrete was 38 MPa, which was 11% greater than that of the potable water concrete that was 33.20 N/mm^2. Similarly, for grade 35 concrete, increase in strength was observed when effluent water was used in concrete. The increase in strength was 7.2% to 12 % for grade 30 concrete and this increase was 3.6% to 9 % for grade 35 concrete. Overall increase in compression strength was observed for treated effluent matrix as compared to control mix prepared by using potable water. The reason for this increase was reported as the higher concentration of chloride salts of sodium and calcium present in the effluent water which results in early strength but cause reduction in ultimate strength because calcium chloride act as catalyst in the hydration reaction of C_3S and C_2S and increases the heat liberation rate

Table 2. 4 Compressive strength with different mixing water (Lee et al. 2001)

Grade (N/mm^2)	Age (day)	Compressive strength(N/mm^2)		
		Mixing water		Percentage increase
		Potable water	Treated effluent	
30	7	24.46	26.22	7.20
	28	33.20	37.17	11.96
	90	38.27	41.24	7.76
35	7	27.54	28.52	3.56
	28	38.41	41.88	9.03
	90	43.56	45.16	3.67

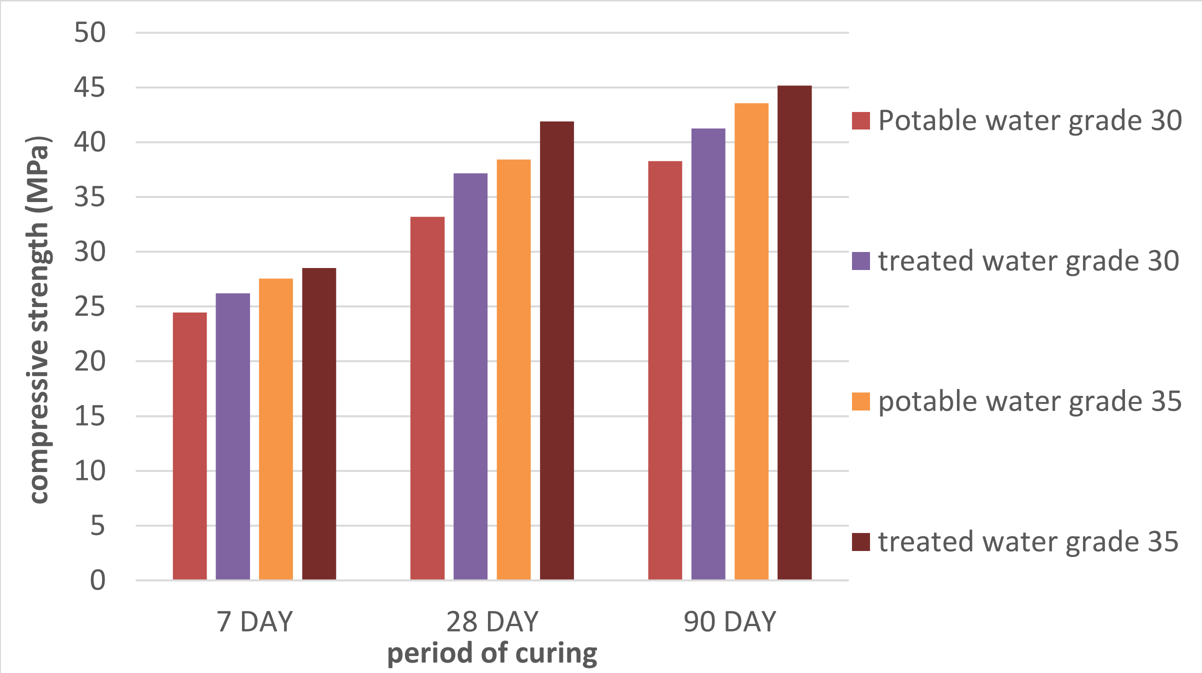

Figure 2.3 Comparison of compressive strength by Lee et al. (2001)

Noruzman et al., (2012) used the treated effluent from domestic sewage treatment plant, heavy industry and palm oil mill. The author compare 28 days compressive strength results with potable water mix and concluded that strength in compression after 28 days curing of matrix mixed with palm oil mill effluent and domestic sewage effluent was lesser than that of the compressive strength of potable water mix as shown in Figure 2.4 At the same time, the strength of heavy industry treated effluent concrete mix was greater as compared to that of the conventional mix made with potable water. Higher strength of concrete mix made with treated effluent of heavy industry was due to the presence of excessive amount of solid particles.

Another reason of increase in strength of heavy industry can be its higher sodium chloride content.

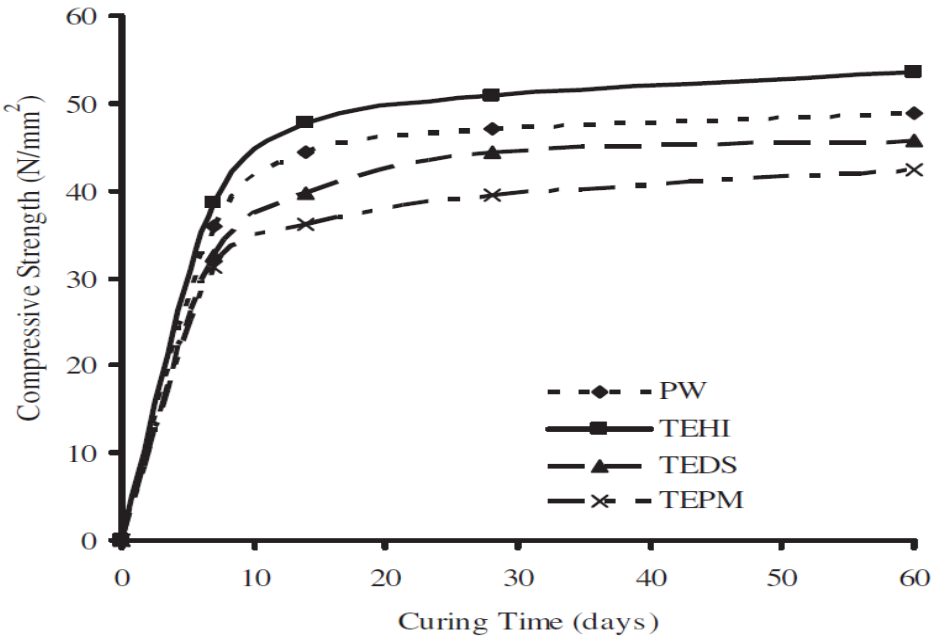

Figure 2. 4 Compressive strength of different mixes by Noruzman et al. (2012)

Assadolahfardi et al., 2016 tested compressive strength of 150 mm cubes made with treated domestic sewage effluent after 28 day of curing and results show that compressive strength varies between 93-96% of the compressive strength of the conventional matrix.

Meena and Luhar. 2019 used three types of waste effluents for mixing and curing purpose of the mix. These were the effluents from tertiary treated waste effluent (TTWE), secondary treated waste effluent (STWE) and third is the normal tap water (TW). Compressive strength was tested after curing of 7, 28 and 90 days was tested and concluded that strength in compression of waste effluent samples was less as compared to the potable water samples as shown in Figure 2.5. This was due to the ettringites, which is converted to compounds like mono sulfate aluminates, and this compound dissolved during hydration. Decrease in compressive strength reported was 29% at 7 days, 20.64 % at 28 days and 14.5% at 90 days when TTWE was used in concrete. This decrease in strength was 32.24% for 7 days, 29% for 28 days and 16.6% for 90 days. In addition, the impurities present in the effluents are responsible for lesser strength as they form a duplex layer between cement paste and aggregates and result in weaker bond.

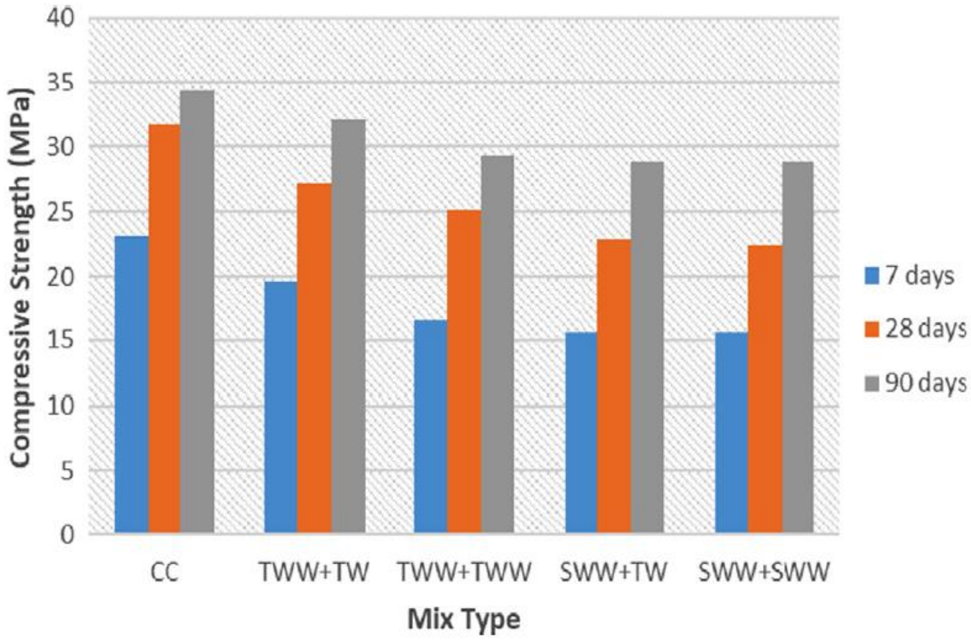

Figure 2. 5 Compressive test results by Meena and Luhar. (2019)

Swami et al. 2015 studied the utilization of treated domestic sewage effluent for mixing of matrix purpose and tested the resultant concrete for compression strength. He observed an increase in the strength when effluent was used in concrete and this increase in strength was 7% for 28 days strength in compression. Filing of the pores by suspended solids present in the effluent are responsible for this gain in strength.

Al-jabri et al. 2011 use the wastewater of car wash station for mixing and curing of the matrix and tested the 7 and 28 days strength in compression of 150 mm cubes. It was observed that strength results of waste effluent specimens was lower than that of the tap water specimens. 7 days and 28 days strength of tap water concrete was 66 MPa and 77 MPa respectively, which was higher as compared to 63.8MPa and 72 MPa respectively of wastewater concrete as shown in Figure 2.6

Ghrair et al., 2016 use the primary treated and secondary treated waste effluent was used in concrete and strength in compression was checked at 7, 28, 120 and 200 days. 7 days strength of waste effluent was very similar to the strength of control mix with very minor difference. However, the 120 days compressive strength of primary treated effluent concrete was 19% less than that of the control mix

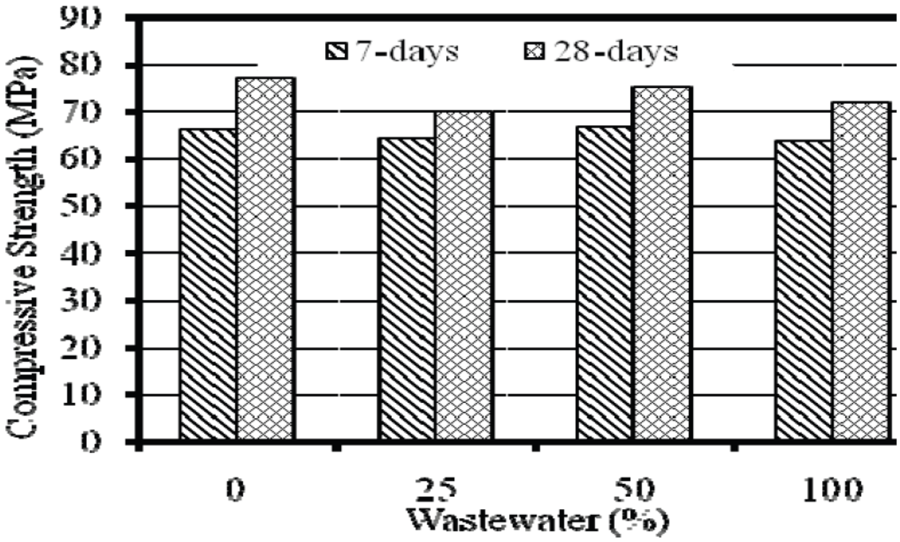

Figure 2. 6 Compressive strength results given by Al-jabri et al. (2011)

Silva and Naik. 2010 used the domestic sewage effluent after treatment in concrete and checked the resultant mix for compressive strength at 1, 7, 14, 28, 56 and 91 days of curing. No significant difference in the strength was noticed for the two concretes as shown in Figure 2.7

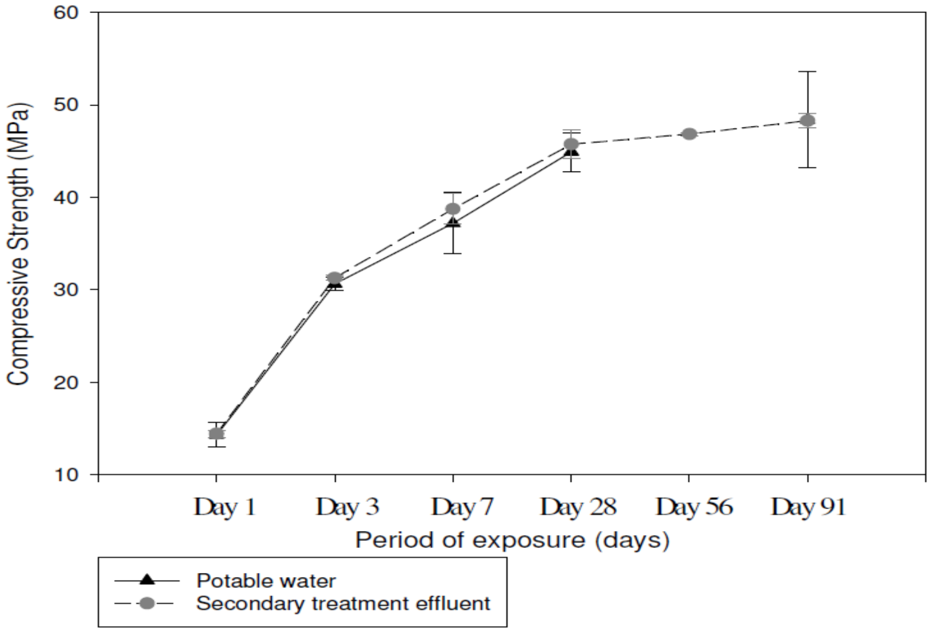

Figure 2. 7: Comparison of compressive strength between waste effluent concrete and potable water concrete (Silva and Nail. 2015)

2.3.2 Tensile strength

Assadolahfardi et al., 2016 studies the tensile strength of cylindrical specimens casted, cured in treated domestic sewage effluent, stated that 28 days tensile strength of these samples made, and cured in waste effluent was 96-100% of the control samples.

Al-jabri et al., 2011 used car wash station water for mixing of concrete, carried out split tensile strength test on cylindrical specimens, and observed a reduced tensile strength of tap water samples as compared to the waste effluent samples. Split tensile of the tap water samples at 28 days of age was 4.73MPa and that of the waste effluent sample was 5.21MPa, which was higher than that of the control sampler.

2.4 EFFECT OF DOMESTIC AND INDUSTRIAL WASTE EFFLUENT DURABILITY PROPERTIES OF CONCRETE

2.4.1 Initial Surface Absorption Test (ISAT)

Al-jabri et al. 2011 used the water from car wash stations for production of concrete and check the durability performance of that concrete by performing surface absorption test. All the samples reported a decrease in surface absorption value with progress of time. Absorption value for the wastewater samples at the same time was greater for the wastewater samples as shown in Figure 2.8

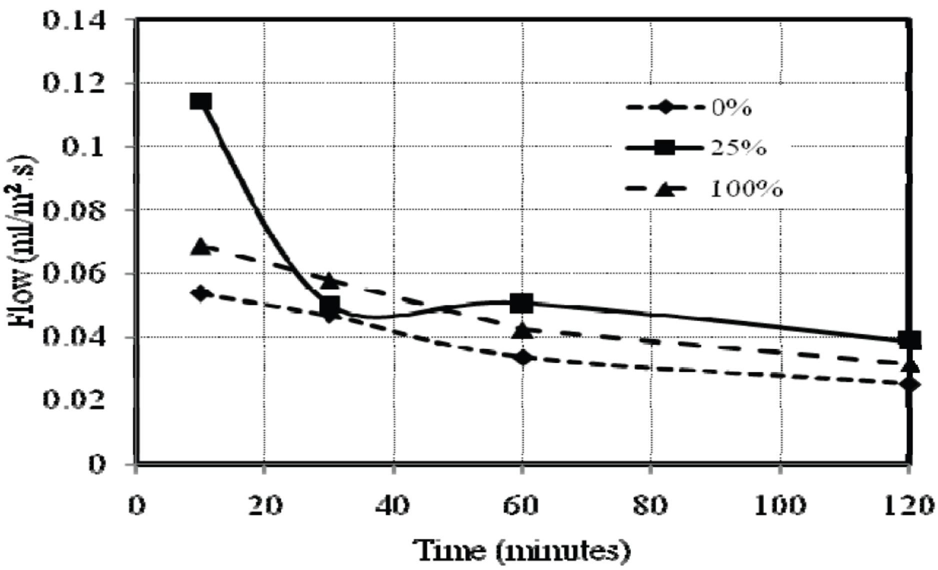

Figure 2. 8 Surface absorption of different mixes w.r.t time (Al-jabri et al. 2011)

Noruzman et al., 2012 studied the permeability properties of concrete mixed with the help of three different types of treated wastewaters and concluded that permeability decrease with time for all the mixes along with the conventional mix. This decrease in permeability with time is due to hydration process, which reduce the porosity of concrete by blocking the pores or by narrowing the pores by formation of hydration compounds **(Bushlaibi and Alshamsi, 2002).** At same time, it was concluded that permeability of concrete made with heavy industry effluent was lesser as compare to other two effluent concretes and this can be due to higher solid content of the heavy industry effluent.

Swami et al., 2015 studied the permeability property of 150 mm concrete cube casted using treated domestic sewage water and compare the results with the specimen casted using the tap water. The porosity of the resultant matrix was lesser as compared to the tap water matrix and this can be due to the pore filling by the suspended solids present in the effluent.

Assadolahfardi et al. 2016 used the treated effluent in concrete and check the permeability of the 150 mm cubes after 60 days of curing in the same water. ISAT test was performed to test the water absorption. It was reported that water absorption of conventional samples was 2.1% whereas; the permeability of effluent concrete samples was 3.1%. An increase in permeability was detected with use of treated effluent in concrete.

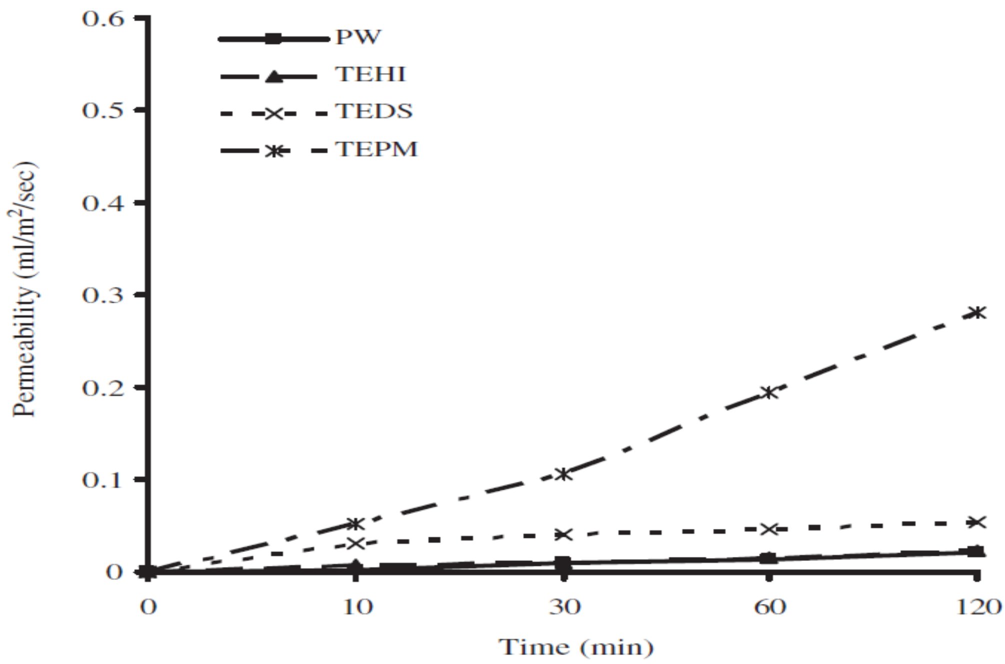

Figure 2. 9 Comparison of ISAT results by Norzman et al. (2012)

2.4.2 Sorptivity

Swami et al., 2015 tested the sorptivity of the cylindrical specimens of 100mm diameter and 50 mm height casted using the treated domestic sewage effluent. He reported the decrease in the porosity of the structure made with wastewater and this is due to the densification of the pore structure by the solids present in the mixing effluent.

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 GENERAL

This chapter gives the details of experimental program applied in this research work for characterization of materials used for making of concrete. The main objective was the evaluation of effect of waste water on concrete when used for mixing and curing purpose. The properties of different materials were assessed by performing various tests on the materials and properties of the resultant concrete were studied by conducting tests on the samples prepared using these materials along with waste effluents as mixing water. Results were compared with the results of tap water samples.The flow of experimental program is shown in Figure 3.1.

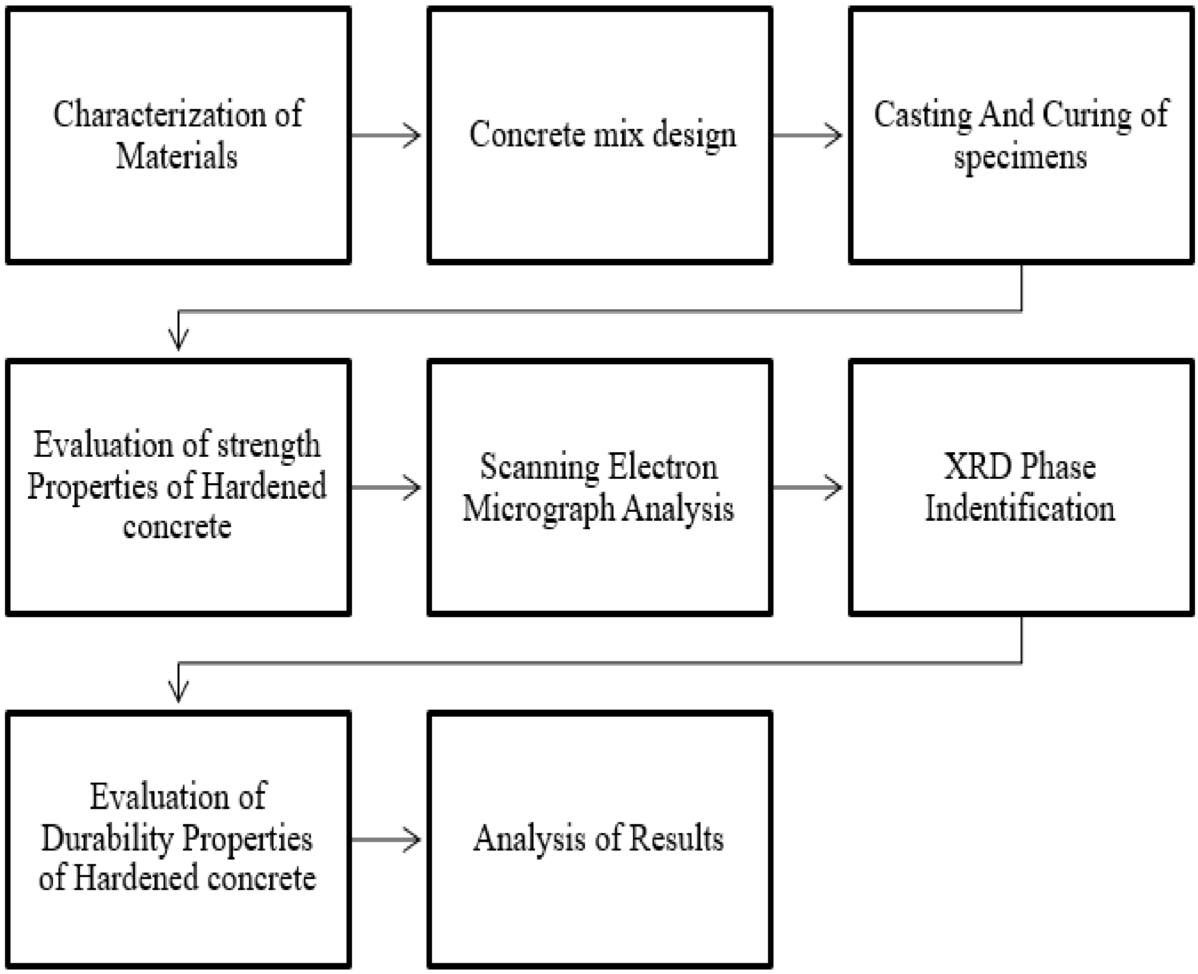

Figure 3.1 The schematic diagram of experimental program

3.2 MATERIALS

Quality of concrete is mainly dependent on the properties of materials used for making concrete. Cement, fine aggregates, coarse aggregates and wạter are the major constituents of matrix and properties of materials used in research are discussed in the following section.

3.2.1 Cement

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Table 3. 1 Physical properties of cement

S.No.	Characteristic	Value	Standard Values (As per IS 8112:2013)
1.	Type	OPC	-
2.	Grade	43	-
3.	Consistency	30%	-
4.	Initial Setting Time	150 minutes	30 minutes (Minimum)
5.	Final Setting Time	385 min	600 minutes (Maximum)
6.	Specific gravity	3.143	-
7.	Percentage Fines	3.5%	

Table 3. 2 Chemical composition of cement used in the research

S.No.	Compound	Compound %
1.	CO_2	6.50
2.	Na_2O	1.42
3.	MgO	0.58
4.	Al_2O_3	1.17
5.	SiO_2	21.74
6.	SO_3	6.11
7.	K_2O	2.85
8.	CaO	59.24
9.	FeO	0.39

3.2.2 Aggregates

Aggregate is the main or principle structure that consists of relatively inert fine and coarser materials. Aggregates contributes about 75% of the body of matrix, hence its influence is very significant. In this study fine and coarse aggregates of 10mm and 20mm were used, as shown in Fig 3.2.

Figure 3. 2 Aggregates used in the present study

IS: 383-1970 defines the fine aggregate, as the aggregates maximum of which will pass 4.75mm IS sieve. Locally available, well-graded, clean, dry Natural River sand of Zone II conforming to IS 383-1970 was used as fine aggregate in the present investigation.

Fineness modulus of aggregates is a number, which gives approximate average size of the particles of the aggregates. Fineness modulus is calculated by adding the percentage of the weight of the material that retains on sieves (opening between 80mm to 150um) and dividing the value by 100. Arrangement of sieves used for sieving of fine aggregates is shown in Figure 3.3. Table 3.3 gives the sieve analysis results for fine aggregate. Physical properties of the fine aggregates are given in Table 3.6.

Figure 3. 3 Arrangement of seives for seive analysis of fine aggregates

Table 3. 3 Sieve analysis of fine aggregates

IS sieve (mm)	Weight retained (gm)	Cum. Wt. retained (gm)	Cum. % age retained	Cum. % age Passing	Cum. % age Passing			
					Zone I	Zone II	Zone III	Zone IV
10 mm	0	0	0	100	100	100	100	100
4.75 mm	28.0	28.0	2.80	97.20	90-100	90-100	90-100	90-100
2.36 mm	186.5	214.50	21.45	78.55	60-95	75-100	85-100	95-100
1.18 mm	177.5	392.0	39.20	60.80	30-70	55-90	75-100	90-100
600 µm	130.0	522.0	52.20	47.80	15-34	35-59	60-79	80-100
300 µm	291.0	813.0	81.30	18.70	5-20	8-30	12-40	15-50
150 µm	138.0	951.0	95.10	4.90	0-10	0-10	0-10	0-15
PAN	49.0	1000.0	ΣC = 292.05					
Fineness modulus of F.A = (∑C)/100 = (292.05/100) = 2.92 Zone of fine aggregates= II								

The Coarse aggregates are defined, as the aggregates maximum of which is will not pass IS sieve of size 4.75mm. Crushed stone aggregates of size 20 mm & 10 mm were used as coarse aggregates for this investigation. The proportion of 20 mm to 10 mm coarse aggregate used for mix design was 60/40 (by weight). The coarse aggregates were tested as per IS 383-1970.

Results of the sieve analysis of 20 mm coarse aggregates and 10 mm aggregates are represented in Table 3.4 and Table 3.5 respectively. The physical properties of the aggregates are represented in Table 3.6

Table 3. 4 Sieve analysis of 20mm coarse aggregates

IS sieve (mm)	Wt. retained (gm)	%age wt. retained	Cumulative wt. retained (gm)	Cumulative %age retained
20mm	160	3.20	160	3.20
10mm	4410	88.20	4570	91.40
4.75mm	360	7.20	4930	98.60
Pan	70	1.40	5000	∑C=193.20
Fineness modulus of C.A (20mm) =(∑C+500)/100 = (193.20+500)/100=6.932				

Table 3. 5 Sieve analysis of 10mm coarse aggregates

IS sieve (mm)	Wt. retained (gm)	%age wt. retained	Cumulative wt. retained (gm)	Cumulative %age Retained
20mm	0	0	0	0
10mm	379	18.95	379	18.950
4.75mm	1442.50	72.125	1821.50	91.075
PAN	178.50	8.925	2000	∑C=110.025
Fineness modulus of C.A (10mm) = (∑C+500)/100 = (110.025+500)/100 = 6.1				

Table 3. 6 Physical properties of 10mm and 20mm coarse aggregates

Size of C.A.	10 mm	20 mm
Type	Crushed	Crushed
Specific gravity	2.695	2.705
Total Water absorption	0.57%	0.33%
Fineness modulus	6.10	6.932

3.2.3 Water

Water is the active ingredient of maximum importance among the constituents of concrete, which forms the binding matrix by chemically reacting with cement. On addition of water, cement undergoes the hydration reaction, which is responsible for strength of cement.

The water suitable for mixing is also suitable for curing of concrete. It is inferred that potable water should be used for mixing and curing purpose of concrete but in today's world, fresh water is depleting day by day and every part of the world is facing water scarcity. To meet the concrete water demand, substitute of fresh water is urgently required which can be used without compromising the concrete quality. The main solution to this problem of shortage of potable water is the reuse of water. Out of total water available to us, 20% is used in industries and 10% is used for domestic purpose. Apart from consuming large amount of fresh water, the industries also produce a huge amount of effluent, which is disposed into the river or lakes. So there are two main problems associated with water, one is the availability of water and second is the disposal of used water. One common solution to both the problems is the reuse of effluent water. If the effluent from different sources can be efficiently used, fresh water can be saved at large extent at the same time environment is also preserved from being polluted. So reuse of water is not need, it is the demand in present world.

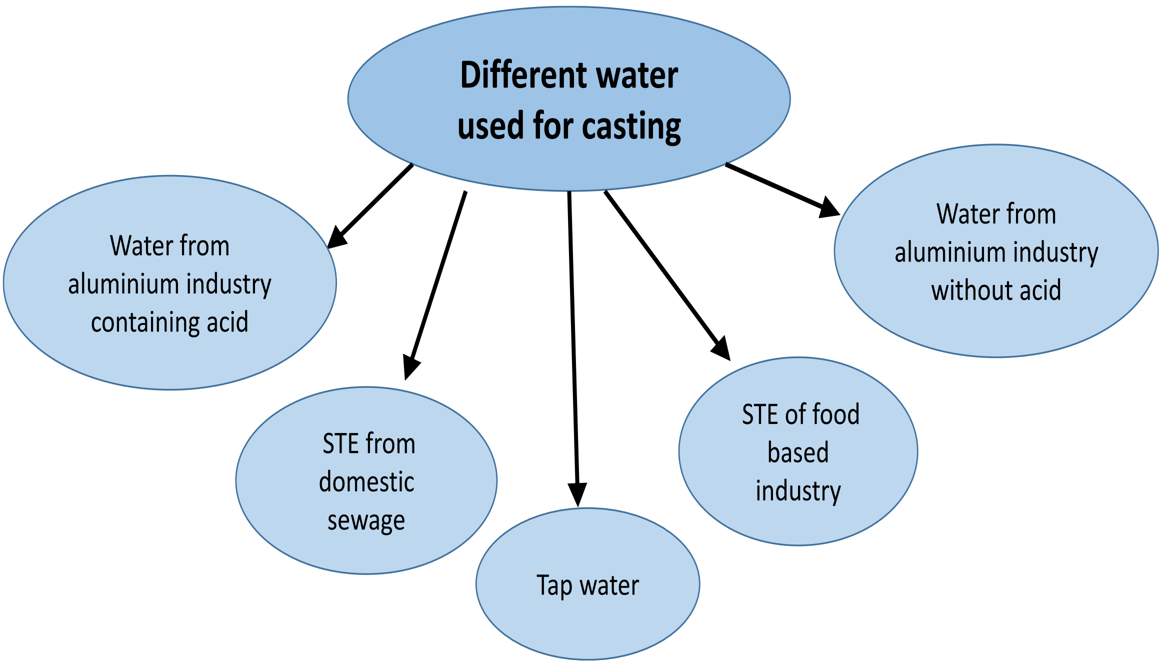

Figure 3. 4 Different water used in this research

In this research, an attempt is made to check the potential of wastewater collected from four different sources to be used as mixing and curing water for concrete.

Waste effluent collected for the research can be broadly classified in two categories: sewage treatment plant (STP) effluent and industrial effluent. STP effluent was collected from two sources; one is from the STP of Thapar Institute and second from the STP of Verka which is a food based industry. Industrial effluent was collected from aluminium industry and this was of two types, which was collected from their different manufacturing process units. Different sources of wastewater collected for the study is shown in Figure 3.4

3.2.3.1 Sewage treatment plant (STP) effluent

For this study, sewage effluent was collected from Thapar sewage treatment plant and Verka effluent treatment plant and was used for the purpose of mixing and curing of concrete. 200 liters of each water was collected. This was the water, which was properly treated before its disposal in municipal sewers, and schematic diagram showing their treatment is shown in Figure 3.5. Some quantity of this water was already in use for the irrigation purpose of local gardens.

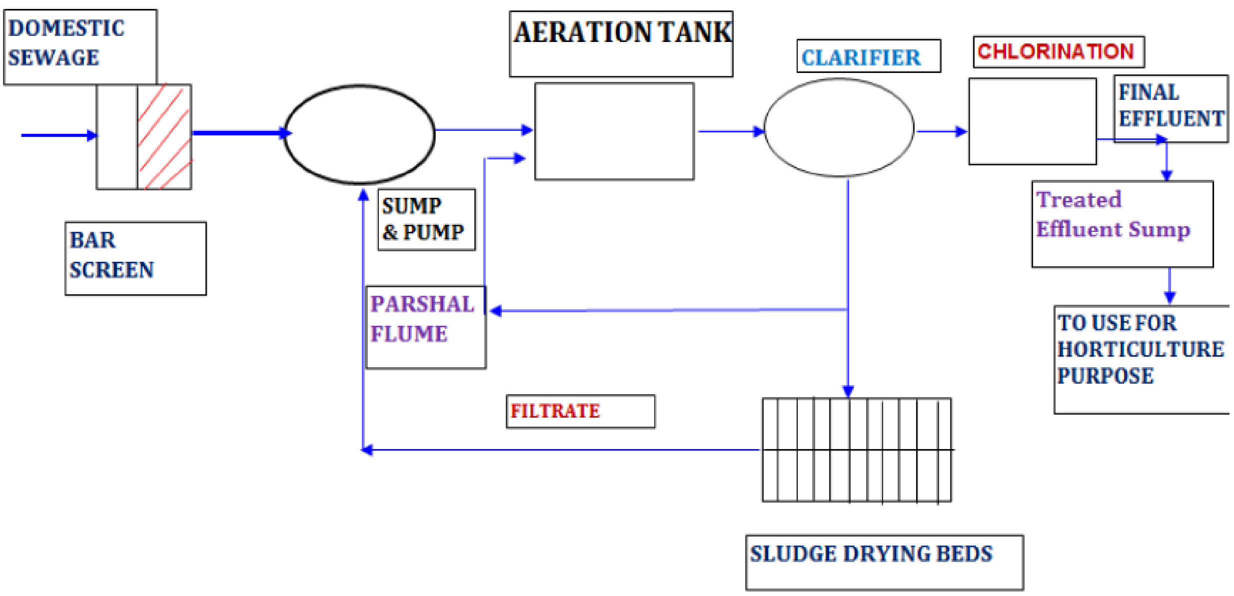

Figure 3.5 Processes involved in sewage treatment plant

3.2.3.2 Aluminium industry effluent

Effluents were also collected from the aluminium industry. Functioning of aluminium industry is shown in Figure 3.6. Water used in the study was collected from second and third process.

According to the industry reports, 600-700 liters of effluent is produced every day, which is disposed to municipal sewers after giving it the desired treatment. Water was collected after the treatment process, which was meant to be thrown out.

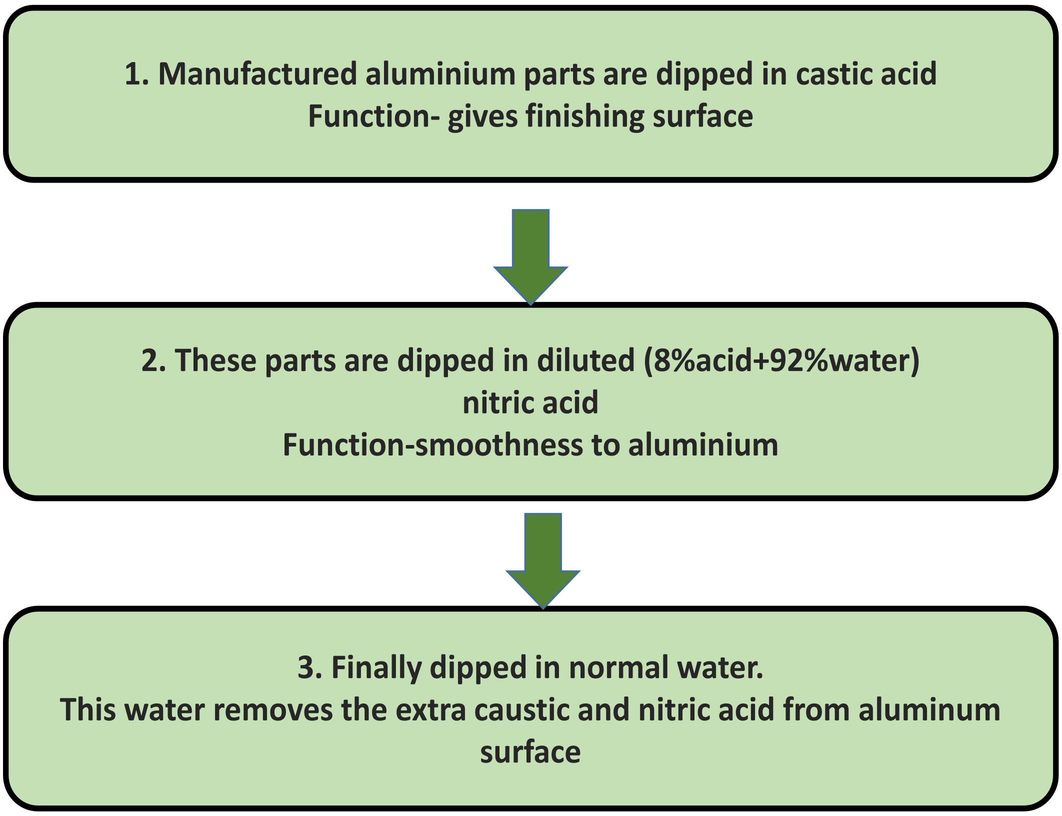

Figure 3. 6 Various process in aluminium industry

Casting and curing of the concrete specimens was done by sewage effluent after knowing its chemical composition. Properties of effluents were tested in SAI laboratory and the chemical composition of the effluents is shown in Table 3.7. The chemical composition of the sewage effluent was in the acceptable limit as per Indian codal guidelines. The density of the sewage effluent was approximately equal to the tap water.

3.2.4 Reinforcing Bar

HYSD steel bars of grade Fe-500 of 12 mm diameter were used. These reinforcing bars were used in corrosion test to evaluate the corrosion intensity of various mixes.

Table 3. 7 Properties of the effluents used in the research

Sr. No	Parameters	Unit	SE1	SE2	AI1	AI2
1	Zinc as Zn	mg/l	<0.05	0.05	<0.05	<0.05
2	Copper as Cu	mg/l	<0.05	0.05	<0.05	<0.05
3	Lead as Pb	mg/l	0.11	0.15	0.17	0.22
4	Cadmium as Cd	mg/l	<0.01	<0.01	<0.1	<0.1
5	Nickel as Ni	mg/l	<0.05	<0.05	<0.05	<0.05
6	Chromium as Cr	mg/l	<0.05	0.40	0.40	0.40
7	Titanium as Ti	mg/l	0.08	0.77	0.89	0.55
8	Magnesium as Mg	mg/l	30.3	26.3	4.77	6.62
9	Barium as Ba	mg/l	2.36	2.53	4.80	0.95
10	Aluminium as Al	mg/l	0.31	0.81	1.91	10.4
11	Sodium as Na	mg/l	106	140	147	197
12	Calcium as Ca	mg/l	47.7	24	13.2	106
13	Iron as Fe	mg/l	0.25	0.59	0.49	0.47
14	Manganese as Mn	mg/l	0.06	<0.05	<0.05	0.06
15	Sulfate(SO_4)	mg/l	86	NIL	419	472
16	Chloride Cl	mg/l	101	105	38	39
17	Nitrate NO_3	mg/l	2.06	2.73	25.4	36.6
18	Total solids	mg/l	1192	1596	1600	999.6
19	pH	-	8.4	8.3	7.6	8.2

3.3 MIX DESIGN

M30 grade of concrete mix was used and the mix was designed as per IS 10262-2009. W/C ratio of 0.48 was adopted and the proportion of cement: sand: aggregates comes to be 1: 1.62: 2.77. The coarse aggregates used in the matrix proportion were of two size i.e. 10 mm and 20 mm. The ratio of 10 mm coarse aggregate to 20 mm coarse aggregate used in the mix design was 60/40 (by weight). The mix proportions of the concrete used in this study are shown in Table 3.8

Table 3. 8 Concrete mix proportions

Material	Quantity (Kg/m^3)
Cement	410.4
Fine aggregates	665.5
Coarse aggregates (10 mm)	454.4
Coarse aggregates (20 mm)	681.6
Water	197

3.3.1 CASTING

Two types of samples were prepared- cubes and cylinders to test the effects of different effluents on the properties of concrete. Cubes of size 150mm were used to conduct tests like compressive strength test at different curing ages and initial surface absorption test at 28 days curing age. Cylinders of diameter 100mm and length 200 mm were used for testing split tensile strength, sorptivity and corrosion current density. Cylinders for corrosion test were embedded with reinforcement bar.

For casting purpose, firstly moulds were properly tightened so that water do not bleed out through the gaps in the moulds and after tightening of the moulds oiling was done so that smooth surfaces can be developed. All the ingredients were taken in required quantity according to the mix design as described in table 3.8. They were mixed in dry form. After dry mixing, water is added slowly along with continuous mixing and mixed for minimum 3 minutes. Different mixes were prepared by using the respective effluent keeping all other parameters (quantity of cement, fine aggregate and coarse aggregates) same. Then mix is poured in to the moulds with continuous compaction, which was done with the help of table vibrator, and top surface was made even by removing the extra material with plane rod. The moulds were placed undisturbed and they were demoulded after 24 hrs of casting. These samples were placed in curing tanks with their respective curing medium as shown in Figure 3.7.

Samples prepared for corrosion testing were embedded with steel reinforcement bar, which was placed at center of cylinder by giving 20mm cover at the bottom, and 50 mm bar was kept outside with drilled hole for corrosion testing purpose as shown in Figure 3.8.

Figure 3. 7 Unmolded cubes and curing of the samples in respective medium.

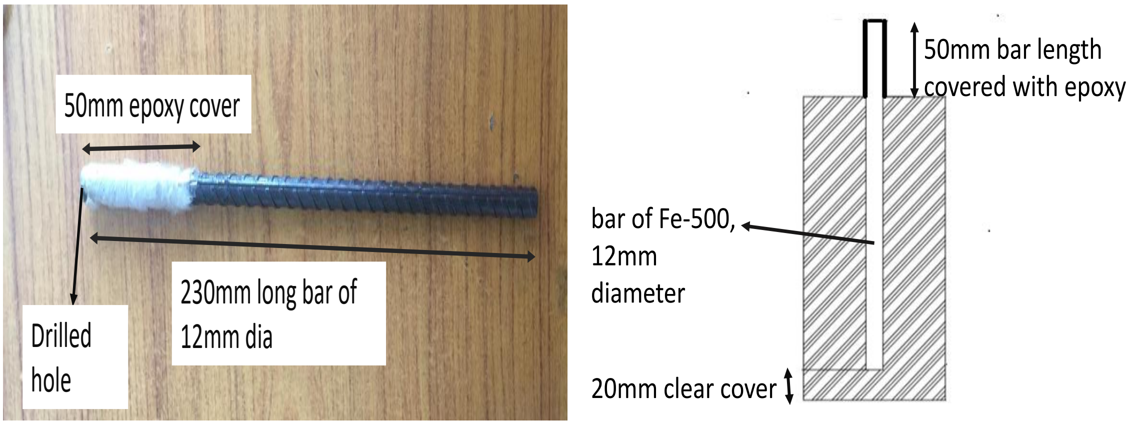

Figure 3. 8 Schematic view of reinforcement bar and cylindrical specimen embedded with bar

3.4 DESIGNATION OF MIXES

There were total five different mixes. Each mix varies from one other by the use of water keeping all other parameters (quantity of cement, aggregates) same. Samples were casted and cured using the same water. There were total five type of mixes and their naming is given in Table 3.9.

Table 3. 9 Designation of concrete mixes

Sr. no.	Description of mix	Designation
1.	Specimens casted & cured using tap water (control)	TW
2.	Specimens casted & cured using Thapar sewage effluent	S1
3.	Specimens casted & cured using Verka sewage effluent	S2
4.	Specimens casted & cured using Al industry water containing acid	A1
5.	Specimens casted & cured using Al industry water without acid	A2

3.5 TESTS

Various tests were performed to study the influence of different effluents on properties of cement and mix. Since, the quality of water affects the fresh properties of cement and concrete, so tests were conducted for both cement and concrete. Cement tests involved the fresh properties like consistency and setting time. The workability property of fresh concrete was tested with the use of slump cone. Various tests were conducted to study the mechanical properties of concrete like its strength in compression and strength in tension and durability properties like permeability, which was tested using ISAT (initial surface absorption test), sorptivity and corrosion current density. Micro structural properties were studied with the analysis of SEM and XRD results.

3.5.1 Tests on Cement

Fresh properties of cement like consistency and setting time were tested. These two properties greatly depend on the properties of water so it become necessary to test these properties as different effluents used for casting were having different composition, which can greatly effect these properties.

3.5.1.1 Consistency

The normal consistency of cement paste is that particular amount of water by weight% of cement which allows a Vicat plunger of 10mm diameter and 50mm length to penetrate up to depth of 32 to 36mm from the top (or 5 to 8mm from the bottom) of the mould. It was determined as per IS 4031: 1988 (part 4). Vicat Apparatus used in the study is shown in Figure 3.9.

3.5.1.2 Initial setting time

Initial setting time is found with the help of vicat apparatus fitted with square needle with 1 mm^2 cross section. Vicat Apparatus (shown in Figure 3.6) was used to found the time required for initial setting and time required for final setting as per IS 4031: 1988 (part 5).Square needle of cross section $1mm^2$ was attached to the vicat plunger .Test is completed when the penetration is 5 to 8 mm from the bottom

Figure 3.9 Different needle attachments of Vicat apparatus and Vicat apparatus fitted with consistency attachment

3.5.1.3 Final setting time

For final setting time, a needle with an annual collar of 5 mm diameter was attached to the plunger and was lowered gently to cover the surface of test block

3.5.2 Workability of Concrete (Slump Test)

Slump test is one of the easiest and popular test used method for determining workability of mix. Test was conducted as per IS 1199:1959 as shown in Figure 3.10. For conducting the test, slump cone of an internal diameter of the slump cone at top is 10cm and at bottom, it is 20 cm with the height of the slump cone 30 cm. The mould is placed on horizontal and rigid surface. Mould was then filled in 4 layers with 25 tempering to each layer. Mould was slowly raised in vertical direction and concrete is allowed to subside. The difference in levels between the height of the mould and that of the highest point of the subsided concrete was measured in mm and this was taken as slump value of the mix.

Figure 3. 10 Slump test apparatus

3.5.3 Hardened Properties of Concrete

Various hardened properties were tested for all the mixes and results were compared with that of the control concrete. Compressive strength is an important structural property of concrete that was tested at 3,7,28 and 90 days of curing age. Split tensile strength was also tested using the cylindrical specimens.

3.5.3.1 Compressive strength

One of the important property of concrete is its compressive strength. Compressive strength of the cubes was tested as per BIS 516:1959 using automatic compression test machine of capacity 3000 KN. Cubes were tested for strength in compression after curing of 3, 7 , 28 and 90 days. The load was increased at a rate 140 kg/cm^2/minutes (approximately) without any impact or shock. For all the mixes, 150mm cubes were casted and tested for strength in compression as shown in Figure 3.11.

3.5.3.2 Split tensile strength test

This test was performed on cylindrical specimens of 100mm diameter, 200mm length, after curing of 28 days, as per IS 5816:1999, by applying the load by automatic compressive machine. Samples were placed in lateral position and load was applied along the longitudinal axis as shown in figure 3.12. Peak load at which the cylinder splits into two parts is noted down and this is called split tensile load. Split tensile strength can be calculated by equation 3.1.

$$split\ tensile\ strength(MPa) = \frac{2P}{\Pi dl} \quad \text{....equation3.1}$$

Where P is the peak load in N

d is the diameter of the cylindrical specimen in mm

l is the length of the specimen in mm

Figure 3.11 Compression testing machine for cube testing

Figure 3.12 Split tensile strength test

3.5.4 Durability properties of concrete

Durability of concrete is very important characteristic that should be considered in the evaluation. Durability mainly depends on permeability of concrete. Water quality plays very significant role in defining the durability of concrete. Two tests were done to test the permeability i.e. ISAT (Initial Surface absorption Test) and sorptivity. Further, rebar corrosion test was carried out using LPR method.

3.5.4.1 Initial surface absorption test

An initial surface absorption test (ISAT) was performed to check permeability of the concrete samples. The initial surface absorption was determined as per recommendations given in BS 1881: part 208:1996. Test was performed on 15 cm cubes after curing of 28 days. Cubes were dried at 50 °C for 24 hours in oven. Set of the test is shown in Figure 3.13. Cube is placed on the stand and clams holding the permeability cap was tightened properly so that water does not oozes out of the permeable cap. Height of the reservoir was adjusted so that when it is filled, a head of 18 cm to 22 cm water is applied to top surface of the cube. Reservoir was connected to inlet of the permeability cap with the flexible tube, which has the valve fitted to it. Initially, valve was closed from the reservoir and reservoir was filled with water. After filling the reservoir, valve was opened and water start flowing from reservoir to the cap. The moment when valve was opened, start time was recorded. The head water in reservoir was maintained to 180 mm to 220 mm and reservoir was kept full all the time. Water start rising in the capillary tube and valve on the reservoir tube was closed after 10minutes, 30 minutes, 60minutes and 120 minutes intervals. The divisions moved by capillary water when valve was closed is noted down.

Results of the ISAT were expressed in (ml/m^2.s). The surface absorption rate goes on decreasing as the test proceeded. Because the pores present on the surface of concrete become filled with water and the moisture content of the concrete increases.

Figure 3. 13 Setup for ISAT test

Number of divisions moved by the water in capillary tube are noted as per given in Table 3.10. According to Table 3.10, if water moves less than three divisions in 5 seconds then reading is taken for 2 minutes and so on. Recorded divisions are calculated for per minute by multiplying the reading by suitable factor. Eg. No. of divisions should be multiplied by 0.5 if reading was taken for 2 minutes to convert the 2 minutes divisions in one minute divisions.

Table 3. 10 Time period for which reading is to be taken

Number of scale divisions moved in 5 sec	Period during which movement is measured
<3	2 min
3 to 9	1 min
10 to 30	30 s
>30	Record initial surface absorption as more than 3.60 ml/(m^{2}s)

3.5.4.2 Sorptivity

This test is used for determination of absorption rate (sorptivity) of water cement concrete by measuring the gain in the sample mass occurring due to absorption of water with respect to time when only one surface of specimen is exposed to water.

In this test method, Cylindrical samples of height 50mm and diameter 100mm were prepared by cutting the larger cylinder of 100mm diameter and 200mm height as shown in fig.3.10. These smaller samples were oven dried at temperature of 50°C. These smaller cylinders were coated with epoxy along the curved surface area and were covered with tape from the top surface so that water is get absorbed by uncovered bottom surface only.

Figure 3. 14 Samples prepared for sorptivity test

First of all initial mass of the samples was recorded before placing it in contact with water. After taking the initial mass reading samples were placed on the small cut pieces of eraser to avoid the direct contact of sample surface with the pan. Pan was filled with tap water so that the water level is 1 to 3 mm above the top of the support device and this water level was maintained throughout the test period. Time was noted from the instant the samples were placed in contact with water. The change in mass of the samples was recorded at 1, 5, 10, 20, 30, 60, 120, 180, 240, 300, 360 minutes, 1, 2, 3, 5, 6, 7 and 8 days. Set up for sorptivity is shown in figure 3.11

Volume of water absorbed by the specimen per unit cross section area of the specimen was calculated and a plot was drawn between the square root of time and volume of the water absorbed. The value of initial & secondary absorption was given by the slope of the best-fit line to initial and secondary curves, respectively. While the constant of the best fit, line equation gives the sorptivity coefficient. If the correlation coefficient (R) is less than 0.98 (linear relationship is not followed by the curve), then the water absorption rate cannot be determined.

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Figure 3. 15 Setup for sorptivity test

3.5.4.3 Corrosion

The term corrosion is used to indicate the conversion of metal by natural agencies into various compounds. Corrosion indicates the durability of the structure.

For corrosion testing LPR method was used. Cylindrical samples of 200mm height and 100mm diameter with a steel bar (Fe 500) of diameter 12 mm and length 230 mm was embedded in it out of which 180 mm length of the bar inside the cylinder and 50 mm bar was outside the concrete cylinder. The outer 50 mm length of the steel bar was covered with epoxy to protect that part of the bar from corrosion. Now only the 180 mm length of the steel bar was prone to corrosion. DC current was supplied to accelerate the corrosion. Cylindrical samples were covered with wire mesh to equally distribute the current to the curved surface area of sample as shown in figure 3.16.

Figure 3. 16 Samples for corrosion testing

After 28 days of curing, the corrosion of the reinforced bar was started by giving a constant anodic potential 0f 5V and a constant positive potential was applied to the reinforcement bar and the samples were kept immersed in NaCl solution of 3.5% throughout the test period. Tafel plot was noted daily to check the progress of corrosion since the corrosion is directly proportional to the current intercept. The positive end of the DC supply was connected to exposed reinforcing bar while negative terminal of DC supply was connected to the SS mesh as shown in Figure 3.17.

Figure 3.17 Setup for corrosion testing and corroded samples with cracks

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Wastewater effluents from different sources were collected and these were used for mixing and curing of matrix. Various tests were performed to check the potential of this effluent to be used in concrete. Testing was done to study the fresh properties of cement like setting time, consistency, fresh properties of concrete like slump value to check its workability, hardened properties of matrix like compression strength, split tensile strength and durability properties of matrix like initial surface absorption test, sorptivity and corrosion current density. Micro structural properties were also investigated by conducting SEM-EDS and XRD on the broken pieces collected after compression strength test. The test results and discussions based on the observations are presented in this chapter.

4.2 PROPERTIES OF EFFLUENTS

In this research, effluent was collected from four different sources and these effluents were used in concrete for the purpose of casting and curing. Each effluent was very different from each another, so their composition could also be different. It became necessary to test the effluents for their chemical composition. SE1 and SE2 were the effluents from sewage treatment plant while AI1 and AI2 were the effluents from aluminium industry. Effect of effluents on properties of concrete was tested. Chemical composition of effluents was tested in SAI laboratories and the results are presented in Table 4.1.

It was seen that solid content was maximum for the SE2 and AI1 and other chemical compositions were tested like concentration of zinc, copper, lead, manganese, cadmium, chromium, titanium, barium, aluminum, sodium, calcium, iron, sulfate (SO_4), nitrate (NO_3) and chloride content. All the heavy metals were within the permissible limits. pH off all the effluents was between 6 and 8.5 which was also satisfying the requirements given by IS 456:2000. According to Kosmataka et al., 2002 concentration of zinc, copper, manganese and lead should be less than 500 ppm and our effluents are satisfying this limit.

Solid content of all the effluents was with in the permissible limits in accordance with IS 456:2000 which states that solid content must be less than 2000 mg/l. Solid content of AI1 effluent which was obtained from the aluminium industry was maximum (1600mg/l) and this higher solid content can be due to the dissolution of the materials involved in the manufacturing process. There are some materials, which are non-soluble in water and increase the solid content of the water.

Chloride ions concentration is maximum for SE2 type effluent, which was obtained from the sewage treatment of food, based industry. Chloride ion concentration of SE1 effluent was also comparable to SE2. These two were the effluents of sewage treatment plant and chlorination process is the last process in these treatment plants. This huge concentration of chlorine in sewage effluents can be due to the residual chlorine of the chlorination process. Higher amount of chlorine content can promote the early strength of the concrete (Harthy et al., 2005)

Sulfate is very important factor to be taken care. Excessive amount of sulfate ion in the mixing water promotes the formation of calcium aluminosulfate (ettringite) during the hydration process of cement. Ettringites are responsible for volume increase and uneven crack patterns in concrete and ultimate loss in strength (Su et al., 2002). Sulfate content was observed maximum in the effluents of aliminium industry (AI1 and AI2) and this higher concentration of sulfate in these two effluents can affect the strength of these two concrete mixes with higher formation of ettringites

Table 4. 1 Concentration of different elements in effluents

Sr. No	Parameters	Unit	SE1	SE2	AI1	AI2
1	Zinc as Zn	mg/l	<0.05	0.05	<0.05	<0.05
2	Copper as Cu	mg/l	<0.05	0.05	<0.05	<0.05
3	Lead as Pb	mg/l	0.11	0.15	0.17	0.22
4	Cadmium as Cd	mg/l	<0.01	<0.01	<0.1	<0.1
5	Nickel as Ni	mg/l	<0.05	<0.05	<0.05	<0.05
6	Chromium as Cr	mg/l	<0.05	0.40	0.40	0.40
7	Titanium as Ti	mg/l	0.08	0.77	0.89	0.55
8	Magnesium as Mg	mg/l	30.3	26.3	4.77	6.62
9	Barium as Ba	mg/l	2.36	2.53	4.80	0.95
10	Aluminium as Al	mg/l	0.31	0.81	1.91	10.4
11	Sodium as Na	mg/l	106	140	147	197
12	Calcium as Ca	mg/l	47.7	24	13.2	106
13	Iron as Fe	mg/l	0.25	0.59	0.49	0.47
14	Manganese as Mn	mg/l	0.06	<0.05	<0.05	0.06
15	Sulfate(SO_4)	mg/l	86	NIL	419	472
16	Chloride Cl	mg/l	101	105	38	39
17	Nitrate NO_3	mg/l	2.06	2.73	25.4	36.6
18	Total solids	mg/l	1192	1596	1600	999.6
19	pH	-	8.4	8.3	7.6	8.2

4.2.1 Density of water

Density of water was checked by using the measuring cylinder, which was marked with volume markings with accuracy of 10ml and the results are shown in Table 4.2. It was concluded that density of various effluents collected from different sources was greater than that of the tap water. This can be due to the presence of solids in the waste effluents. It was also noticed that solid content was maximum for SE2 and AI1 effluents and density is maximum for these effluents.

Table 4. 2 Density of different waters

Type of water	Density (Kg/m^3)
TW	1000
SE1	1008
SE2	1009
AI1	1008.5
AI2	1004.5

4.3 FRESH PROPERTIES OF CEMENT

Fresh properties of cement like initial and final setting time were tested. The results are discussed in the following sections.

4.3.1 Setting time of cement

Initial setting time and final setting time were tested using Vicat apparatus as per IS 4031:1988 (part 5) and results are shown in Table 4.3.The initial & final setting time of the paste made by tap water was 150 and 385 minutes, respectively. The cement pastes prepared using different effluents were having setting time more than that of tap water cement paste. Setting time for SE2 type mix was maximum and the reason for this delay in setting time can be the solid content present in the mixing effluent, which retard the formation of calcium silicate hydrate (CSH) which is responsible for cement hydration.

Similar results regarding the effect of using wastewater from sewage effluent plant on setting time of cement were given by **Assadolahfardi et al. (2016). Noruzman et al. (2012)** also used the effluent discharge from heavy industry and observed an increase in setting when this effluent was used in concrete.

In addition, higher amount of zinc, sodium and copper can be the reason for this delay in setting as salts of zinc and copper act as retarder **(Lee et al. 2001).** SE2 effluent was having the maximum concentration of zinc and copper among all the effluents and this can be the reason for longest setting time of the SE2 type concrete. This increased setting can be also due to higher solid content of the effluents (**Assadolahfardi et al., 2016)** which was also maximum in case of SE2 effluent (1597 mg/l)**.** Similar to the effluents of sewage, aluminium industry effluents were also having higher concentration of solid content that cause the increase in setting of AI1 and AI2 effluent concretes**.** Setting time can also be delayed due to oils in the effluent as presence of oil hinders the hydration process which retard the formation of calcium silicate hydrate (**Jones1990).**

According to IS 456:2000, setting time for OPC should not be minimum 30 min and not greater than 10 hours. According to BS 3148 and BSEN 1008 (2002), the difference in initial setting time of the cement paste mixed using waste effluent and cement paste mixed with drinking water should be less than 30 minutes. BS 3148: 1980 states that setting time for Ordinary Portland cement should not be less than 75 min. All the mixes are following this permissible limit of setting time. All the mixes made with different effluents are satisfying the codal provisions for setting time. Apart from delayed hydration, the difference between initial and final setting time (**Δt)** has also shown increment by using the different effluents as shown in Figure 4.1. It further confers delay in the hydration process.

Table 4. 3 Initial and final setting time of various mixes

Type of water	Initial setting time	Final setting time	Δt
TW	150 min.	385 min.	235 min.
SE1	171 min.	415 min.	244 min.
SE2	190 min.	461 min.	271 min.
AI1	162min.	450min.	288 min.
AI2	165 min.	452min.	287 min.

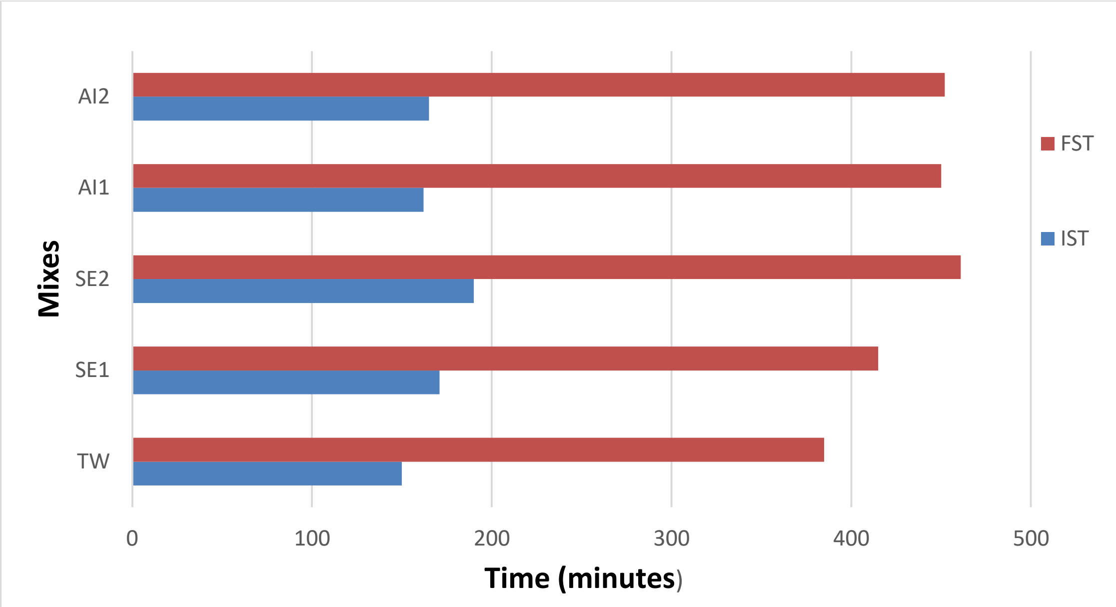

Figure 4.1 Comparison of initial and final setting time of mixes

4.3.2 Slump property of concrete

To check the workability of mixes, slump test was performed by using the cone as per IS 1199:1959. This test was done on a fresh concrete mix, which was prepared for the casting of samples using the different effluents. Test results are shown in Table 4.4 and comparison is represented in figure 4.2. Test results shows that slump value of all the effluents was less than that of the tap water mix. Slump value of all the effluents along with tap water was in range of 65-78mm except the SE2 mix whose slump was very less i.e. 50mm. Slump was less due to higher concentration of solid particles, which absorb the water, as a result less amount of water is available for lubrication of aggregates and mix becomes harsh. Slump value of AI1 mix was also lesser due to the higher concentration of solids in the effluent as compared to other effluents.

The results of slump test were in accordance with the results of **Noruzman et al., 2012** who also reported the decrease in slump with increasing solid content. Due to higher solid content, less water is available to the concrete. **Assadolahfardi et al., 2016 and Meena and Luhar., 2019** also reported decrease in workability with use of waste effluent in matrix. According to these authors, the decrease in workability when wastewater was used can de due to the higher solid content of the wastewater. According to **Meena and Luhar. 2019** sludge particles of the effluent are spongy in nature so they have higher water absorbing ability and result in decreased workability of concrete.

Table 4. 4 Slump values of various concrete mixes

Mixing agent for concrete mix	Slump value (mm)
TW	78
SE1	71
SE2	50
AI1	65
AI2	78

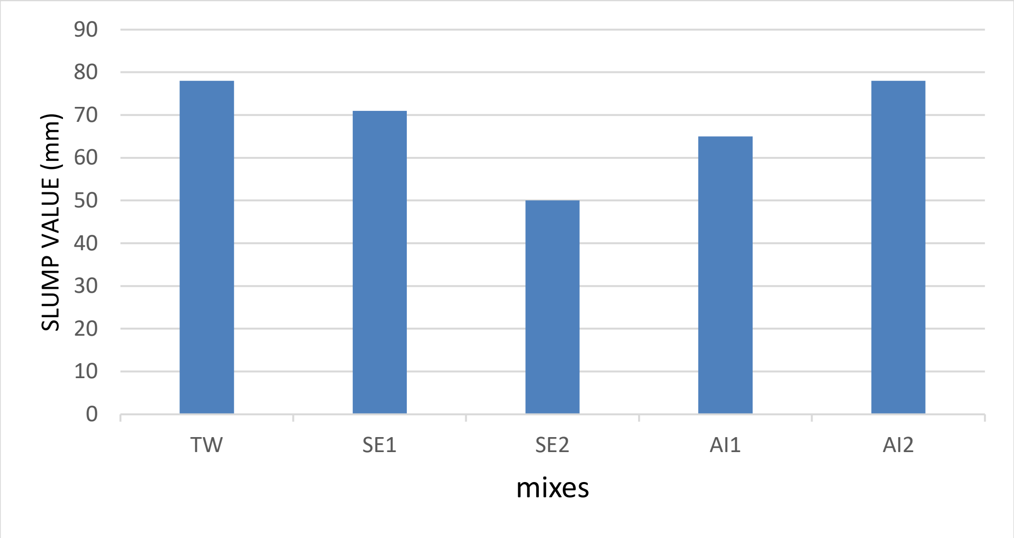

Figure 4. 2 Comparison of slump values of different concrete mixes

4.4 Hardened properties of concrete

Hardened properties like strength in compression and strength in tension were examined and results are shown in the following section. Compressive strength was test was performed on 15 cm cubes and tensile strength was tested on cylinders of 10 cm diameter and 20 cm height.

4.4.1 Compressive strength

Compressive strength test was carried out on 15 cm cubes after 3, 7, 28 and 90 days of curing. Test was done using automatic compressive load machine having load capacity of 3000KN at a loading rate of 140kg/s and the results are shown in Table 4.5. For all mixes, significant increase in strength was observed till age of 28 days but thereafter, the enhancement in compressive strength was negligible, as shown in Figure 4.3. It observed that the ultimate strength of SE1 and SE2 was very similar to each other as these were very similar types of effluents. Comparison of strength of different effluent concretes at same curing age is shown in Figure 4.4.

Table 4. 5 Compressive strength of different concrete mixes

Curing period (Days)	Compressive strength (MPa)				
	TW	**SE1**	**SE2**	**AI1**	**AI2**
3	19.8	14.2	17.5	17.7	16.08
7	25.2	21.87	22	21.5	19.6
28	35.8	25.53	24.37	22.5	25.2
90	36.5	26.2	25	23.36	26

It can be concluded that strength in compression for all the effluent concretes was lesser than that of the tap water mix. It clearly indicates that the quality of water effluent effects the structural properties of matrix. With the use of water rich in organic effluents or heavy metals, the compressive strength of matrix reduces. Similar observations regarding the decrease in strength of concrete with use of domestic sewage effluent and heavy industry effluent was reported by **Al-jabri et al., 2011.** According to **Meena and Luhar. 2019** strength is directly proportional to quality of mixing effluent in matrix. Decrease in strength was 28%, 13.21%, 28.6% and 28.29% for SE1 effluent concrete at the curing age of 3, 7,28 and 90 days respectively when compared to the test results of tap water samples. The decrease in strength was 11.6%, 12.69%, 31% and 31.5% for SE2 effluent at the curing age of 3, 7, 28 and 90 days respectively. It can be seen that decrease of SE1 and SE2 type concrete is very similar to each other as these are similar effluents up to some extent. Similarly the compressive strength of AI1 effluent decreases by 10.6%, 14.6%, 37% and 36% at 3, 7, 28 and 90 days respectively. For AI2 type mix, decrease is 15.15%, 22.22%, 29.6% and 28% for 3, 7, 28 and 90 days respectively. The lesser strength of effluent matrix can be due to the impurities present in these effluents as a duplex layer is formed between the cement paste & aggregates which results in the weak bond between the cement paste and the aggregate which results in decrease in strength of compression **(Meena and Luhar. 2019).**

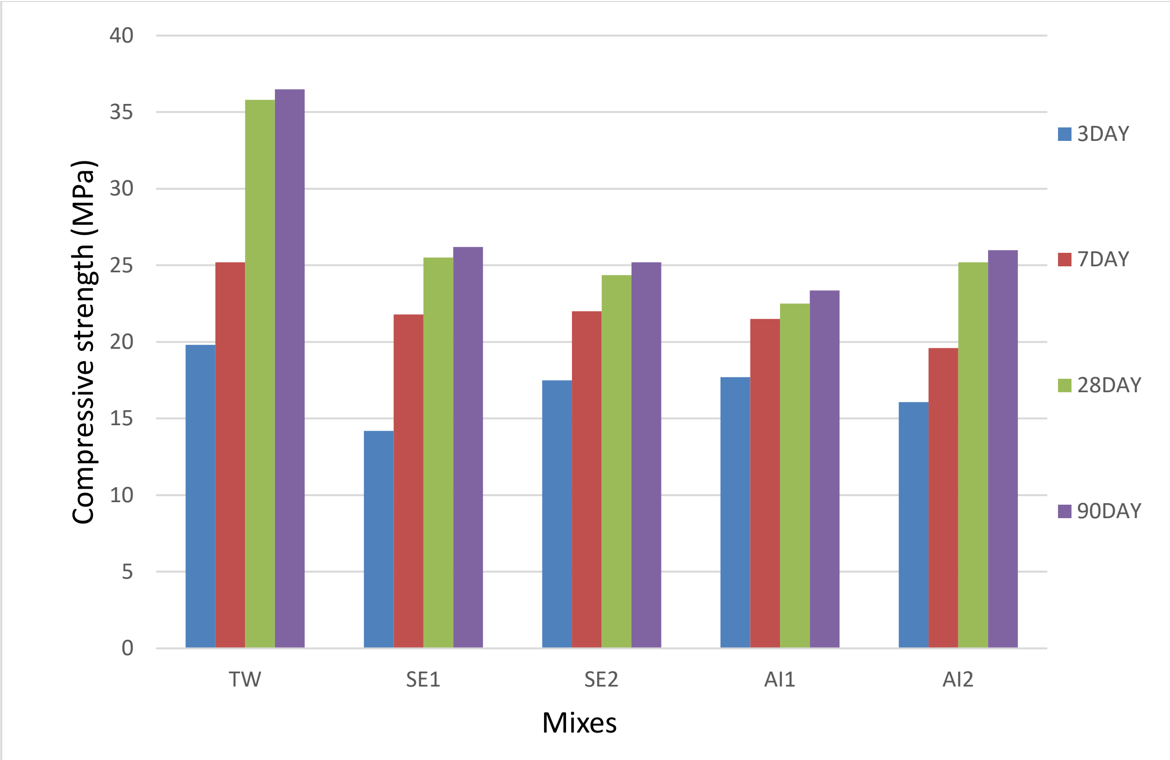

Figure 4. 3 Variation of compressive strength with respect to time

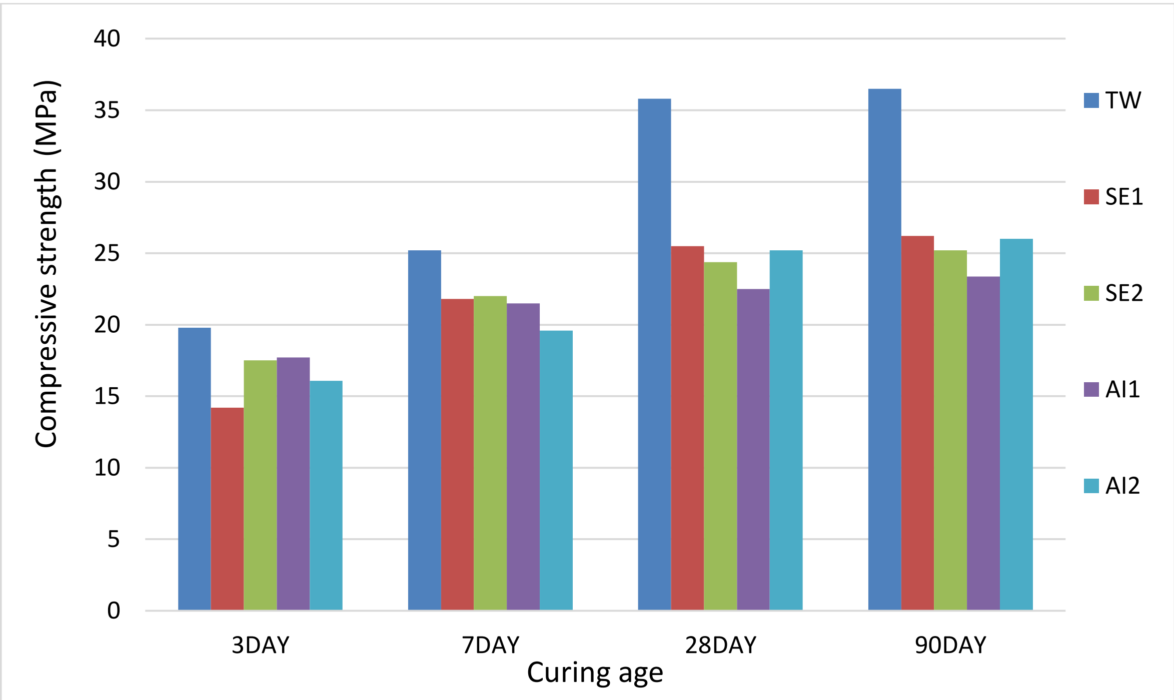

Figure 4. 4 Comparison of compressive strength of samples w.r.t curing age

The gain of early strength in all the effluent mixes was greater as compared to the ultimate strength and this higher early strength can be due to higher concentration of chloride salts of sodium and calcium. However, at the same time these salts results in lesser ultimate strength. SE1 effluent was having minimum amount of sodium concentration (106 mg/l) and the 3 day strength of the concrete made with this effluent is minimum so it can be stated that other three effluents with higher sodium concentration gain early age strength due to higher concentration of sodium in them. It was stated that chloride salt of calcium act as catalyst in the hydration reaction of C_3S and C_2S (**Lee et. al., (2001))** which results in higher early age strength. Chloride content was maximum in SE2 type effluent and this can be the reason for its enhanced early strength **(Harthy et al., 2005)** and due to the higher amount of solid content (**Noruzman et al., 2012)** because fine solids can fill the voids in the matrix. Noruzman et al. (2012) reported higher compressive strength for concrete mix made using heavy industry effluent due to higher solid content but this was not inferred in this research in case of AI1 effluent which was having the maximum solid content. This can be due to adverse effects of other impurities being dominating over the positive effect of solid content.

According to **BS 3148** and **BS EN 1008 (2002),** The average 28 days strength in compression of the concrete mixed with non-potable water should not be less than 90% of that of the drinking water concrete. According to **IS 456:2000** the compressive strength of the matrix should not be less that 85% of that of the concrete made using drinking water.

It shows that effluents cannot be used without any pretreatment if the codal guidelines are to be fulfilled. However, they can still be used if the mix design takes into consideration the loss in strength while mix proportion.

4.4.2 Split tensile strength

Split tensile strength test was conducted on cylindrical samples after 28 days curing. Results of the test are represented in Figure 4.5. It is observed that split tensile strength of the mixes is lesser in comparison with the split tensile strength of tap water mix but the decrease is not much considerable except that for the SE1 effluent concrete.

Assadolahfardi et al., (2016) also reported the decrease in tensile strength when waste effluent was used in the concrete production and curing. But at the same time increase in split tensile strength was reported by **Al-jabri et al. 2015**

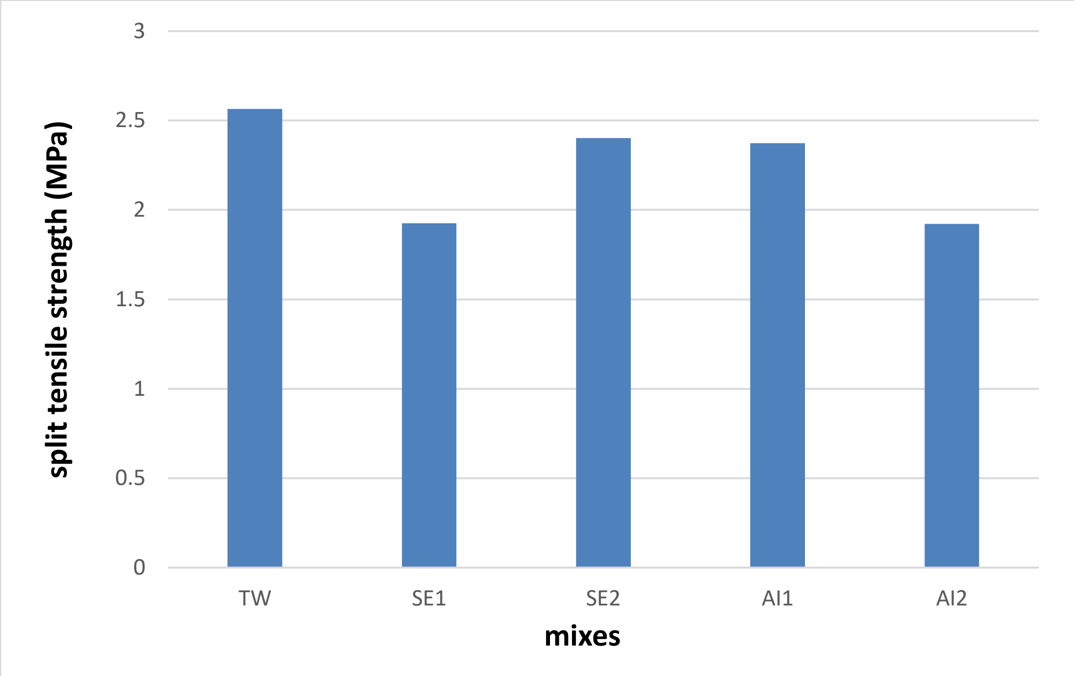

Figure 4.5 28 days split tensile strength

4.5 DURABILITY PROPERTIES

Quality of water used in matrix is very important from its durability point of view. Various test were conducted to check the durability properties of the mixes made with different effluents and the results were analyzed. Various tests conducted to evaluate durability were Initial Surface Absorption Test, Sorptivity test and corrosion current density. The observation of these tests are discussed in this section.

4.5.1 Initial Surface Absorption Test (ISAT)

An initial surface absorption test (ISAT) was conducted to check the permeability of the concrete samples. Test was performed on 28 days cured samples as per BS 1881 (Part 208)1996. The observations of the ISAT were conducted at 10, 30, 60 and 120 minutes and results of the ISAT were expressed in ml/m².s. as shown in Table 4.6 and comparison is shown in Figure 4.6 and 4.7.

Table 4. 6 Initial surface absorption test results of various mixes

	Flow (ml/m².s)				
Time	**TW**	**SE1**	**SE2**	**AI1**	**AI2**
10 min.	0.22	0.34	0.31	0.3	0.24
30 min.	0.1	0.15	0.145	0.095	0.12
1 hour	0.045	0.08	0.06	0.055	0.055
2 hour	0.022	0.05	0.03	0.04	0.035

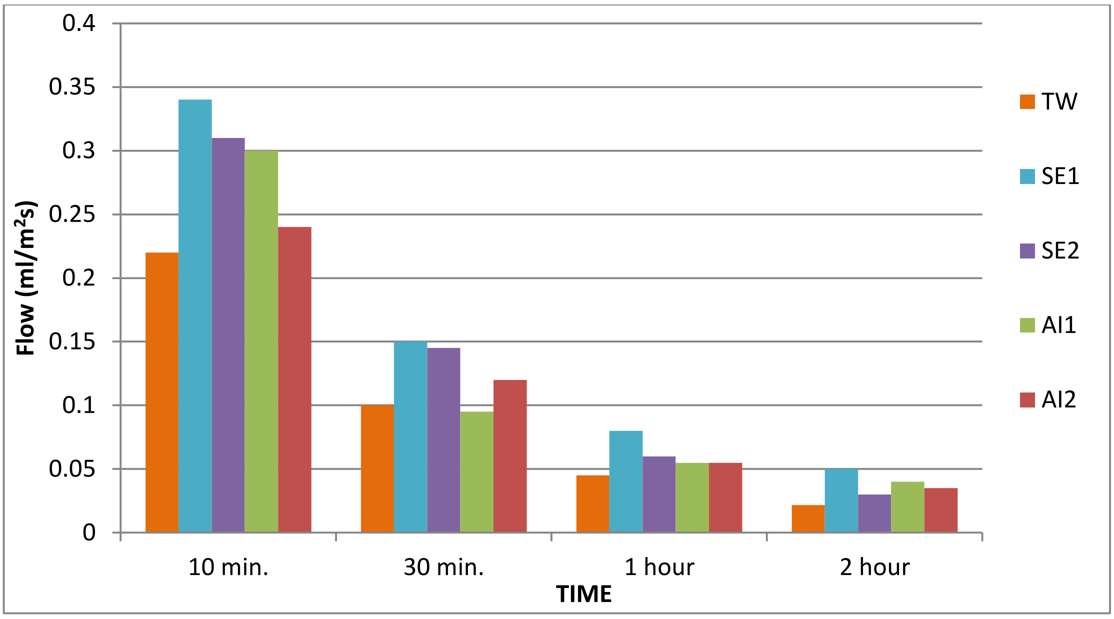

Figure 4. 6 Surface water absorption of concrete with time for different concrete mixes

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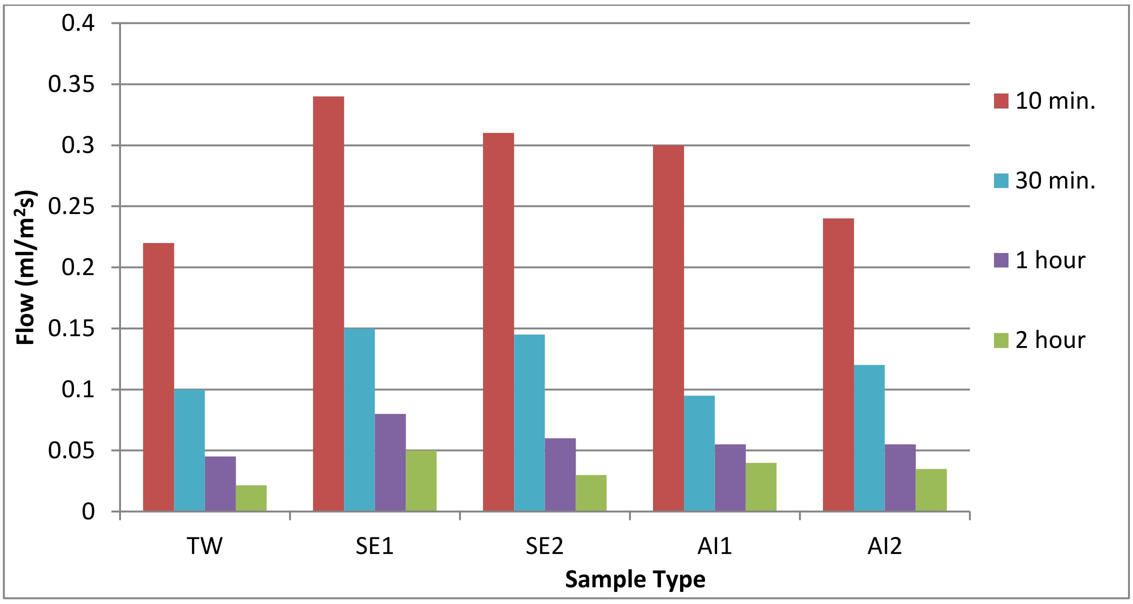

Figure 4. 7 Surface absorption of different mixes

The test results concluded that all mixes follow the same pattern of reduction of surface water absorption with time as observed by **Noruzman et al., 2012**. According to **Noruzman et al., 2012,** this decrease in permeability with time is due to hydration process, which reduce the porosity of concrete by blocking the pores or by narrowing the pores by formation of hydration products **(Bushlaibi and Alshamsi, 2002).** The flow values of specimens other than control sample are higher for all the intervals. This is because of the formation of unstable compounds over the surface of concrete specimens. These unstable compounds dissolve and pores are formed over the surface of concrete specimen. The flow value of all specimens made using waste effluent is greater as compared to the tap water samples as shown in Figure 4.6.

4.5.2 Sorptivity

This test was based on the absorption of water when only one surface of the specimen is allowed to absorb water due to the capillary rise between the pore systems of specimen. The change in mass of the specimen was recorded at 1, 5, 10, 20, 30, 60, 120, 180, 240, 300, 3600 minutes and 1, 2, 3, 5, 6, 7 and 8 days. A plot was drawn between the square root of time and volume of the water absorbed. The value of the initial absorption is given by slope of the curve upto 6 hours and secondary absorption was given by the slope of the best fit line from 6 hours onward respectively. While the constant of the best fit line equation gives the sorptivity coefficient. Results of the test conducted are shown in table 4.7 and the comparison is shown in figure 4.7.

It is observed from the graph that the absorption of effluent matrix is much more than that of the control mix. This can be due to the impurities present in the effluents that form the unstable compounds and these compounds vanishes with time leaving behind the pores. Due to these pores, more water get absorbed. Absorption is maximum for AI2 concrete and it is minimum for tap water sample and SE2 sample among the effluent mixes. This decreased sorptivity of SE2 concrete can be due to the higher solid content which occupy the pores of the structure or narrow the pores due to which less water is absorbed by the specimen as seen in AI1 concrete also.

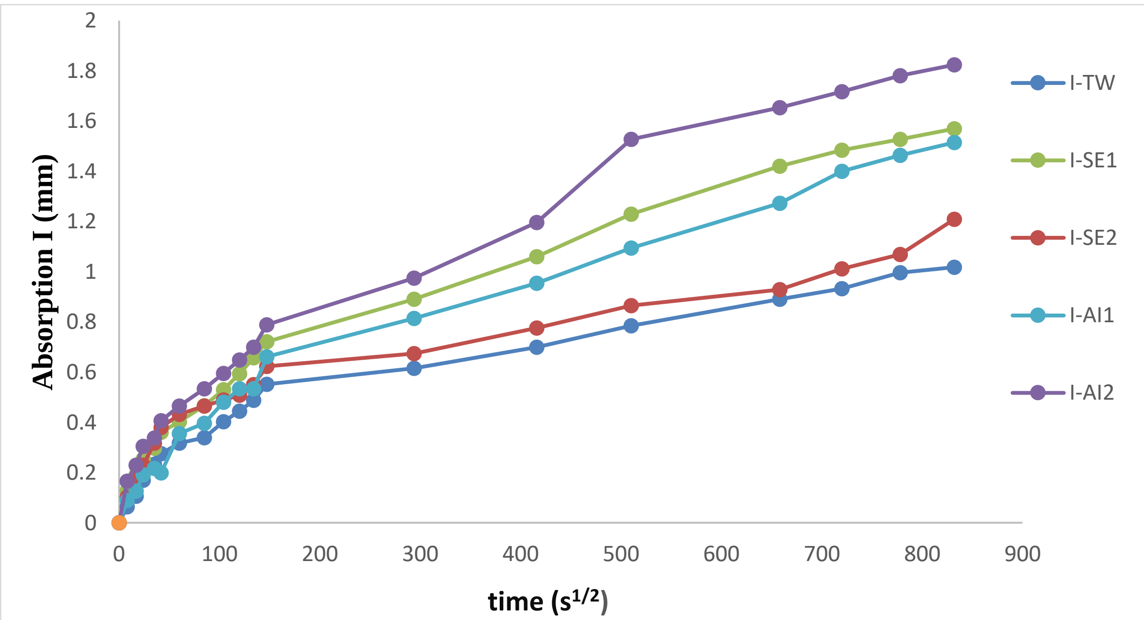

Figure 4. 8 Graphical representation of the sorptivity results

Table 4. 7 Sorptivity test results of concrete specimens treated with bacteria cured for 28 days

Sample Type	Final Absorption (mm)
TW	1.018
SE1	1.569
SE2	1.2
AI1	1.514
AI2	1.82

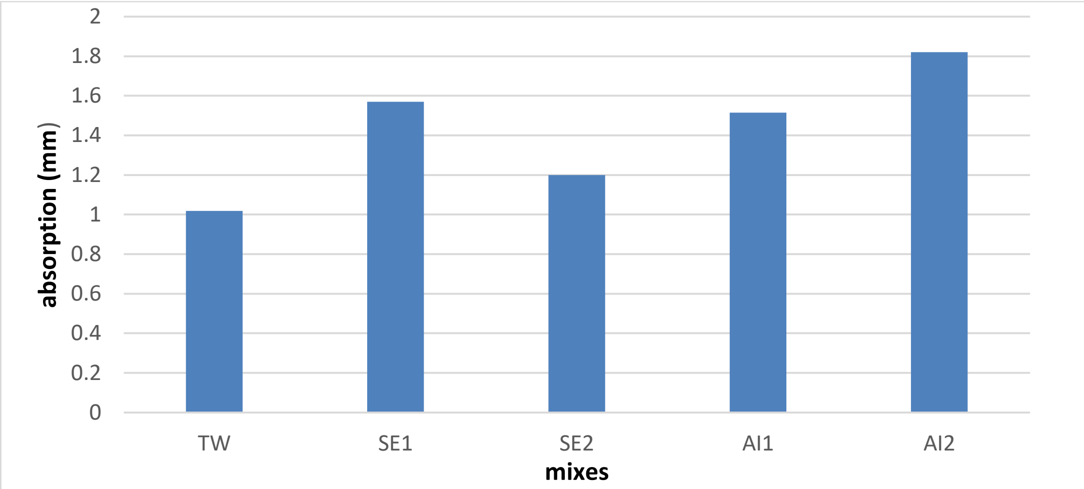

Figure 4. 9 Comparison of final absorption of various mixes

4.5.3 Corrosion Current Density

Corrosion test was performed on 28 days cured cylindrical samples using the LPR method. Reading were taken daily and the rest potential and I corr value were noted. Results are shown in Table 4.8 and tafel plot showing Icorr is represented in Figure 4.8. The corrosion is said to have occurred when the current value is greater than or equal to 0.1 microampere. It was observed that under uniform environment, tap water takes the longest period while the SE1 sample takes the minimum interval of time for corrosion. This can be due to high permeability and higher water absorption of the effluent samples that allow easy movement of ions from salt water to the reinforcement bar. From sorptivity test, it was observed that SE1 concrete was having higher value of absorption and due to this higher absorption, water easily ingress the concrete and lead to early corrosion of this sample. On the other hand, TW and SE2 samples were having permeability and the corrosion of these samples takes the longest time to occur.

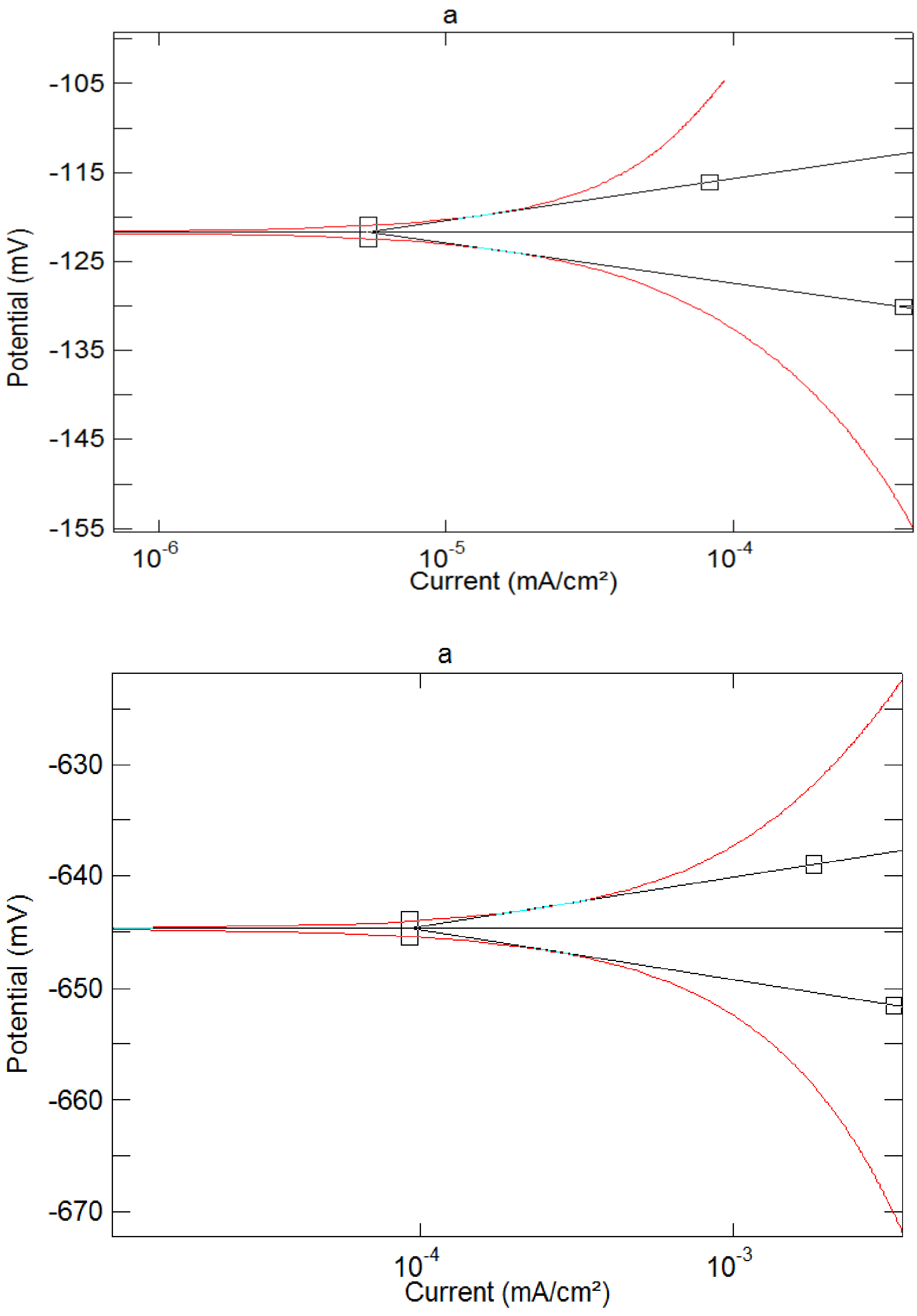

Figure 4. 10 Tafel plot of the initial (before DC supply) and the final (when corrosion occurs) corrosion current density of the AI2 specimen.

Table 4. 8 I_{corr} ($\mu A/cm^2$) values of the various specimens at various time intervals

Days	TW	SE1	SE2	AI1	AI2
0	0.00977	0.01017	0.00448	0.00452	0.00537
2	0.01455	0.04058	0.0637	0.053	0.077
4	0.02946	0.07649	0.0665	0.0715	0.0708
6	0.03701	0.1157	0.0539	0.055	0.0697
8	0.05022	-	0.0773	0.073	0.0729
10	0.06041	-	0.0629	0.0673	0.1165
12	0.07762	-	0.106	0.112	-
14	0.185	-	0.173	-	-

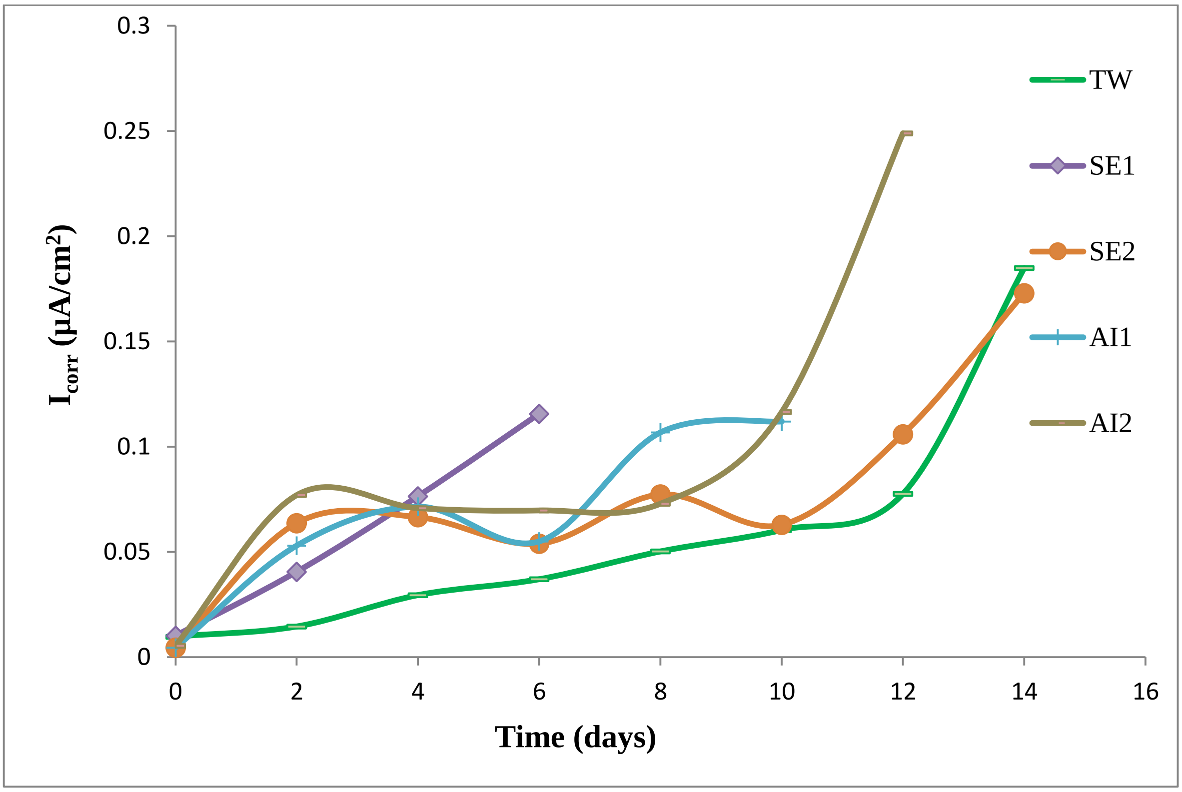

Figure 4. 11 Relationship between I_{corr} and time of various specimens at constant reinforcing bar voltage

Table 4. 9 Variation of rest potential (mv) with time

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Days	TW	SE1	SE2	AI1	AI2
0	-136.4	-126.4	-119.9	-99.6	-130.3
2	-212.2	-325.2	-321.4	-481.6	-388.1
4	-277.2	-433.7	-329.4	-487.2	-426.1
6	-333.4	-473.1	-385.7	-438.3	-474.7
8	-370.7	-	-444.9	-687.3	-522.1
10	-405.5	-	-425.8	-652	-416.4
12	-445.4	-	-696.2	-	-670
14	-485.7	-	-576.3	-	-

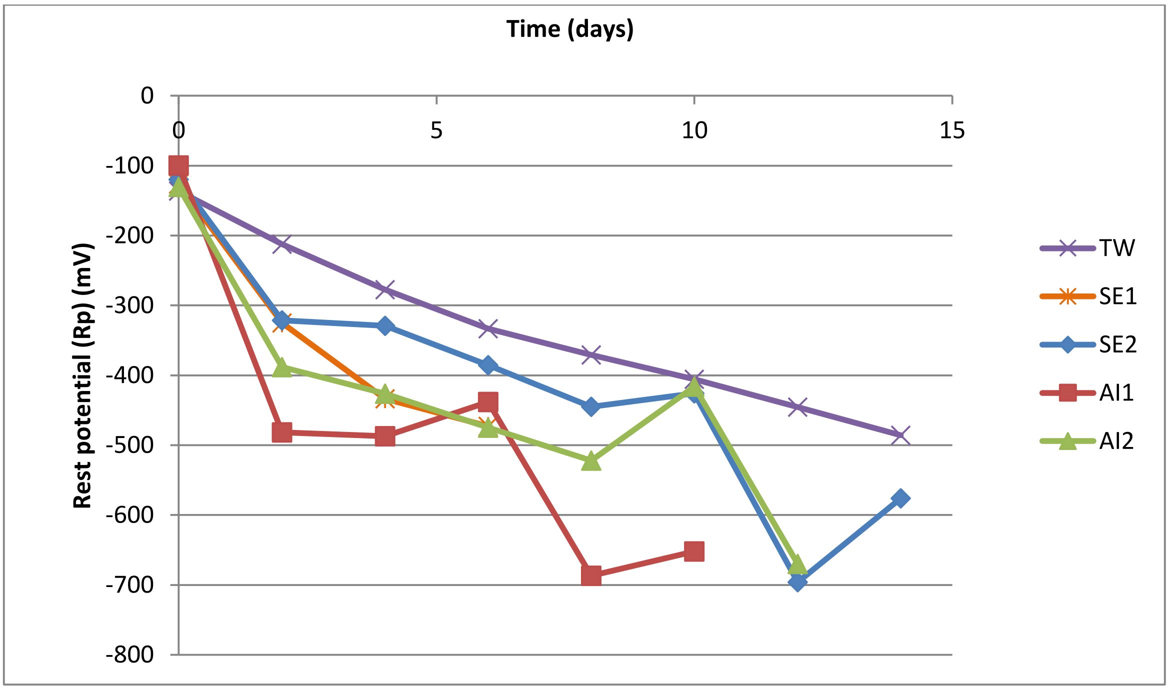

Figure 4. 12 Relationship between R_p (mV) and time interval (days) of various specimens at constant reinforcing bar voltage

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4.6 MICROSTRUCTURE ANALYSIS

4.6.1 SEM-EDS

For SEM-EDS analysis, a broken sample piece was selected from the specimen after 28 days of curing from each concrete matrix. Scanning electron microscopy (SEM) was used to analyze the compositional variation in the observed concrete specimen. The micro structural crystal's elemental composition and chemical characterization was determined by energy dispersive X-ray spectroscopy (EDS).

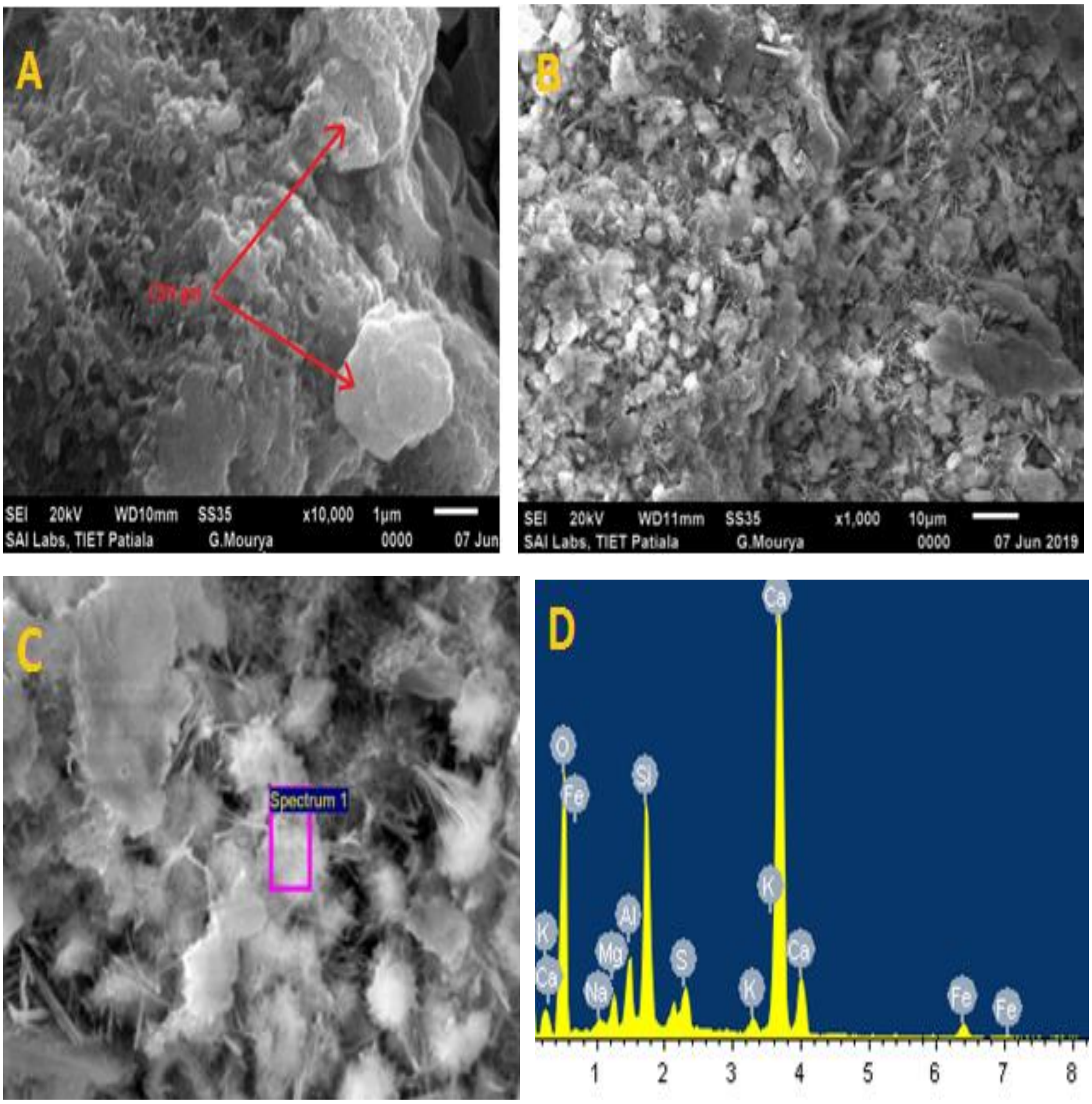


Figure 4. 13 SEM-EDS of TW specimen

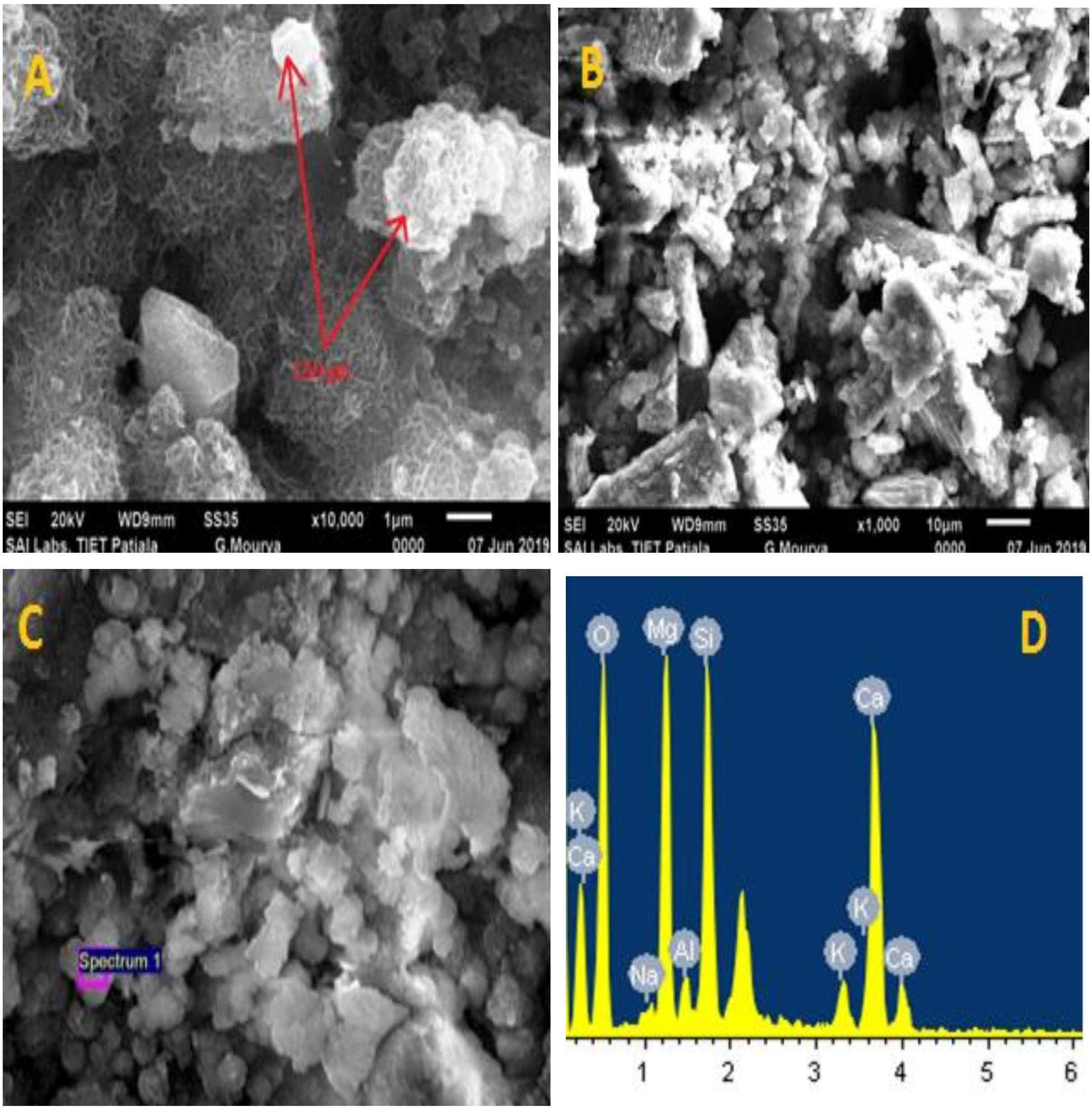
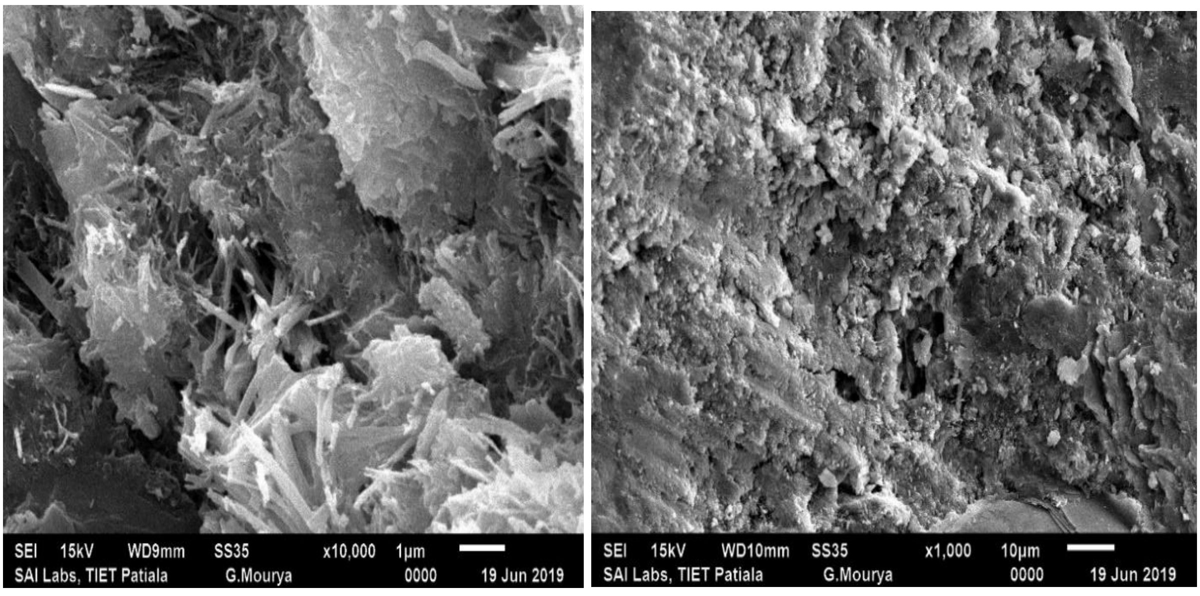


Figure 4. 14 SEM-EDS of S1 specimen



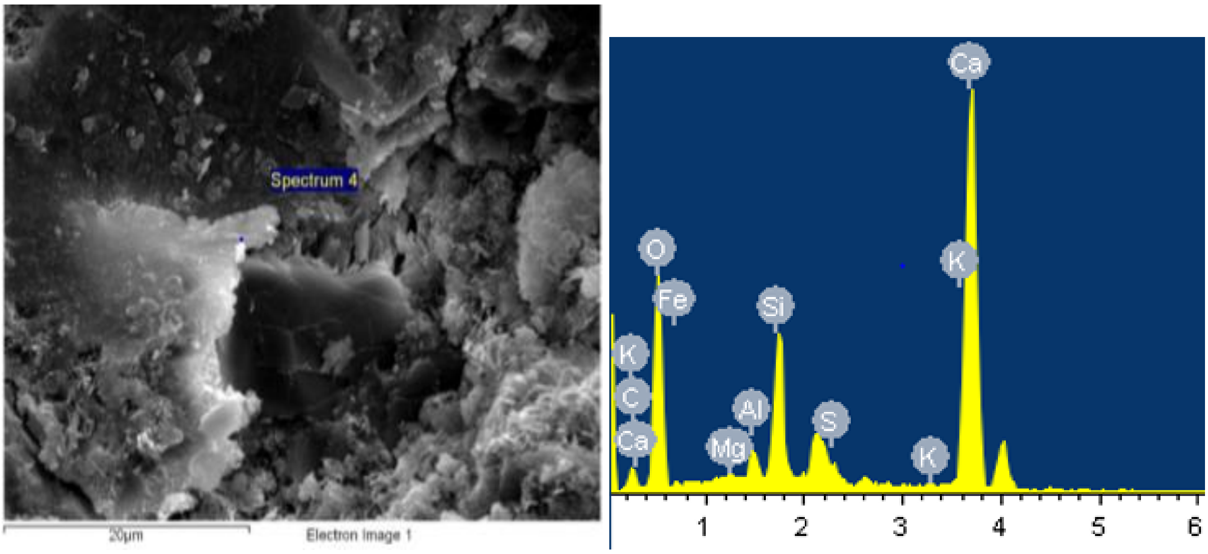


Figure 4. 15 SEM-EDS of SE2 specimen

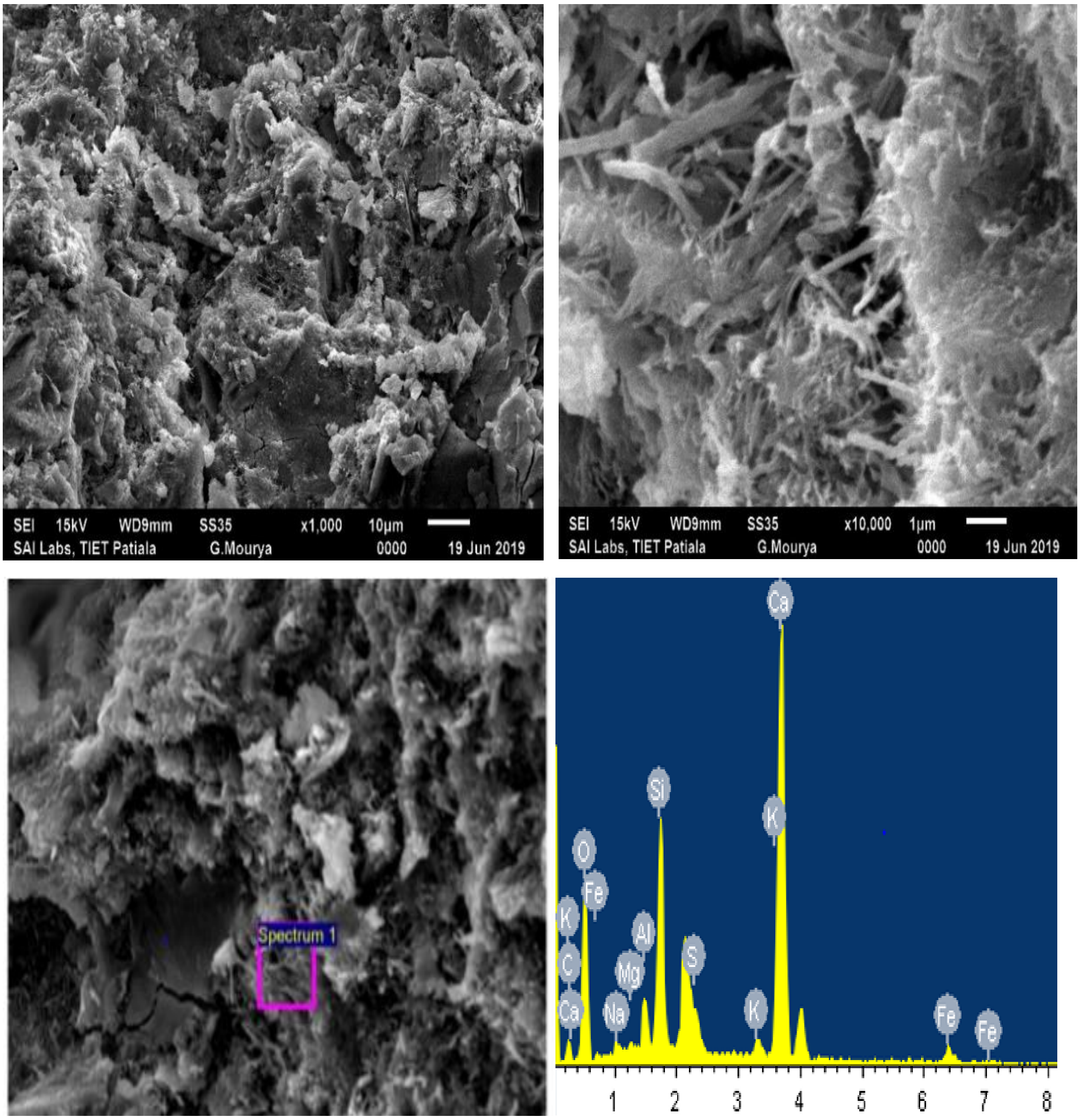


Figure 4. 16 SEM-EDS of AI1 specimen

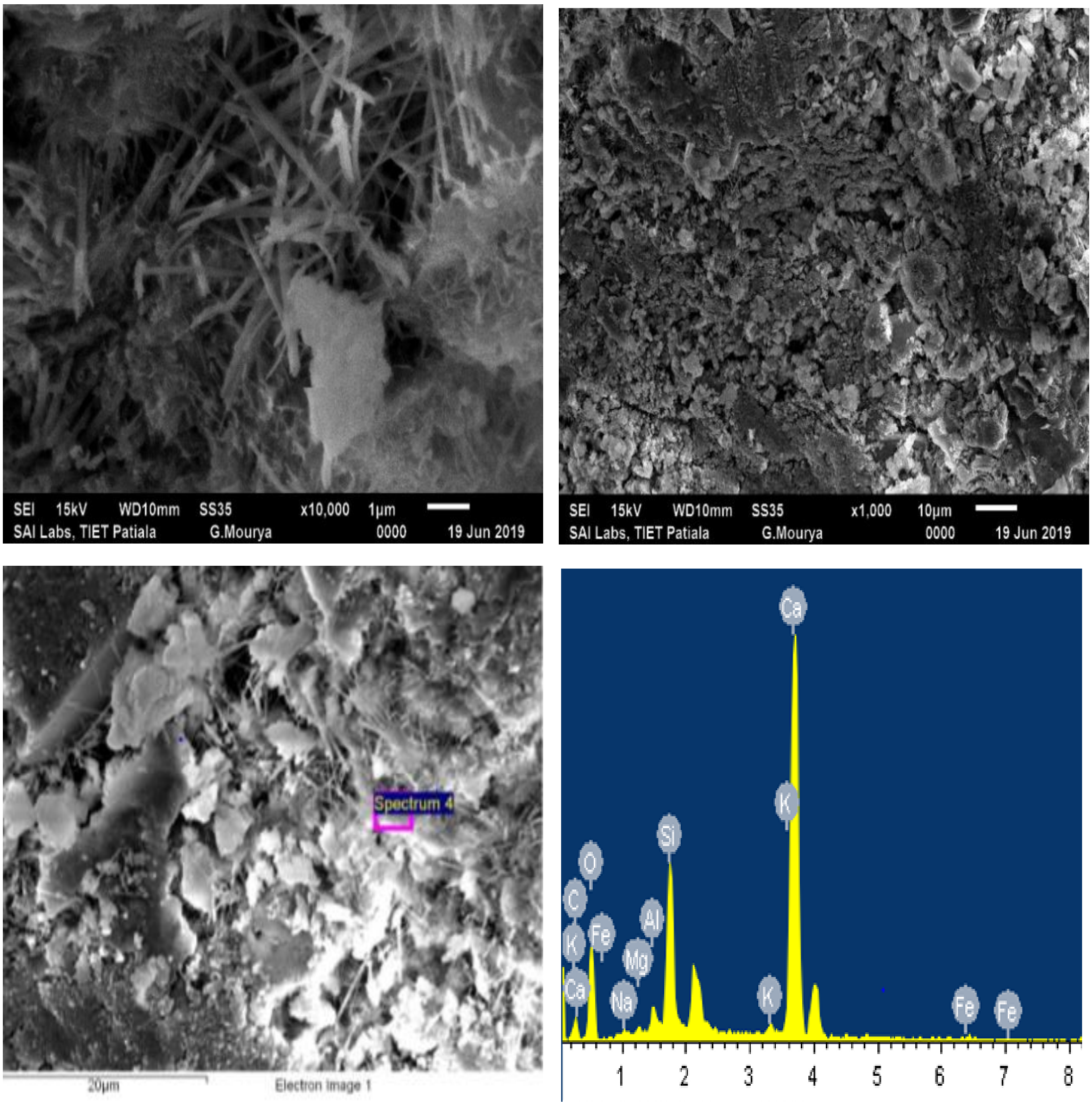


Figure 4. 17 SEM-EDS of AI2 specimen

Ettringite (sulfoaluminate) are formed during hydration process of cement and higher amount of sulfate result in higher formation of ettringites. Formation of ettringites cause significant increase in volume, which lead to uneven pattern of cracks loss in strength **(yilmaz et al., 1997; dhir and newlands, 1992; su et al., 2002).**

4.6.2 XRD

The orientation and structure of even single grain or crystal was determined by XRD. The shape and size of the crystal and internal stresses in the crystal can also be determined by the XRD. For the X-ray diffraction, the powdered concrete sample passing through 90μ was needed. Sample scanning was done at 10 degree to 80 degree to observe the XRD pattern. The peaks in the XRD pattern showed the presence of different elements in the matrix.

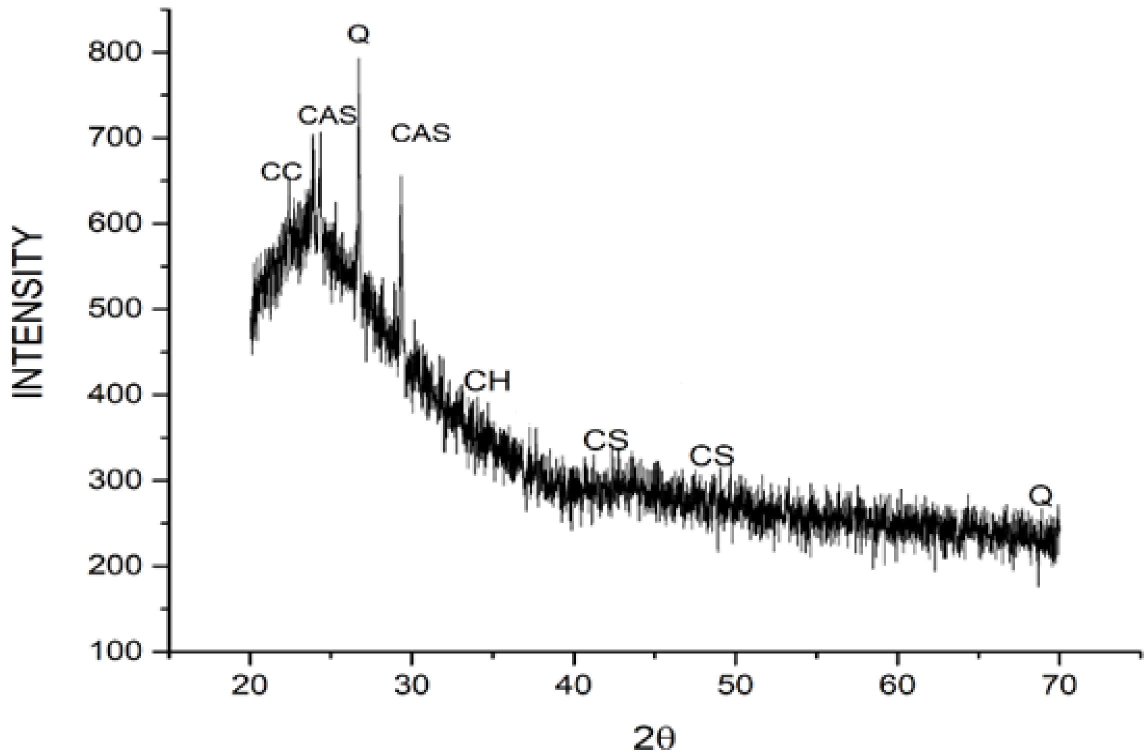


Figure 4. 18 XRD pattern for TW specimen where Q-Quartz, CC- Calcium Carbonate, CH- Calcium Hydroxide, C_2S- Calcium Di-silicate, C_3S- Calcium Trisilicate

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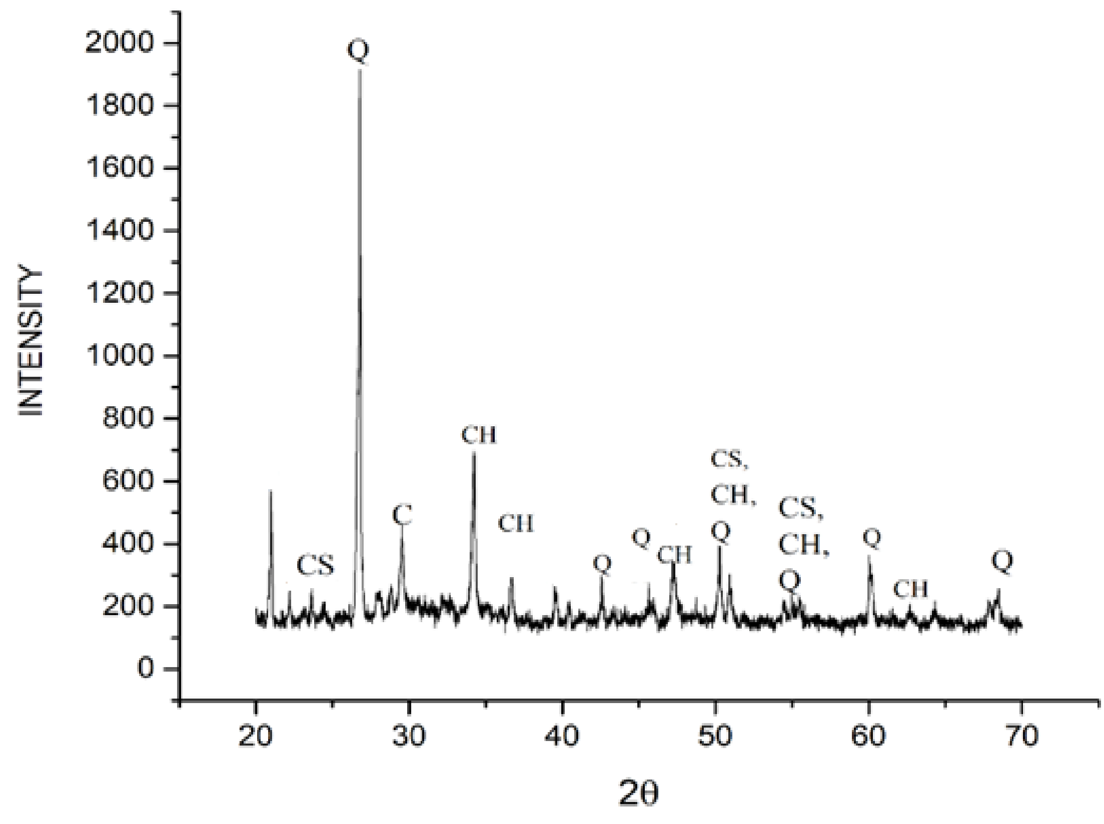

Figure 4. 19 XRD pattern for SE1 concrete where Q-Quartz, CC- Calcium Carbonate, CH- Calcium Hydroxide, C_2S- Calcium Di-silicate, C_3S- Calcium Trisilicate

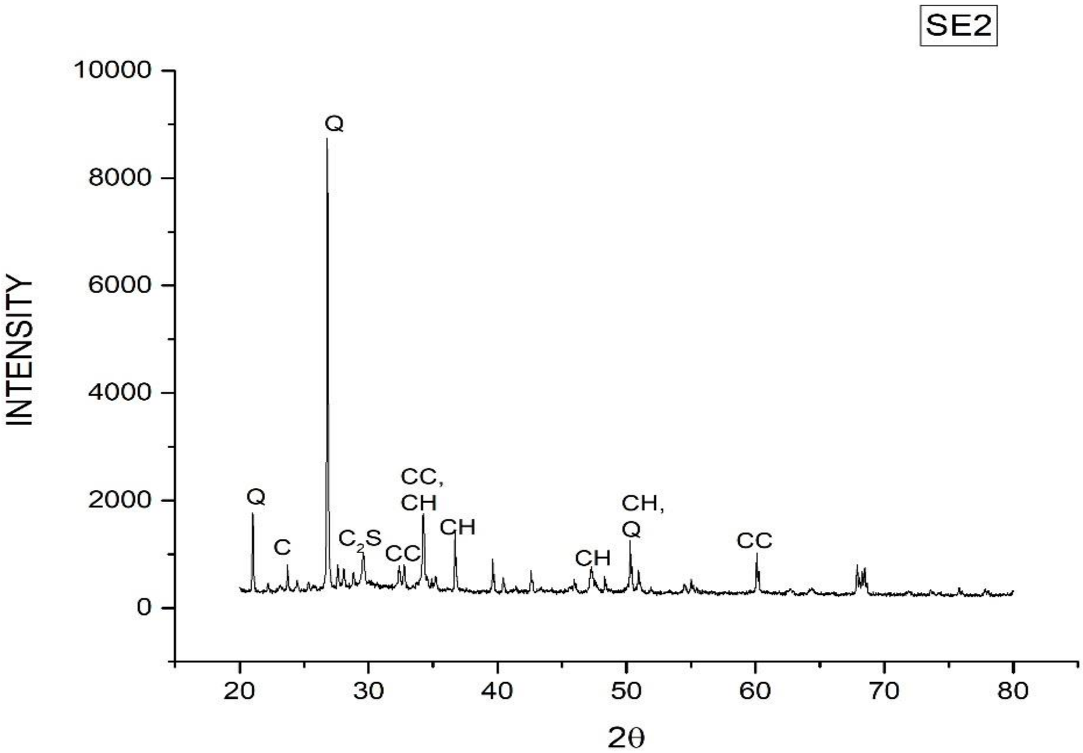

Figure 4. 20 XRD pattern for SE2 specimen where Q-Quartz, CC- Calcium Carbonate, CH- Calcium Hydroxide, C_2S- Calcium Di-silicate, C_3S- Calcium Trisilicate

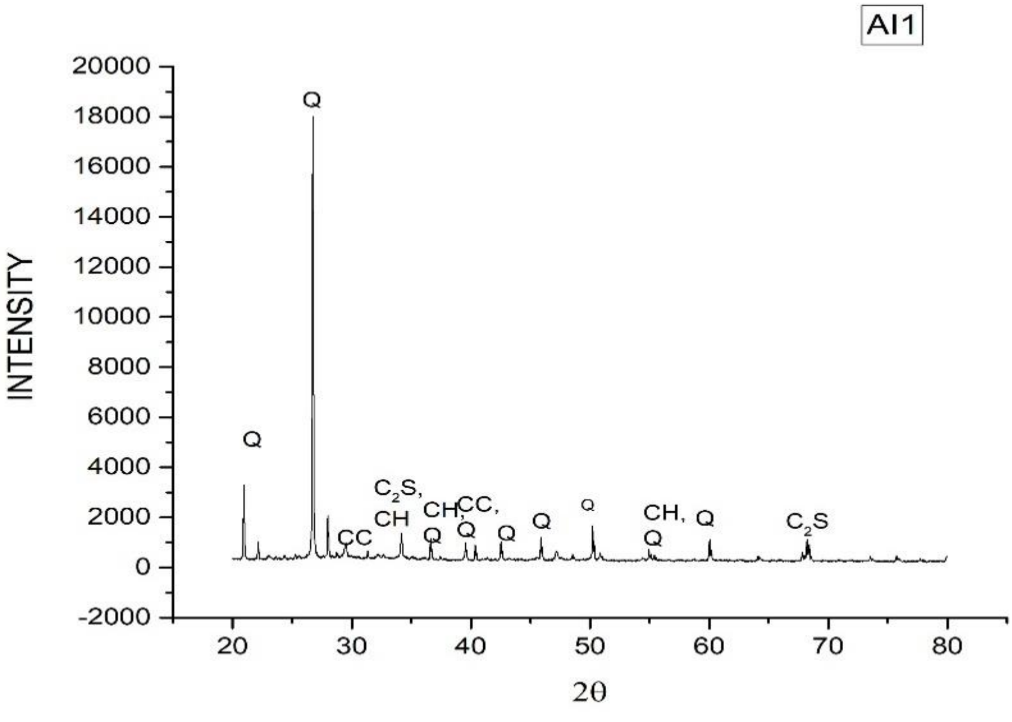

Figure 4. 21 XRD pattern for AI1 specimen where Q-Quartz, CC- Calcium Carbonate, CH- Calcium Hydroxide, C_2S- Calcium Di-silicate, C_3S- Calcium Trisilicate

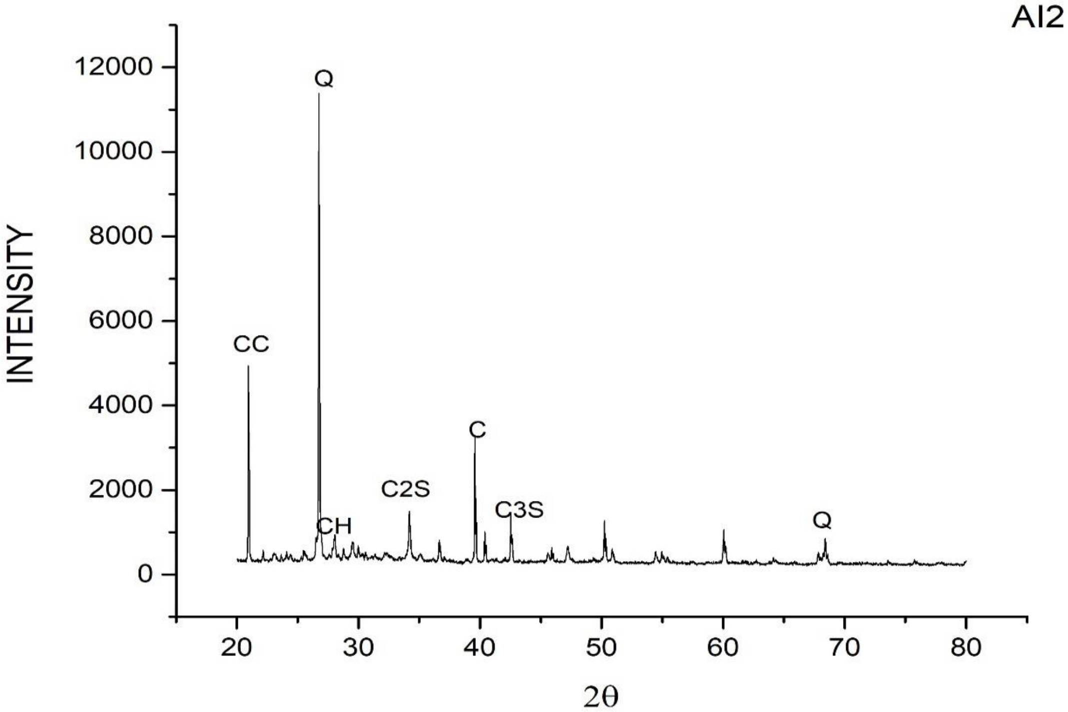

Figure 4. 22 XRD pattern for AI2 concrete sample where Q-Quartz, CC- Calcium Carbonate, CH- Calcium Hydroxide, C_2S- Calcium Di-silicate, C_3S- Calcium Trisilicate

CHAPTER 5

CONCLUSIONS

In this research, an attempt is made to check the potential of waste effluent to be used in mixing and curing of concrete, which can save huge amount of fresh water. Wastewater from four different sources was collected and was used for casting and curing of concrete. Two of the effluents were of sewage treatment plant and other two from aluminum industry. Various tests were performed like setting time. Workability, compressive strength, tensile strength, absorption and rebar corrosion on the resultant concrete and based on the tests performed, following conclusions are made.

Properties of all the effluents were within the permissible limits described by relevant Indian and British standard codes for water to be used in concrete.

1. Setting time increases for all the mixes when effluent water is used and this is because of the solid particles, which hinders the hydration process of cement especially in AI1 and SE2 effluent concretes. Setting of all the mixes was in the limits as per IS 456:2000 i.e. setting time of all the mixes was greater than 30 minutes and final setting time was less than 600 minutes. Workability of concrete using effluent was also effected by solid content, and was minimum for SE2 and AI1 type effluent concrete. It is due to higher solid content of effluents and these two effluents were having maximum solid contents.
2. Strength in compression for all waste effluent concretes was less than that of the concrete made by using tap water and the ultimate decrease in 28 days compressive strength for all the mixes was in range of 30% to 35%. The reduction in strength was minimum for SE1 and AI2 type effluent concrete. These effluents can be used in concrete by giving some other treatment before its use in concrete or we additional factor of safety should be taken during the design while using these effluents in concrete.
3. Permeability of all the effluent mixes was nearly same but greater than that of the tap water mix. Permeability was lesser for SE2 and AI2 concrete mix as compared to other mixes but was greater than that if the control mix with minor difference. This decreased permeability of this concrete was the consequence of higher solid content of the effluent, which fill the pores of the concrete. It indicates that the concrete made by SE2 and AI2 will have lesser penetration of aggressive ions in concrete. Therefore, this has better durability properties, which can also be observed from corrosion results.

4. Corrosion current density test shows that corrosion performance of SE2 and AI1 concretes are comparable to the tap water results means these have better resistance to corrosion due to lesser chloride content and lesser permeability and water absorption. However, SE1 effluent was having the poorest performance in terms of corrosion resistance.
5. From micro structural analysis it can be observed that voids and ettringnite formation is more for concrete specimens made with effluent water as compared to that of tap water specimen. However, the difference was not much.

- From this research, it can be concluded that effluents from aluminum industry shows better mechanical properties with lesser water absorption. Water absorption for SE1 concrete was greater that can affect durability of concrete, which is also seen from corrosion values of SE1 concrete. It shows necessity of pretreatment to remove the elements that are detrimental to concrete. In addition, by giving the required treatment to the element that is causing adverse effect, these effluents can be successfully used in the concrete production, which can lead save huge amount of water for our future generations.
- Scope of future work- waste effluents can be used in concrete with some pretreatments to reduce the detrimental effects of the harmful elements present in them and to enhance the mechanical and durability properties of the concrete produced using waste effluents.

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