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Use of Treated Domestic Effluent as Mixing Water for Concrete and Its Effects on Strength and Water Penetration at 28 Days

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ABSTRACT

The study tests the feasibility of utilizing treated domestic effluent as mixing water for ordinary concrete. The treated wastewater used for the investigation was collected from a typical sewage treatment plant in Bhimavaram (India). Collected samples were chemically characterized to check conformance with the recommendations of relevant standards for use in concrete production. The 28 day's compressive strength, surface hardness and water penetration characteristics of concrete produced using wastewater were tested at par with the relevant standards and were found to be similar or better than those measured for the control concrete mixed using tap water.

Keywords : Concrete, Sustainability, Treated Wastewater, Freshwater Scarcity.

I. INTRODUCTION

Natural growth of urban population and its confluence with transmigrating rural masses has resulted in the evolution of densely populated metropolitan settlements in developing countries. Presently, 1.4 million new dwellers add to the global urban population every week, of which, 0.88 and 0.23 million emerge in the developing countries of Asia and Africa respectively. The concentration of expanding Afro-Asian urban masses in only a few cities casts an overwhelming influence on the resources, of which, water is a critical instance. The issue of freshwater scarcity is so aggravated that it calls for immediate attention by the stakeholders to achieve sustainability in its utilization. As the population in developing world continues to surge, the chronic exploitation of freshwater reserves is expected to rise in order to suffice the agricultural, industrial and domestic demands.

On account of its extensive use in contemporary construction practice, concrete has emerged as the most widely consumed manmade entity of present era. The enormous consumption of concrete in consequence entails a major environmental footprint and necessitates adoption of conservative measures to minimize the utilization of implicated natural resources. Practices have been developed to this end since the late nineteenth century and the ones currently in vogue include: (i) use of industrial by products such as, blast furnace slag, fly ash and silica fume for producing blended cements and also as supplementary binders in concrete; (ii) development of energy efficient techniques of clinker production with better heat recovery systems and modern kilns; (iii) use of alternative fuels such as waste types, biomass, sewage sludge, municipal solid waste and waste oil in cement plants; (iv) use of recycled tires, plastics, glass and construction and demolition debris as aggregate in concrete.

II. METHODOLOGY AND MATERIALS

The treated effluent and tap/potable water are used as the mixing waters for concrete. Concrete contains cement, water, fine aggregate, coarse aggregate and admixture (if required). The obtaining results of the treated effluent cubes are compared with the standard conventional concrete cubes casted using tap/potable water. These cube samples were cast in the mould size 150mm X 150mm X 150mm. After 24 hours the specimens were de-mould and these specimens are cured in the curing bath up to getting the ultimate strength, i.e. after 28 days the concrete cubes are getting their ultimate strength. These respective cubes are tested on 7 days, 14 days and 28 days for compressive strength test on Universal Testing Machine (UTM), rebound hammer test, non-evaporable water content and initial surface absorption test.

MATERIALS:

CEMENT:

Ordinary Portland cement is by far the most important type of cement. The OPC was classified into three Grades viz., 33 Grade, 43 Grade and 53 Grade depending upon the strength of the cement at 28 days when tested as per IS 4031-1988. If the 28 days strength is not less than 33 N/mm^2, it is called 33 grade cement, if the strength is not less than 43 N/mm^2, it is called 43 Grade cement, and if the strength is not less than 53 N/mm^2, it is called 53 Grade cement.

Physical properties of Portland cement (43 grade)

S. No.	Properties/Characteristics	Test results	Requirements as per IS 12269-1987
1	Normal Consistency	6 mm	---
2	Setting time a) Initial Setting Time b) Final Setting Time	28 minutes 24 Hours	Not less than 30 minutes Not more than 600 minutes
3	Specific Gravity	3.15	---
4	Fineness of cement by sieving through sieve No.9 (90 microns) for a period of 15 min.	5.36%	<10% (by weight)
5	Compressive strength of cement (28 days)	43 MPa	43 MPa
6	Specific surface area	3200 cm^2/gm	---

Chemical composition (%) of cement

Chemical Properties	**Ordinary Portland Cement (OPC)**
Silicon Dioxide (SiO_2)	21.77%
Calcium Oxide (CaO)	57.02%
Magnesium Oxide (MgO)	2.71%
Sulphur Trioxide (SO_3)	2.41%
Aluminium Oxide (Al_2O_3)	2.59%
Ferric Oxide (Fe_2O_3)	0.65%
Loss on Ignition	2.82%

AGGREGATE

Generally aggregates are divided into two types

(1) Fine aggregate

(2) Coarse aggregate

Fine Aggregate

Fine aggregate are material passing through an IS sieve that is less than 4.75 mm gauge beyond which they are known as coarse aggregate. Fine aggregate form the filler matrix between the coarse aggregate. The most important function of the fine aggregate is to provide workability and uniformity in the mixture. The fine aggregate also helps the cement paste to hold the coarse aggregate particle in suspension.

Grading of Aggregate

Packing of aggregates in the mix, as influenced by the gradation, shape and surface texture, has an important effect on the workability and finishing characteristics of fresh concrete, consequently on the properties of hardened concrete. Minimum voids can be obtained by good grading i.e., by adopting a sample of aggregate that contains all standard fractions of aggregate in required proportion.

Fineness Modulus

Fineness modulus is a grading index of coarseness or fineness of the material. The larger the figure, the coarser is the material. It is an empirical factor obtained by adding the cumulative percentage of aggregate retained on each of the standard sieves ranging from IS 80mm to 150 micron sieve and dividing this sum by an arbitrary number 100. The fineness modulus of coarse aggregate used in this work is 6.54.

Water Absorption

Some of the aggregates are porous and absorptive. Porosity and absorption will affect w/c ratio and hence the workability of concrete. The porosity of aggregate will also affect the durability of concrete when the concrete is subjected to freezing and thawing and also when the concrete is subjected to chemically aggressive liquids. Aggregates that are dry absorb more water while mixing and thereby affect the workability.

Density

The density of the recycled coarse aggregate is lower than natural aggregate. When compared with natural aggregate, recycled coarse aggregates have lower density because of the porous and less dense residual mortar lumps that is adhering to the surfaces. When the particle size is increased, the volume percentage of residual mortar will increase too.

Coarse Aggregate

The coarse aggregate are granular materials obtained from rocks and crushed stones. Coarse aggregate form the main matrix of the concrete, in case of coarse aggregate maximum 20 mm coarse aggregate is suitable for concrete work. But where there is no restriction 40 mm or large size may be permitted. Crushed granite aggregate conforming to IS: 383-1970 was used for the preparation of concrete. Coarse aggregate of size 20 mm having the specific gravity of 2.8.

Testing of Fine Aggregate

1. Specific gravity
2. Fineness modulus

Specific gravity of fine aggregate

Pycnometer is used for this test. A 500g of sample is taken and placed in the pycnometer. Now pour distilled water into it until it is full. The entrapped air is eliminated by rotating the pycnometer on its side, the hole in the apex of the cone being covered with a finger. Wipe out the outer surface of pycnometer and weigh it (W). Transfer the contents of the pycnometer into a tray, care being taken to ensure that all the aggregate is transferred. Refill the pycnometer with distilled water to the same level. Find out the weight (W1). Drink water from the sample through a filter paper. Place the sample in oven in a tray at a temperature of 100ºC to 110º C for 24±0.5 hours during which period, it is stirred occasionally to facilitate drying. Cool the sample and weigh it (W2)

Calculation:

$$\text{Specific gravity} = \frac{\text{weight of dry sample}}{\text{weight of equal volume of water}}$$

Fineness modulus of fine aggregate

- For grading of aggregates is one which the consecutive opening are constantly doubled, such as 10mm, 20mm,40mm etc. the aggregates used for making concrete are normally of the maximum size 80mm, 40mm, 20mm, 10mm, 4.75mm, 2.36mm, 600micron, 300micron and 150micron.
- The aggregate fraction from 4.75mm to 150micron is termed as coarse aggregate.
- Grading pattern of a sample of coarse aggregate is assessed by sieving a sample successively through all sieve mounted one over another in order of sieve size, with larger sieve on top.
- The materials retained on each sieve after shaking, represents the fraction of aggregates coarse than the sieve in question and finer than the sieve above. The sieve done by mechanically or manually

Sieve Analysis of Fine Aggregate

S. No.	I.S. Sieve No.	Weight retained (gm)	Percentage weight retained	Cumulative percentage retained	Percentage passing
1.	4.75mm	0	0	0	100
2.	2.36mm	0	0	0	100
3.	1.18mm	92.6	9.26	9.26	100
4.	600µ	156.4	15.64	24.9	95.88
5.	300µ	426.5	42.65	67.55	90.48
6.	150µ	274	27.4	94.95	75.90
7.	PANµ	50.5	5.05	100	43.97
Total :				296.66	

Fineness modulus = 296.66/ 100 = **2.96**

Testing of Coarse Aggregate

1. Specific gravity
2. Fineness modulus

Specific gravity of coarse aggregate

A sample of aggregate not less than 2 kg is taken. It is thoroughly washed to remove the finer particles and dust adhering to aggregates. It is then placed in wire basket and immersed in distilled water at a temperature between 22º to 33ºc. Immediately after immersion, the entrapped air is removed from the sample by lifting the basket containing it 25 mm above the base of the tank and allowing it to drop 25 times at rate of about one drop per second. During the operation, care should be taken that the basket and aggregate remain completely immersed in water. They are kept in water for a period of 24 ± 1/2 hours afterwards. The basket and aggregates are then jolted and weight (weight A_1) in water at a temperature 22º to 33ºc. The basket and the aggregate are then removed from water and allowed to drain for a few minutes and then aggregates are The aggregate is transferred to the second dry cloth and further dried. The empty basket is again immersed in water, jolted 25 times and weighed in water (weight A_2).

Calculation

$$\text{Specific gravity} = \frac{C}{B-A}$$

Where A = the weight in gm of saturated aggregate in water (A_1-A_2)

B = the weight in gm of saturated surface-dry aggregate in air and

C = the weight in gm of oven-dried aggregate in air.

Taken out from the basket and placed on dry cloth and the surface is gently dried with the cloth.

Fineness Modulus of Coarse Aggregate

- The coarse aggregate are granular materials obtained from rocks and crushed stones. They may be also obtained from synthetic material like slag, shale, fly ash and clay for use in light-weight concrete.
- The maximum size of coarse aggregates used is 20 mm. It is well graded and its specific gravity is 2.71 and fineness modulus is 7.17 .The materials is of uniform color and has good angularity and it will be free from dust and organic matter etc.
- For grading of aggregates is one which the consecutive opening is one which the consecutive openings are constantly doubled, such as 10mm, 20mm,40mm etc. the aggregates used for making concrete are normally of the maximum size 80mm,40mm,20mm,10mm,4.75mm,2.36mm,600micron,300micron and 150micron.
- The aggregate fraction from 80mm to 4.75 mm is termed as coarse aggregate.
- Grading pattern of a sample of coarse aggregate is assessed by sieving a sample successively through all sieve mounted one over another in order of sieve size, with larger sieve on top.
- The materials retained on each sieve after shaking, represents the fraction of aggregates coarse than the sieve in question and finer than the sieve above. The sieve done by mechanically or manually

Table 3.5 Sieve Analysis of Coarse Aggregate

S No.	I.S. Sieve No.	Weight Retained (gms)	Percentage weight retained	Cumulative Percentage Retained	Percentage Passing
1.	40mm	0	0	0	100
2.	25mm	470	9.4	9.4	90.6
3.	20mm	1720	34.4	43.8	56.2
4.	16mm	820	16.4	60.2	39.8
5.	12.5mm	1840	36.8	97	3
6.	10mm	80	1.6	98.6	1.4
7.	6.3µ	15.5	0.31	98.91	1.09
8.	4.75µ	11	0.09	100.00	0
9.	PAN	0	0	100.00	0
Total :				607.91	

Fineness modulus = 607.91 / 100 = **6.0791**

WATER

The treated effluent from the sewage plant and normal tap water are used as the mixing waters in concrete. The standards of both the tap water and treated effluent are discussed below

Table 3.7: Analysis of Water (Limitations As Per IS: 456-2000)

PARAMETERS	CONCENTRATION(mg/l except for pH)		
	TREATED EFFLUENT	TAP WATER	LIMIT
Ph	7.10	7.10	6.5-8.5
TURBIDITY	17 ntu	0	5-10 ntu
ELECTRICAL CONDUCTIVITY	704	232	1500-3000 us/cm
SALINITY	343	131.8	1500
TDS	456	177.4	500-2000
FLOURIDE	0.99	0.13	1.0-15
IRON	0.18	0.03	0.3-1.0
SULPHATE	41	8.1	200-400
ALKALINITY	80	48.1	200-600
HARDNESS	145.6	70	300-600
NITRATE	22	2	0-45
CHLORIDE	102	28.3	250-1000

ADMIIXTURES

No admixtures are used in either of the concrete cubes casted using tap water and treated effluent.

MIX DESIGN PROCEDURE

In the present investigation mix proportioning is done using BIS method for, M 30 grade concrete. The resulting mixes are modified after conducting trials at laboratory by duly following the Indian standards guidelines to achieve following mix proportion by weight.

(a) Design stipulations

i) Characteristic compressive strength required in field at 28 days.

ii) Maximum size of aggregate

iii) Degree of workability

iv) Degree of super vision

v) Type of exposure

(b) Test data for Materials

Cement used OPC 53 grade cement

i) Specific gravity of cement : 3.15

ii) Specific gravity of coarse aggregate : 2.85

iii) Specific gravity of fine aggregate : 2.65

iv) Fine aggregate : Zone II

(c) Target mean strength of concrete

The target mean compressive strength ($\check{f}_{ck}$) strength at 28 days is given by

$$(\check{f}_{ck}) = f_{ck} + ts$$

Where f_{ck} = characteristic compressive strength at 28 days

S = standard deviation. (for M30 grade S=6)

$(\check{f}_{ck})$ = 30 + 1.65 x 6 = 39.9 Mpa

(d) Selection of water/ cement ratio

From the graph according to compressive strength of cement at 28 days and compressive strength of concrete water/cement ratio is taken as 0.45

(e) Determination of cement content

Water cement ratio = 0.45

Water = 186 liters

Cement content = 186/0.45 = 413.33 Kg/m^3

Cement content per = 413.33 kg

Fine aggregates required = 795.848 kg

Coarse aggregates required = 1283.868 kg

Water content = 186 liters

Table 3.8 Design Mix Proportion of Concrete in (kg/m^3)

MIX		WATER (W)	CEMENT (C)	FINE AGGREGATE (F a)	COARSE AGGREGATE (C a)
M-30	BY WEIGHT (kg)	186	413.33	795.848	1283.868
	RATIO	45	1	1.92	3.13

Preparation of Testing Specimen Mixing

Mixing of ingredients is done in grinder mixer of capacity 40 liters. The materials weighed according the mix design proportions and the cementations materials are thoroughly blended and then the aggregate is added and mixed followed by gradual addition of water and mixing. Wet mixing is done until a mixture of uniform color and consistency are achieved which is then ready for casting. Before casting the specimens, workability of the mixes was found by slump cone.

Workability Tests

To find the workability of the obtained mix compaction factor test apparatus and slump cone apparatus are used.

Slump Test

The workability test for concrete performed was slump cone test. Initially the fresh concrete is poured into cone in three layers and after each layer it is damped using a rod. It is leveled at the top and lifted as the cone is removed the concrete flows. Hence the slump obtained is 75mm.

Compaction Factor Test

Compaction factor measures the workability in an indirect manner by determining the degree of compaction achieved by a standard amount of work done by allowing the concrete to fall through a standard height.

Casting of Specimens

The cast iron moulds are cleaned and it is applied with mineral oil on all sides before concrete is poured in to the moulds. The moulds are top surface is finished level and smooth as per IS 516-1969. Moulds were kept on table vibrator and the concrete was poured into the. The moulds in three layers by tamping with a tamping rod and the vibration were effected by table vibrator after filling up moulds. The specimens were removed from moulds after twenty four hour***s.***

Curing of Specimens

The test specimens shall be stored on the site at a place free from vibration, under damp matting, sacks or other similar material for 24 hours + ½ hour from the time of adding the water to the other ingredients. The temperature of the place of storage shall be within the range of 220 to 32 0C. After the period of 24 hours, they shall be marked for later identification, removed from the moulds and, unless required for testing within 24hours, stored in clean water at room temperature.

Testing of Specimens

A time schedule for testing of specimens is maintained to ensure their proper testing on the due date and time. The specimens were taken out and allow drying under shade Specimens stored in water shall be tested immediately on removal from the water and while they are still in the wet condition. Surface water and grit shall be wiped off the specimens and any projecting fins removed. The cast specimens are tested as per standard procedures, immediately after curing the specimens in water for a period of 7 and 28days

Rebound Hammer Test

The test was carried out using three replicates of 150 mm cubes and in compliance to the provisions of ASTM C805-08 to obtain indications of surface hardness and abrasion resistance of concrete. A grid comprising of sixteen squares was marked on each of the four moulded surfaces of the cube. The rebound values (on a scale of 10-100) were measured at the nine inner points on each surface (a total of 36 points) by holding the specimen firmly between the jaws of a compression testing machine.

Water Absorption Test

30 full size units shall be measured for length, width and height. Cored units shall also be measured for minimum thickness of face, shells and webs. From these 3 blocks are to be tested for block density, 8 blocks for compressive strength, 3 blocks for water absorption and 3 blocks for drying shrinkage and moisture movement. Three blocks shall be dried to constant mass in a suitable oven heated to approximately 1000C. After cooling the blocks to room temperature, the dimensions of each block shall be measured in centimetres to the nearest millimetre and the overall volume computed in cubic centimetres. The blocks shall then be weighted in kilograms to the nearest 10 gm. The density of each block calculated as follows

$$\text{Density in kg/m}^3 = \frac{\text{Mass of block in kg}}{\text{Mass of block in } cm^2} * 10^6$$

The water absorption calculates as given below:

$$\textbf{Absorption Percent} = \frac{(A-B)}{B} * 100$$

Where, A= wet mass of unit in kg;
B = dry mass of unit in kg.

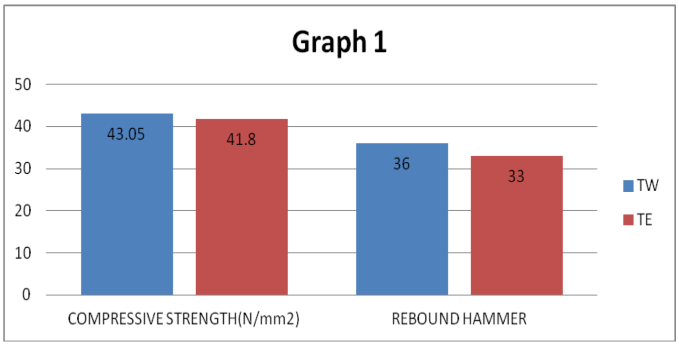
III. RESULTS AND DISCUSSION

Compressive Strength and Rebound Hammer Strength

Average test results for compressive strength and rebound hammer

MIXING WATER	COMPRESSIVE STRENGTH(N/mm2)	REBOUND HAMMER
W/C RATIO	0.45	0.45
TW	43.05	36
TE	41.80	33
% GAIN	2.90%	9.09%

Graph



Non Evaporable Water Content

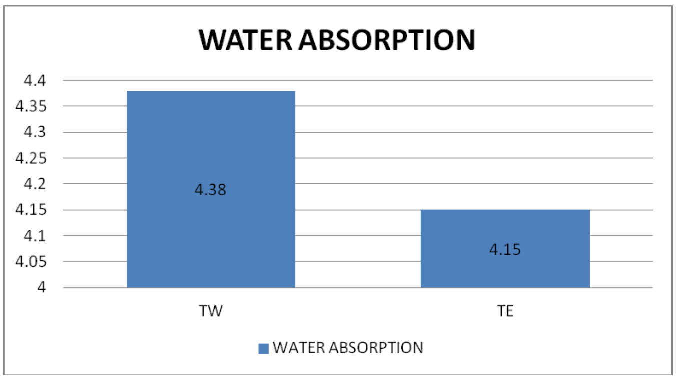
Non-evaporable water content (%)

MIXING WATER	W/C RATIO
	0.45
TW	4.3
TE	4.5
% GAIN	4.66

Water Absorption Test

MIXING WATER	WATER ABSORPTION
RATIO	0.45
TW	4.38
TE	4.15

Graph



IV. CONCLUSION

- Motivated by the issue of water scarcity faced in urban centres across the country and in arid regions of western India, the objective of the present study has been to analyse the efficiency of mixing schemes which may serve as alternatives to the use of fresh water conventionally used for the purpose.

- The work investigated the feasibility of utilizing treated domestic effluent generated in a typical Indian urban settlement as mixing water by evaluating its influence on the properties of compressive strength development and water absorption of ordinary concrete.
- The findings of the study substantiate the viability of waste water mixing in achieving better strength and surface density characteristics at the age of 28 days, especially for mixes of high w/c ratio.
- Prolonged use of waste water for mixing has however been found to be determinable towards the development of compressive strength. The observed behaviour has been attributed to the action of pore clogging caused due to precipitation of dissolved solids present in a significant concentration in waste water.

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