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UTILIZATION OF WASTEWATER FOR PRODUCTION OF SUSTAINABLE CONCRETE

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Abstract

At present, 16 % of fresh water is being used in the construction industry. Freshwater is a finite and precious resource that is essential for sustaining life. This resource is becoming more and scarcer with increasing demand. Similarly, disposal of waste water is also a great threat for human health on environmental grounds. This research work is offering solution to these two global problems with the collaboration of concrete industry. Particularly, the analysis of the testing results on concrete cubes prepared by using Raw Waste Water and Primary Treated Waste Water shows encouraging results. A series of compressive strength tests was carried out on 324 concrete cubes as per British Standard. Test cubes were cast by using three types of water i.e., fresh tap water, primary treated waste water and municipal raw sewage. The qualitative analysis of three types of water was carried out in an environmental engineering laboratory. Research was spread over two types of cements i.e., Ordinary Portland Cement and Sulphate Resistant Portland Cement. Two mix. ratios (1:2:4 & 1:1.5:3) and three water/cement ratios (0.55, 0.60 & 0.65) were used in casting cubes. Curing was stopped at the age of 3, 7, and 28 days and compressive strength test carried out. Results are plotted and effect of using different types of water, cement, mix ratio, water/cement ratio and curing period, on compressive strength of concrete is discussed. Results thus obtained has satisfactorily proved that municipal waste water in its raw form or after getting some preliminary treatment can be effectively used in casting some special forms of concrete work.

Keywords
Wastewater, Raw Sewage, Sulphate Resisting Cement, Compressive Strength.

1. Introduction

Concrete is the major element of structural works in the construction industry, which not only provide structural strength, but also give safety, protection, multipurpose designing flexibilities and durability. At the moment, concrete can be said as the material which is being used more than any other man-made product (Gottfried, 1993). The concreting activities are water intensives, thus requiring huge amount of water during preparation and after lying. Presently, construction industry is using fresh water which is over taxing already scarce fresh water resources. Hence it would be suitable to use effluent discharge from houses and from treatment plants. Using wastewater can actually save around 16% of the total volume of fresh water being utilized in construction industry. In this way the valuable fresh water can be saved on one hand but also the waste water management may become easier (New York, 1997).

It should be noted here that building materials and construction operations consume 16% of the earth's fresh water every year. Increase in water utilization is causing lowering of water table in different regions. Building constructions and operations are water intensive activities, requiring huge volume of water. Although abundance of water is available in the oceans but it is too salty for housing, industrial and may be other types of constructions. According to available statistics, manufacturing of building materials and building construction consumes 16% of the earth's fresh water every year on the average of 7 liters of water/ft3 of concrete job (Salako *et al.*, 1988).

Water pollution and shortage of water are one of the gravest issues the world is dealing with. Usage of wastewater instead of fresh water wherever possible is an option available which will help in reduction of water shortage and pollution related to water too.

Considerable amount of research has been done in past using waste water. (Asadollahfardi *et al.*, 2016) investigated properties of high strength concrete by adding wastewater from three car wash stations. He concluded that wastewater from car wash stations is within limits defined by ASTM and can be used in concrete production. Authors tested the compressive strength of concrete produced and cured with use of treated wastewater and concluded that there was 5-10% reduction in both compressive and tensile strength of concrete prepared and cured using treated wastewater as compared to control samples. Similar sort of outcome was seen in research done by in study (Tay & Yip, 1987). He observed slight reduction in long-term strength parameters of concrete elements with use of treated wastewater.

In study (Al-Ghusain & Terro, 2003) authors also used wastewater in concrete mixing and checked the fresh and hardened properties of concrete in addition to checking corrosion potential of mixes. He found out that addition of wastewater had no effect on fresh properties, although compressive strength reduced and corrosion potential increased with deteriorating water.

2. Materials and Methods

Ordinary Portland cement (Fecto brand) conforming to ASTM C-150 Type I and Sulphate Resistant Portland Cement were used in the research. Sizes of ¾// and down from Margallah hills quarry site was used conforming to specifications for coarse aggregate (BSI, 1992). Sand from Lawrnespur quarry site was used as fine aggregate. As per classification results (Ursula *et al.*, 2000) it belonged to "Fine Grading" zone and its Fineness Modules was 2.65. Three types of water were used for mixing of concrete:

1. Municipal Raw Wastewater (MWW)
2. Municipal Primary Treated Wastewater (PTW)
3. Tap Water (TW)

The study was conducted in Wah/Taxila city, 50 KM from Islamabad, the capital of Pakistan, due to availability of various types of wastewater streams (both treated and un-treated) in sufficient quantities having different constituents and characteristics. This city is located between 72°-43´ and 72°-48´East of Greenwich, and between 33°-45´ and 33°-48´ North of equator. Wah grew in size as well as in its importance during the last four decades due to establishment of one of the biggest ordnance factories in Asia. Population of the city is estimated to 213000 persons. The sewerage system had been designed to carry domestic only, while the other wastes e.g., industrial, storm etc. is directed to separate drains. Treatment facility is provided to residential as well as factory areas. Sanitary waste water treatment plant is situated adjacent to Shah Wali Colony in the city, while each factory has its own separate treatment plant to treat the industrial waste water before getting it discharged into the natural drain named Dhamra Kas. Recently effluent from the sewerage treatment plant is being used for the agricultural purposes. There is no awareness for using this wastewater for mixing concrete. The only use of wastewater is for irrigating food crops. The waste water (treated and un-treated) that has been used for mixing of concrete in the research was purely municipal.

a) *First sample* of water was collected from the entrance point of Sewerage Treatment Plant (as shown in the Fig.s 1 & 2), where Municipal Waste Water is in its raw form.
b) *Second sample* was taken after completion of the following treatment works (Churched & Waris, 1999).

2.1 Screening

Municipal Waste Water was passed through the screen bars 1 square in. X-sectional area and fixed @ 1// c/c (fig. 3).

2.2 Grit Chamber

Then the waste water was directed to Grit Chamber (fig.4) and Vortex pump (fig.5) in order to remove pebbles, grit and sand from the waste water up to some extent. Grit tank also removed larger food particles (i.e., garbage etc).

Figure 1: Collection point of Sample # 1

Figure 2: Entrance point of Raw Sewage in Treatment Plant

Figure 3: Screening

Figure 4: Grit Tank

Figure 5: Vortex Pump

2.3 Primary Clarifier Tank

After removing grit, water was directed to the Primary Clarifier Tank (fig.6) $45^{/}$ in diameter where water flows slowly as per detention time, to allow organic suspended matter to settle down in the bottom or float on the surface for removal with the help of a skimmer that moves slowly (@ 1/45 rev/ minute. After getting primary treatment (Al-Jabri *et al.*, 2011), water was directed into Aeration Tank. However, samples were collected from water before entering into aeration tank (fig. 7).

c) *Third sample* of water that was used in the research mixing concrete was tap water fit for drinking and having no odor and taste.

The qualitative analysis (Alpha, 1975) of the three types of water was done in an environmental Engineering laboratory and results so obtained are given in Table 1.

Figure 6: Primary Clarifier

Figure 7: Sample Collections at Aeration Tank

Table 1: Chemical Analysis Results

Sr. No.	Parameter	T. W	P.T.W.	M.W. W
1	Conductivity (US/cm)	845	3075	5860
2	TDS (ppm)	676	1913	4943
3	Total hardness (ppm of CaCO3)	275	450	825
4	Ca hardness (ppm of Ca CO3)	175	200	200
5	Mg hardness (ppm of Ca CO3)	75	250	425
6	SiO2 (ppm)	20	35	55
7	Sulphates (ppm)	60	350	980
8	Chlorides (ppm)	80	425	840
9	COD (ppm)	12	18.8	30.1
10	BOD (ppm)	15	238	280

3. Sample Casting

An intensive research program was planned by casting and testing test cubes. Two types of cements i.e., 'Ordinary Portland Cement' and 'Sulphate Resisting Portland Cement", were used in the research. For each cement, two mix. ratios (1:2:4 & 1:1.5:3) were used. Each mix. ratio was cast by using three types of collected samples of water and for each sample of water three water cement ratios (0.55, 0.60 & 0.65) were used. In this way a total no of 324 cubes were cast conforming to BS: 12390: Part 3 (BSI, 2002). The detailed casting program is explained in the table 2 below:

Table 2: Casting Program

Cement Type	**Mix Ratio**	**Water Type**	**W/C Ratio**	**No. of Cubes Curing Period**		
				3 days	**7 days**	**28 days**
O.P.C	1:2:4	T.W.	0.55	3	3	3
O.P.C	1:2:4	T.W.	0.6	3	3	3
O.P.C	1:2:4	T.W.	0.65	3	3	3
O.P.C	1:2:4	M.W.W.	0.55	3	3	3
O.P.C	1:2:4	M.W.W.	0.6	3	3	3
O.P.C	1:2:4	M.W.W.	0.65	3	3	3
O.P.C	1:2:4	P.T.W.	0.55	3	3	3
O.P.C	1:2:4	P.T.W.	0.6	3	3	3
O.P.C	1:2:4	P.T.W.	0.65	3	3	3
O.P.C	1:1.5:3	T.W.	0.55	3	3	3
O.P.C	1:1.5:3	T.W.	0.6	3	3	3
O.P.C	1:1.5:3	T.W.	0.65	3	3	3
O.P.C	1:1.5:3	M.W.W.	0.55	3	3	3
O.P.C	1:1.5:3	M.W.W.	0.6	3	3	3
O.P.C	1:1.5:3	M.W.W.	0.65	3	3	3
O.P.C	1:1.5:3	P.T.W.	0.55	3	3	3
O.P.C	1:1.5:3	P.T.W.	0.6	3	3	3
O.P.C	1:1.5:3	P.T.W.	0.65	3	3	3
S,R..P.C	1:2:4	T.W.	0.55	3	3	3
S,R..P.C	1:2:4	T.W.	0.6	3	3	3
S,R..P.C	1:2:4	T.W.	0.65	3	3	3
S.R.P.C	1:2:4	M.W.W.	0.55	3	3	3
S.R.P.C	1:2:4	M.W.W.	0.6	3	3	3
S.R.P.C	1:2:4	M.W.W.	0.65	3	3	3
S.R.P.C	1:2:4	P.T.W.	0.55	3	3	3
S.R.P.C	1:2:4	P.T.W.	0.6	3	3	3
S.R.P.C	1:2:4	P.T.W.	0.65	3	3	3
S.R.P.C	1:1.5:3	T.W.	0.55	3	3	3
S.R.P.C	1:1.5:3	T.W.	0.6	3	3	3
S.R.P.C	1:1.5:3	T.W.	0.65	3	3	3
S.R.P.C	1:1.5:3	M.W.W.	0.55	3	3	3
S.R.P.C	1:1.5:3	M.W.W.	0.6	3	3	3
S.R.P.C	1:1.5:3	M.W.W.	0.65	3	3	3

S.R.P.C	1:1.5:3	P.T.W.	0.55	3	3	3
S.R.P.C	1:1.5:3	P.T.W.	0.6	3	3	3
S.R.P.C	1:1.5:3	P.T.W.	0.65	3	3	3
Total				**108**	**108**	**108**
Grand Total			**324**			

4. Sample Testing

A series of compressive strength tests was carried out for three different ages of 324 concrete cubes. In the compression test, the cube while still wet, was placed with the cast face in contact with the platens of testing machine. Then a constant rate of stress @ 30 to 60 psi/second was applied. Because of non-linearity of the stress strain relation of concrete at high stresses, the rate of increase in strain was increased progressively as failure approached as shown in fig 8.

Figure 8: Compression Test in Progress

5. Results And Discussions

5.1 Effect of Curing Period on Compressive Strength

5.1.1. Curing Period - 3 days

Sample cubes prepared with mixing all types of waters for 3 days curing period were used to determine the compressive strength. Results prove that concrete gains its strength with the passage of time. Compressive strength achieved after 3 days curing period is far less than the minimum requirement for Grade C20 concrete i.e. 2900 psi as defined in BS 5328: 1981. So concrete cannot be used for load bearing structures just after three days curing period. Hence these results indicate that curing periods should be increased. As far as the type of mixing water is concerned, the test results revealed that compressive strength for Raw Waste Water is minimum and compressive strength attained using Primary Treated Water is less than that for the Tap Water, when O.P.C. is used. This is so because of the presence of sulphate ions (980 ppm for R.W.W. and 350 ppm for P.T.W) and chloride ions (840 ppm for R.W.W. and 425 ppm for P.T.W.) in mixing water but for S.R.P.C. compressive strength achieved for both types of water i.e. P.T.W & R.W.W. is comparatively more because S.R.P.C. resist sulphate attack more efficiently due to its chemical composition as shown in fig 9 to fig 14.

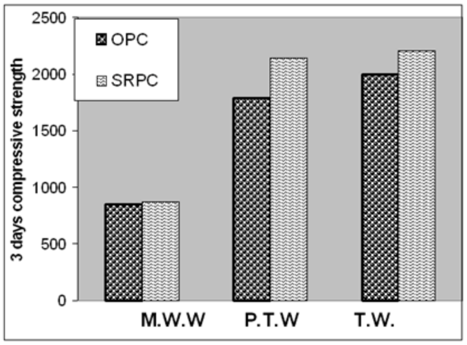

Figure 9: Mix Ratio 1:2:4, W/C Ratio 0.55

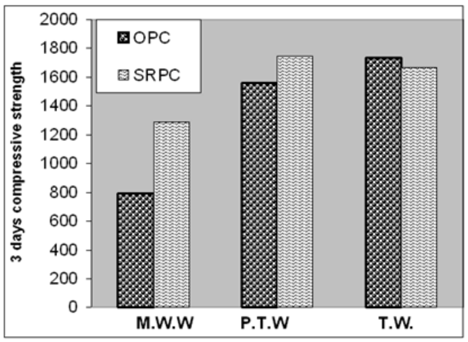

Figure 10: Mix Ratio 1:2:4, W/C Ratio 0.60

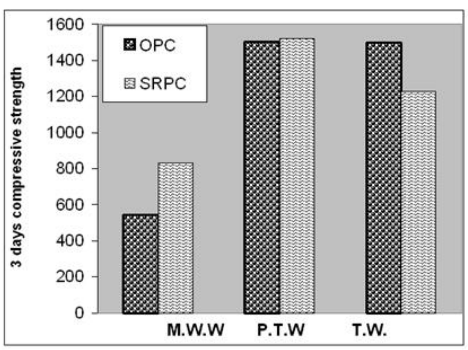

Figure 11: Mix Ratio 1:2:4, W/C Ratio 0.65

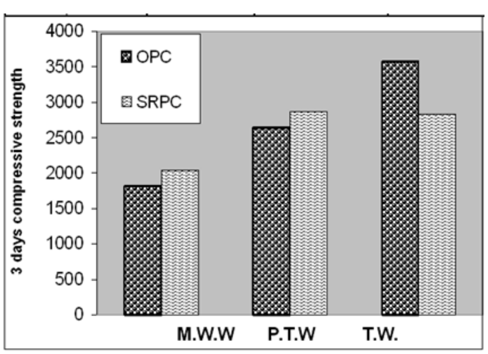

Figure 12: Mix Ratio 1:1.5:3, W/C Ratio 0.55

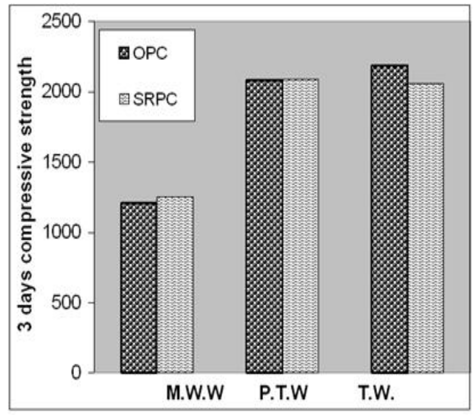

Figure 13: Mix Ratio 1:1.5:3, W/C Ratio 0.60

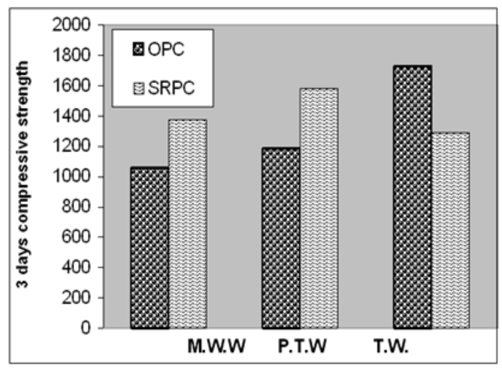

Figure 14: Mix Ratio 1:1.5:3, W/C Ratio 0.65

5.1.2. Curing Period - 7 days

Sample cubes prepared with mixing all types of waters for 7 days curing period were used to determine the compressive strength. Results show that compressive strength achieved after 7 days curing period is somewhat less than the minimum requirement for Grade C20 & C30 concrete i.e. 2900 psi for 1:2:4 mix. & 4200 psi for 1:1.5:3 mix. respectively as defined in BS 5328 : 1981. So concrete cannot be used for load bearing structures just after 7 days curing period. Such types of concrete can be used, for non-load bearing structures i.e. for lean concrete, construction of partition walls, etc. as shown in fig 15 to fig 20.

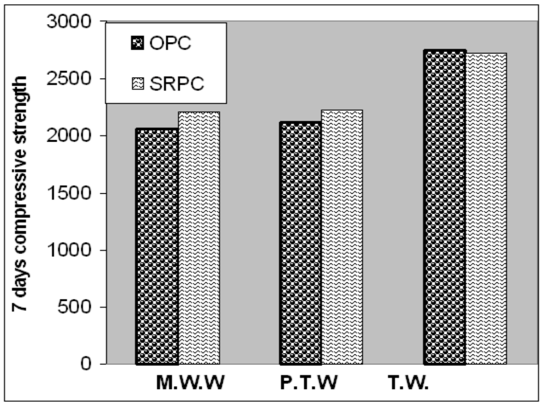

Figure 15: Mix Ratio 1:2:4, W/C Ratio 0.55

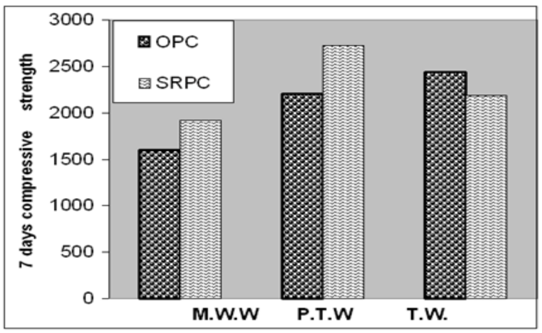

Figure 16: Mix Ratio 1:2:4, W/C Ratio 0.60

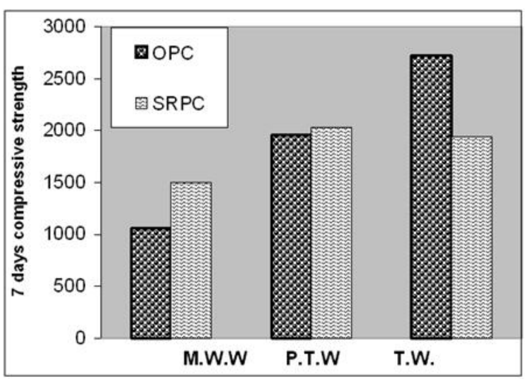

Figure 17: Mix Ratio 1:2:4, W/C Ratio 0.65

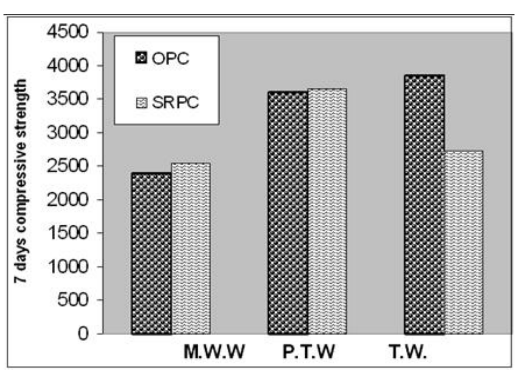

Figure 18: Mix Ratio 1:1.5:3, W/C Ratio 0.55

Fig

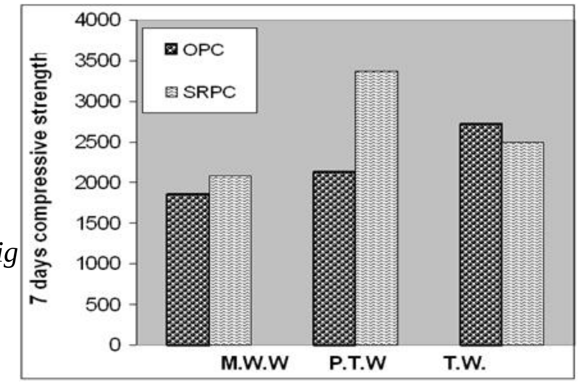

Figure 19: Mix Ratio 1:1.5:3, W/C Ratio 0.60

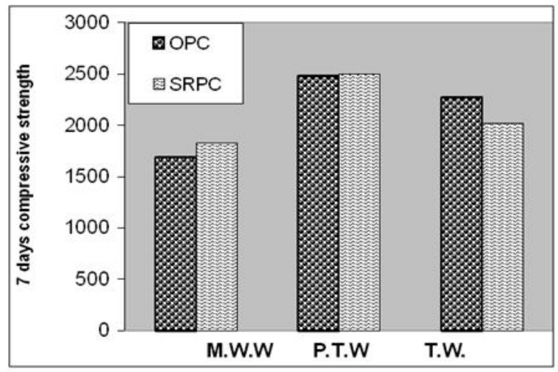

Figure 20: Mix Ratio 1:1.5:3, W/C Ratio 0.65

Sample cubes prepared with using all types of waters for 28 days curing period were used to determine the compressive strength. Results show that compressive strength achieved after 28 days curing period is more than sufficient for load bearing structures. As far as types of mixing water is concerned, the test results revealed that when O.P.C. is used, compressive strength for Raw Waste Water is the least while compressive strength attained using Primary Treated Water is somewhat greater but even less than that for the Tap Water. However, P.T.W. and R.W.W. fulfils the minimum requirement of compressive strength for Grade C20 concrete i.e. 2900 psi as defined in BS 5328: 1981. So it can be used for load bearing structures. In case of

Fig. 18 – Mix Ratio 1:1.5:3, W/C Ratio 0.55

S.R.P.C. compressive strength achieved with P.T.W and R.W.W. after 28 days curing period is somewhat higher than that with using O.P.C. because S.R.P.C. resists sulphate and chloride ions more efficiently due to its chemical composition as shown in fig 21 to fig 26.

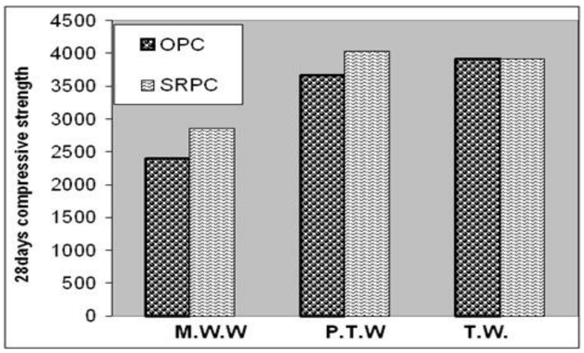

Figure 21: Mix Ratio 1:2:4, W/C Ratio 0.55

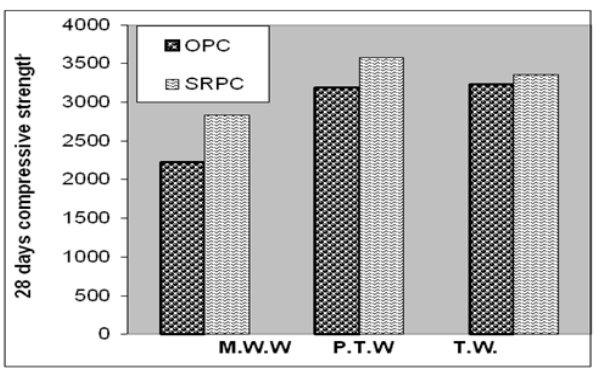

Figure 22: Mix Ratio 1:2:4, W/C Ratio 0.60

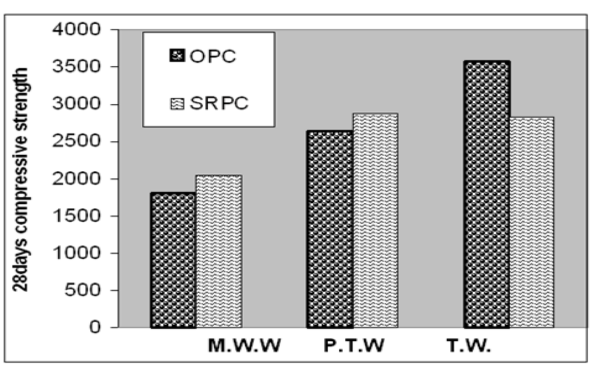

Figure 23: Mix Ratio 1:2:4, W/C Ratio 0.65

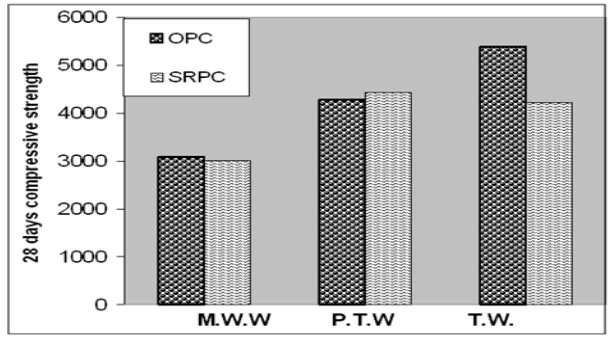

Figure 24: Mix Ratio 1:1.5:3, W/C Ratio 0.55

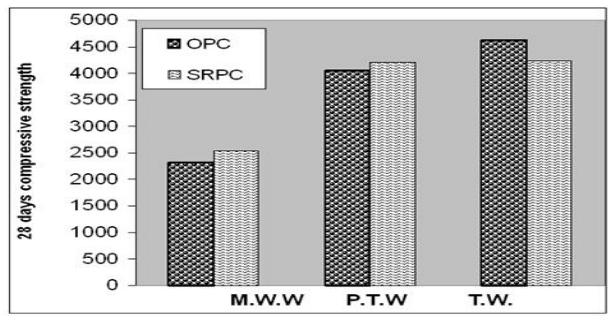

Figure 25: Mix Ratio 1:1.5:3, W/C Ratio 0.60

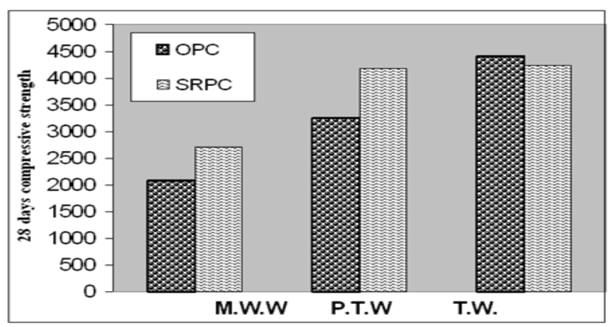

Figure 26: Mix Ratio 1:1.5:3, W/C Ratio 0.65

6. Summary

All the desired properties of concrete are studied by varying curing period. The compressive strength of concrete was, using different types of waste water for curing period of 3, 7 and 28 days. It was observed from test results (figures 9 to 26) that compressive strength of concrete is directly proportional to the increase in curing time.

6.1 Effect of Changing W/C Ratio on Compressive Strength

Cubes were cast using three types of W/C Ratios i.e. 0.55, 0.6, 0.65. It was observed that compressive strength decrease when W/C ratio increases from 0.55 to 0.65, provided other parameters are kept constant. This trend was observed for both types of cement, all types of water and both types of mix ratios. This is because when concrete is mixed, some water is utilized in the hydration of cement. When excess water present in concrete evaporates, cavities are left in the concrete. This is why compressive strength decreases with an increase in W/C ratio.

6.2 Effect of Changing Water Types on Compressive Strength

The analysis of the trial results on concrete cubes prepared by using different types of water i.e. Tap Water, Primary Treated Waste Water and Raw Waste Water shows that compressive strength of cubes cast by Raw Waste Water is the least and is greater for the Primary Treated Waste Water and Tap Water. Low values of compressive strength for Raw Waste Water are primarily due to the presence of chloride ions, sulphate ions and total dissolved solids. Chloride and sulphate ions attack on aggregates present in the concrete and hence reducing the strength of concrete. So Raw Waste Water shows the least strength as it has highest values of chloride 840 ppm, Sulphate 980 ppm and T.D.S 4943 ppm. But after primary treatment, the concentration of chloride ions is reduced to 425 ppm, whereas sulphates are reduced to 350 ppm and T.D.S. to 1913 ppm. Thus the concrete prepared by mixing P.T.W. shows more compressive strength as i.e. 3663 psi for 1:2:4 mix (Grade C 20 concrete) and 4289 psi for 1:1.5:3 mix (Grade C 30 concrete). Both values are greater than compressive strength defined in BS 5328:1981.

6.3 Effect of Changing Type of Cement on Compressive Strength

For Raw Waste Water and Primary Treated Water, S.R.P.C gives more strength as compare to O.P.C (As shown in fig. 9 to 26) The reason for this is that sulphate resistant cement has low C3A content and low C4AF content. Therefore, this cement resists the sulphate attack more efficiently while in case of O.P.C, sulphate ions present in Raw Waste Water (980 ppm) and Primary Treated Water (350 ppm) enters into chemical reaction with constituents of concrete, and produces sulphoaluminate hydrates which results into the reduced compressive strength as is obvious from our results. When tap water is used with these two cements, Ordinary Portland Cement shows better compressive strength as compare to S.R.P.C because silicate contents are higher in S.R.P.C as compare to O.P.C resulting in less compressive strength.

6.4 Effect of Concrete Mix. Ratio on Compressive Strength

Cubes were cast and tested for two mix ratios i.e. 1:1.5:3 and 1:2:4. The strength for mix ratio 1:1.5:3 was more than that for 1:2:4 for Tap Water. This is due to presence of more cement content in 1:1.5:3 as compared to 1:2:4 mix. Same trend was observed in case of Primary Treated Water and in Raw Waste Water. Maximum compressive strength for Primary Treated Waste Water using 1:2:4 mix. Is 3662 psi and for 1:1.5:3 mix is 4204 psi. 1:1.5:3 mix. Is rich in cement so it gives more strength to the concrete. Both values obtained by Primary Treated Water are more than sufficient for load bearing structures.

7. Rate Of Gain Of Strength

The rate of gain of strength of Water type, Mix ratios, Water to cement ratios and effect of cement type are shown in fig 27 to fig 38.

7.1 Effect of Water Type on Rate of Gain of Strength

Graphs drawn for the rate of gain of strength as shown in fig show that the concrete cast by mixing Raw Waste Water gains strength at uniform rate i.e. the curve obtained has constant slope. This is because of presence of total dissolved solids (4943 ppm). The rate of gain of strength in case of Primary Treated Water and Tap Water is almost same i.e., slope is steeper at start and afterwards turns to flat which is similar to previous research (Al-Jabri *et al.*, 2011). The water used in his research was similar to what tap water should have and can be used in concrete production without loss in strength of concrete.

7.2 Effect of Mix. Ratio on Rate of Gain of Strength

By changing mix ratio, the rate of gain of strength is no more changed in case of all types of waste water.

7.3 Effect of W/C Ratio on Rate of Gain of Strength

For MWW, the rate of gain of strength is not affected by changing W/C ratio. While in case of Primary Treated Water and Tap Water, as the W/C ratio increases rate of gain of strength also increase. Although 28 days compressive strength decreases as W/C ratio increases but reverse is true in case of rate of gain of strength. This is because that at higher water cement ratios, the concrete become more workable and the water present in the concrete readily evaporates thus concrete become hard and gains strength rapidly.

7.4 Effect of Cement Type on Rate of Gain of Strength

Change of cement type has no effect on the rate of gain of strength. Both cements show the same behavior as far as rate of gain of strength is concerned.

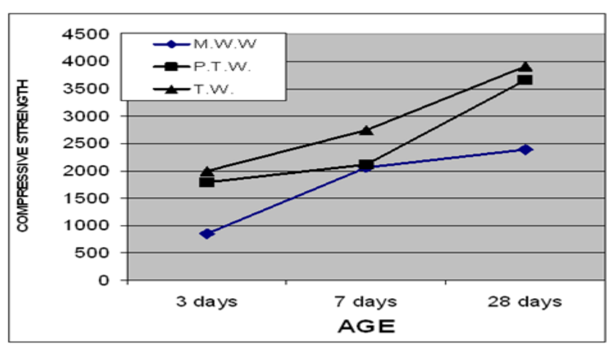

Figure 27: OPC - Mix Ratio 1:2:4, W/C Ratio 0.55

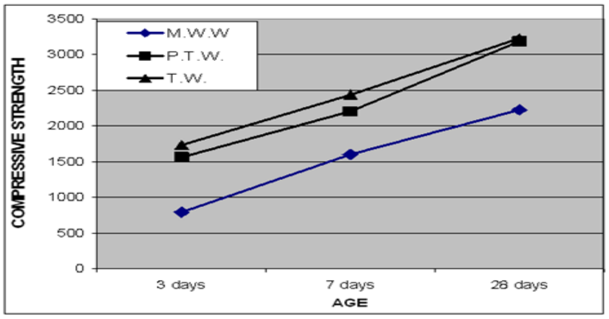

Figure 28: OPC - Mix Ratio 1:2:4, W/C Ratio 0.60

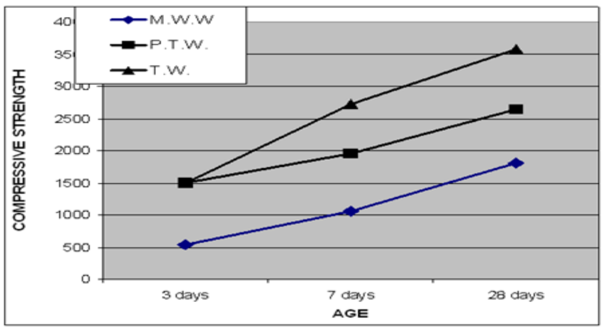

Figure 29: OPC - Mix Ratio 1:2:4, W/C Ratio 0.65

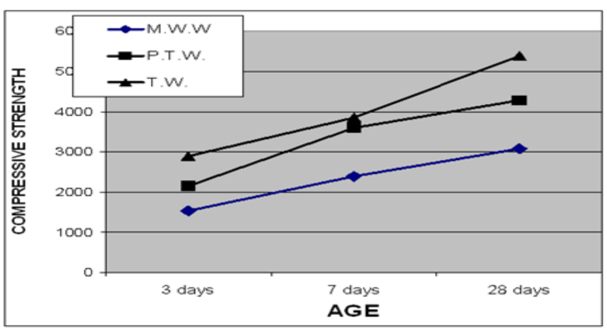

Figure 30: OPC - Mix Ratio 1:1.5:3, W/C Ratio 0.55

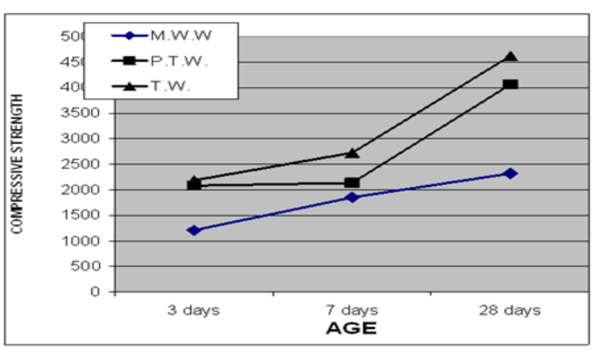

Figure 31: OPC - Mix Ratio 1:1.5:3, W/C Ratio 0.60

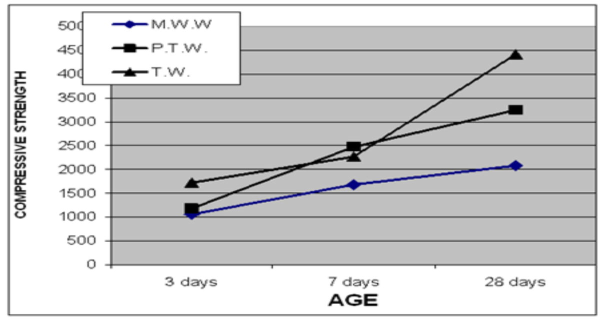

Figure 32: OPC - Mix Ratio 1:1.5:3, W/C Ratio 0.65

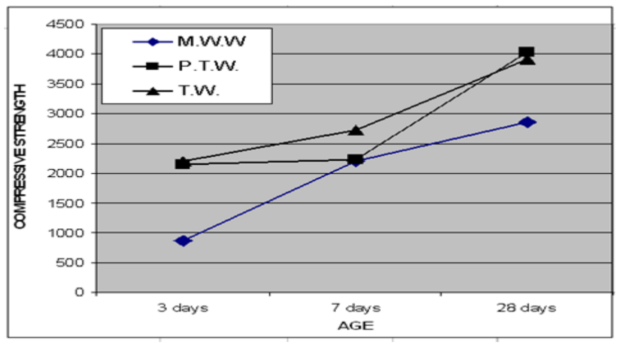

Figure 33: SRPC - Mix Ratio 1:2:4, W/C Ratio 0.55

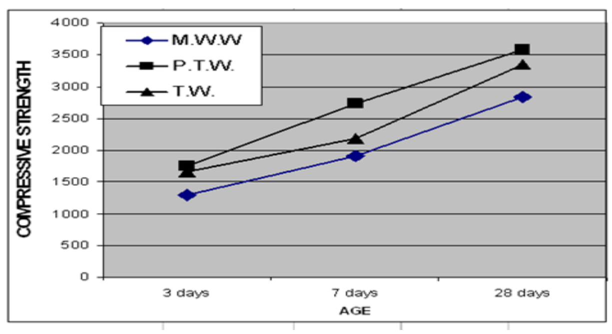

Figure 34: SRPC - Mix Ratio 1:2:4, W/C Ratio 0.60

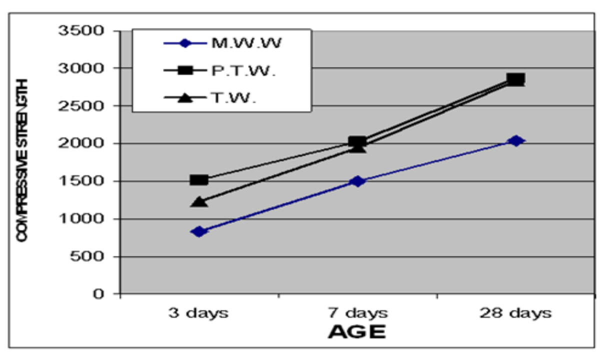

Figure 35: SRPC - Mix Ratio 1:2:4, W/C Ratio 0.65

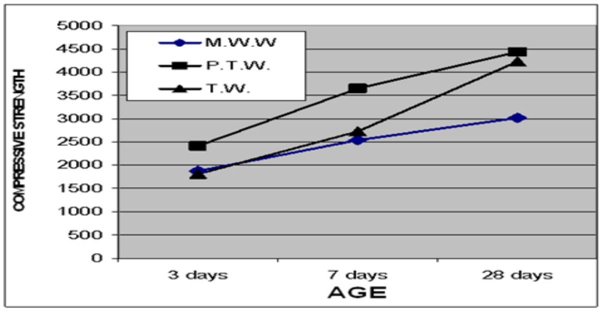

Figure 36: SRPC - Mix Ratio 1:1.5:3, W/C Ratio 0.55

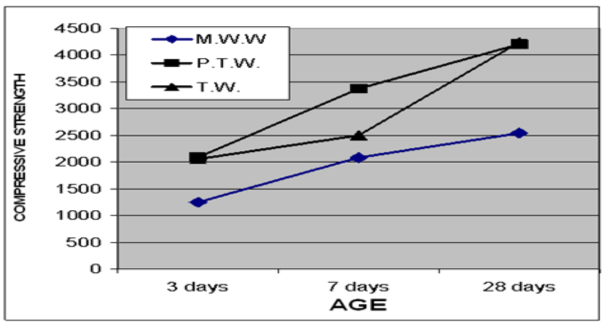

Figure 37: SRPC - Mix Ratio 1:1.5:3, W/C Ratio 0.60

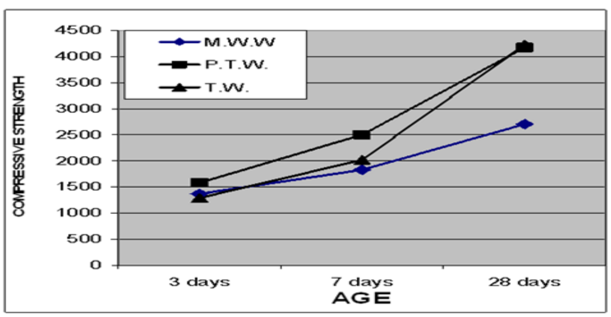

Figure 38: SRPC - Mix Ratio 1:1.5:3, W/C Ratio 0.65

8. Conclusions

This study was aimed to utilize waste water for production of sustainable concrete. Following are the major findings of this study;

1) As Far as type of cement is concerned S.R.P.C. gave more compressive strength with Raw Waste Water and Primary Treated Water as compare to O.P.C.
2) The compressive strength for mix ratio 1:1.5:3 was more than that for 1:2:4 for all types of water used.
3) Compressive strength of cubes cast by Raw Waste Water was the least. However, it increased for the Primary Treated Waste Water and Tap Water.
4) The concrete prepared by mixing PTW gives 28 days compressive strength equals to 3663 psi with O.P.C. and 4038 psi with S.R.P.C. for 1:2:4 mix. (Grade C20 concrete). The required compressive strength for 1:2:4 mix defined in BS Code 5328: 1981 (designated as Grade C20 concrete) is 2900 psi. Thus the compressive strength achieved by mixing P.T.W. is more than the minimum required compressive strength as far as 1:2:4 mix. is concerned.
5) In case of 1:1.5:3 mix, the BS Code 5328: 1981 recommends the minimum strength for 1:1.5:3 mix (Grade C 30 concrete) as 4200 psi. In this research, the 28 days compressive strength achieved by mixing P.T.W. is 4289 psi with O.P.C. and 4433 psi with S.R.P.C. Both are more than the recommended minimum strength.
6) From above mentioned points, it can be concluded that Primary Treated Waste Water with COD ranging from 12 to

18.8 and BOD ranging from 15 to 238 can be used for all type of PCC. Works which includes foundation work, rigid pavements, protective works, drainage works, walk ways, footpaths and underground plain cement concrete works without compromising on compressive strength.

9. References

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