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Self-Healing of Wastewater Concrete Using Bacteria

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Abstract

Water is the most essential thing for any living organisms to survive in the earth. For construction industry water is one of the essential components and its demand is increasing day by day. Due to continuous contamination of natural water resources, utilization of underground water resources increases in worst manner. To meet out the water demand for construction works many countries are using wastewater from treatment plants. In our paper Waste water from treatment plant has been tested to know the content of contaminants and minerals which are harmful and have utilized for the preparation of M25 grade concrete and the same grade with tap water as conventional concrete. Bacillus subtillus is the bacteria used for achieving self-healing of micro crack in the concrete which increase the strength to a smaller extent. Bacteria have been added in different proportions such as 0.5%, 1% and 2% in waste water for the preparation of concrete and its compressive strength and tensile strength have been found out. Experimental results of bacterial concrete have confirmed the presence of calcite crystals which had been filled in micro cracks that leads to increase in Compressive strength and tensile strength of concrete. SEM analysis shows the evidence for the presence of Calcite Crystal in concrete, which has been confirmed by the EDAX report. Wastewater from treatment plant could be effectively used for concrete which found a valuable replace for fresh water in concrete.

Keywords:Self-Healing, Wastewater, Bacteria, Calcite crystals.

1.Introduction

Water scarcity is one of the biggest challenges, which the world is going to face in future. Nothing could not be in system without water, which includes construction Industry also. As per S. Bardhan (2011), 27.2klit of water has been used for construction per year on an average per sq.mof built-up area in a building

In the increasing demand for portable water for domestic and industrial purpose it is mandatory to find the solution for the problem. The use of water which is unfit for human consumption becomes important in construction uses. In Arab countries the water scarcity is the major problem. Some researches (Tay& Yip 1987, K.S. Al-Jabari et al. 2011, Asif Rashid and Inamdar 2016) had undergone an investigation in use of wastewater for concrete mixing. Some of them had concluded the important information of possibilities in using the treated water. .[1-6]

Al Ghusain et .al (2003) had investigated on use of treated wastewater in concrete mixing. The strength values for concrete made with Preliminary treated wastewater and Secondary treated wastewater are lower than those values for concrete made up of Tertiary treated wastewater and Tap water. Tay and Yip (1987) specifies that water which is not suitable for drinking can be used in the concrete mix. K.S. Al-Jabri et.al, (2011) had carried out the experiment in wastewater from car wash used in high strength concrete. G.Asadollahfardi et.al, (2016) has investigated on use of treated domestic wastewater before chlorination to produce concrete. The compressive strength of the concrete of treated water is 11 percent lesser than the control mix at 21 Days but later the strength remains similar to control concrete. Omar A. E1-Nawawy & Shamim Ahmad (1991) had used the treated effluent in concrete mixing in an arid climate that the concrete compressive strength is 20%lower than concrete made with portable water.

SalmabanuLuhar et.al, (2017) has found that as percentage of treated wastewater increases, the compressive strength of concrete decreases due to the ettringite is converted into a stable compound like mono sulphate aluminates, and finally dissolves during the hydration process[7-12].

When the concrete is made with wastewater, to ensure the strength and also to study behaviour of bacteria in wastewater, bacterial concrete is used. Concrete structures are more prone to micro-cracks due to sustainable loading. Micro cracks on the surface of concrete make the whole structure vulnerable because water seeps into the cracks and the concrete degradation occurs. In addition to achieve self-healing of concrete, bacteria are added. Bacterial concrete is embedding of bacteria for achieving self-healing properties in concrete. According to Pradeep Kumar et.al (2015), the bacterial concrete would possess high strength in M20 concrete and the bacteria would help in precipitation of calcite, also Bacillus subtillus are witnessed for crack healing in concrete. Further, he found that the compressive strength of the bacterial concrete is 33.32 Mpa for 30ml injection of bacillus subtillus in the concrete.

Thanh Ha Nguyen et.al, (2019) had found that the 400μm cracks width of bacterial concrete was completely closed after 44 Days of water immersion. Hana Schreiberova et.al, (2019) reveal that the addition of calcium lactate led to a cementitious material with significantly higher compressive strength at all ages and Calcium lactate would help in strength gaining process and also in self-healing process. NidhiNain et.al, (2019) indicated that Bacillus subtilis shows increase of 14.3% in compressive strength and 25.3% increase in tensile strength compared to the conventional specimen also the micro pores can be healed and hence the durability of the concrete had increased.

Kunamineni Vijay et.al, (2017) confirmed that bacterial concrete could increase the compressive strength and self-healing properties in concrete and added to that by using bacteria, which decreases water penetration and chloride ion permeability. Kim Van Tittel boom et.al, (2010) results shows that enhanced crack repair might be obtained through a biological treatment of bacteria. Henk M. Jonkers et.al, (2010) refers that bacteria would acts as a self-healing agent to catalyse the process of autonomous repair of freshly formed cracks.[13-16]

In wastewater, the bacteria are added to enhance the self-healing property of bacteria to achieve self-healing property. The entire work is related to the bacterial influence in wastewater and effects of strength parameters in concrete.

1.1 SEWAGE TREARMENT PLANT

Wastewater treatment is a process used to remove contaminants from wastewater or sewage and convert it into an effluent that can be returned to the water cycle with minimum impact on the environment, or directly reused. Sewage treatment plant referred to the place where the treatment process is carried out. Secondary treatment process is carried in the treatment plant where the water is taken for experimental work. Secondary treatment is the portion of treatment sequence removing dissolved and colloidal compounds measured as biological oxygen demand (BOD). The United States Environmental protection Agency states that secondarytreated sewage is expected to produce effluent with a monthly average of less than 30 mg/l BOD and less than 30 mg/l suspended solids.[17-24]

2 EXPERIMENTAL INVESTIGATION

2.1 MATERIALS

2.1.1CEMENT:

Cement is a binder, a substance used for construction that sets, hardens and adheres to other materials to bind them together. Ordinary Portland cement (OPC 53 grade confirms to IS 12269:2013) has been used in the entire project as binding material.

Table 1 Physical Properties of Cement

Properties	Values	IS Code
Initial setting time	35 min	IS 4031 (Part V):1988
Final Setting time	240 min	IS 4031(Part V):1988
Specific Gravity	3.15	IS 2720 (Part III):1980
Consistency	34 %	IS 4031(Part V):1988

2.1.2 BACTERIA:

Bacteria are microscopic organisms, single celled creatures which live mostly on the surface of objects where they grow as colonies. Bacillus Subtilis is a Gram-positive, catalyst-positive bacterium, found in soil. A member of genus Bacillus, Bacillus subtilis is rod-shaped and can form a tough, protective endospore, allowing it to tolerate extreme environmental conditions. The principle mechanism of bacterial crack healing is that the bacteria themselves act largely as a catalyst, and transform a precursor compound to a suitable filler material. The newly produced compounds such as calcium carbonate-based mineral precipitates act as a type of bio-cement which effectively seals newly formed cracks.

2.1.3 FINE AGGREGATE:

Aggregate is the granular material used to produce concrete or motor and when the particles of granular material are so fine that they pass through a 4.75mm sieve, it is called fine aggregate. Sieve analysis test is conducted and sand belongs to Zone II. The sand used for the experiment is M-sand.

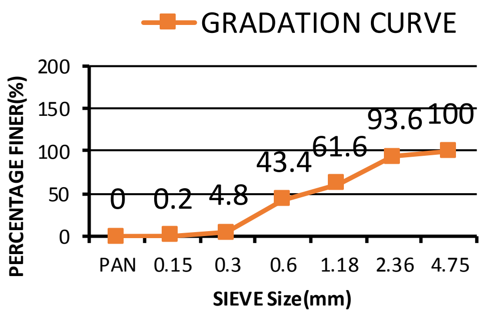


Fig.1 Gradation of fine Aggregate

The fine aggregate conforming to zone II as per IS 383-1970 table 4 was used and the specific gravity of fine aggregate is 2.8.

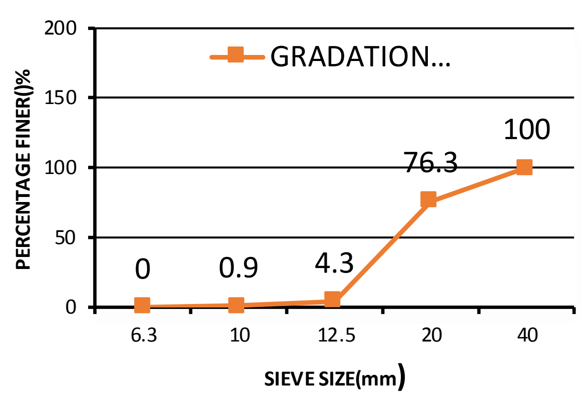


Fig. 2 Gradation curve of coarse aggregate

2.1.4 COARSE AGGREGATE:

Coarse aggregate are particulates that are greater than 4.75mm. Coarse aggregate binds with cement to form concrete and gives strength to it. Grading of coarse aggregate is shown in Figure 2. The curve shows that coarse aggregate is well graded.

2.1.5 WATER:

Wastewater collected from nearby treatment plant is used in concrete. Water quality parameters are tested according to the requirement of IS 456:2000. The parameters are tested using standard Titrimetric method and the values obtained are tabulated in table 2.

Table 2 Wastewater Titrimetric test results

Parameters'	**Value**
pH	8.2
Total suspended solids(TSS)	324 mg/ml
Total dissolved solids (TDS)	1045 mg/ml
Total alkalinity as $CaCo_3$	257 mg/L
Total acidity as $CaCo_3$	60 mg/L
Chlorides	527 mg/L
Total hardness	127 mg/L

2.2 MIX PROPORTION:

Mix proportions have to foe preparing 1 m^3 of concrete are tabulated in table 3.

Table 3 Quantity of materials per m^3 of concrete

Cement	445 kg
Water	201 liters
Fine aggregate	697 kg
Coarse aggregate	1136 kg
Water cement ratio	0.45

2.3 SAMPLES:

Concrete cube had been casted with various proportions of bacteria in wastewater. Samples aken for comparison are conventional mix, concrete made with wastewater (WW), concrete with 0.5% bacteria added in wastewater (B0.5), 1% bacteria added in wastewater (B1) and 2% bacteria added in wastewater (B2). The conventional concrete (C) was made with normal tap water and other mix were made with wastewater. Concrete specimens are tested for compressive strength and tensile strength at 28 Days.

3 Test Results and Discussion

3.1 COMPRESSIVE STRENGTH OF CONCRETE

The compressive strength of concrete is tested according to IS: 516:1959. The load applied on sample is 140 $kg/cm^2/min$ on compression testing machine.

Table 4 Average Compressive Strength of concrete

S. No	Specimen	Average Compressive Strength		
		7 Days	14Days	28Days
1	**C**	16.98	20.54	28.37
2	**WW**	16.04	23.74	29.74
3	**B0.5**	17.32	24.47	30.5
4	**B1**	15.99	23.72	27.66
5	**B2**	14.97	22.2	26.95

The values from table 4 shows comparative compressive strength of cube concrete. Initially the compressive strength of concrete with control mix at 28 Days achieved the target mean strength. Compressive strength of concrete made with bacterial concrete (B0.5) possesses higher strength than conventional concrete in earlier Days. The wastewater from the treatment plant is directly used in concrete without adding any chemical admixtures.

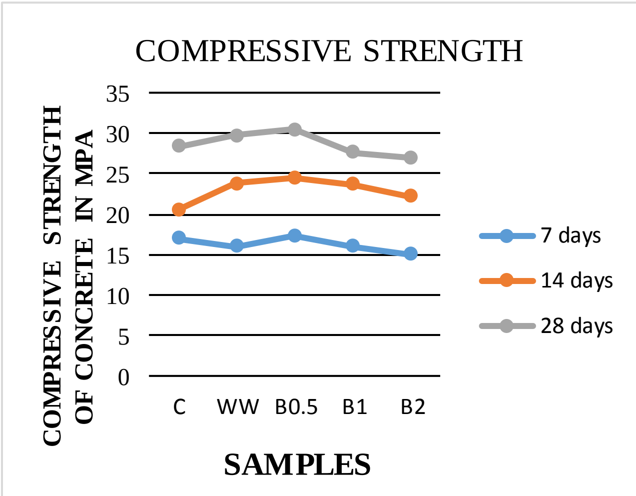


Fig. 3 Average Compressive Strength of Concrete

In later days the compressive strength of B0.5 shows greater strength than all other samples compared. This indicates that bacteria have masterful character in wastewater concrete. The wastewater properties had been controlled by bacteria Bacillus subtillus as the earlier strength of wastewater concrete is higher. The improvement in compressive strength by inclusion of bacteria is probably due to deposition of calcite on the bacterial cell surface and within the pores of cement sand matrix, which fill the pores. Based on results of Ramachandran et al. 2001 the bacteria forms endospore due to lack of nutrients and this endospore acts as fiber to fill the pores and voids. Therefore, the bacteria help as filler material and thus the compressive strength of B0.5 increases abruptly.[25-31]

The strength of B2 concrete is 30.5 MPa at 28 days which is less than all other bacterial proportions. This shows that strength of concrete is very much influenced by bacterial concentrations.

The strength falls off when bacterial proportions increases. When concentration of bacteria increases the formation of calcite precipitation decreases and the strength also decreases rapidly. In B2 concrete the bacterial proportion is 1% greater than B1 concrete hence the compressive strength is slightly lesser than B1 concrete. Therefore, the formation of calcium precipitate influences the compressive strength of bacterial concrete.[32-38]

3.2 SPLIT TENSILE STRENGTH OF CONCRETE

The tensile strength of concrete is one of the basic and important properties which greatly affect the extent and size of cracking in structures. The test is conducted based on IS: 5816 :1999. The load applied on specimen is 1.2 $N/mm^2/min$.

Table 5 Average Tensile strength of concrete

S.No	Specimen	Average Tensile Strength In N/Mm^2		
		7 Days	14 Days	28 Days
1	C	1.75	2.6	2.93
2	WW	1.79	2.66	2.99
3	B0.5	1.88	2.79	3.14
4	B1	1.72	2.55	2.87
5	B2	1.44	2.13	2.4

Experimental values of Split tensile strength are tabulated in Table 5. Split tensile strength of concrete is very low compared to compressive strength because concrete is weak in tension. The wastewater concrete cylinder shows 3.5 MPa when compared to conventional concrete. The B0.5 bacterial concrete also possesses high tensile strength than conventional concrete.

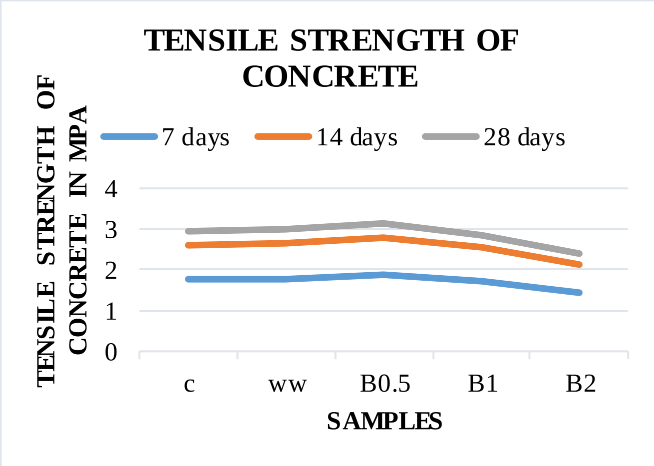


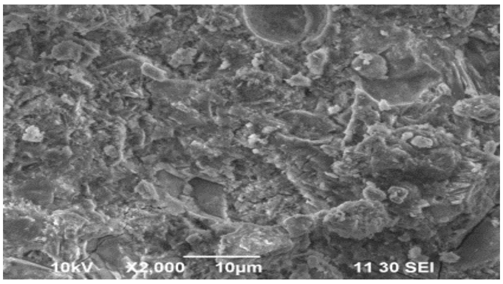
Fig. 4 Average Tensile Strength of Concrete

The tensile strength of conventional concrete is 2.93 MPa at 28days Days. The average tensile strength of concrete for M25 concrete is 3.5 MPa at 28 Days.

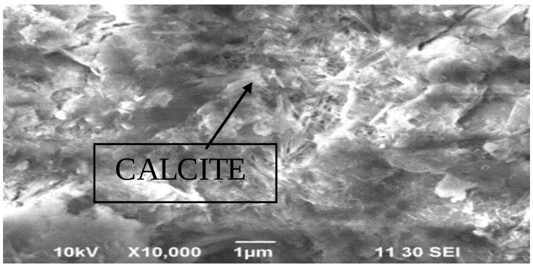
The wastewater concrete shows increase in tensile strength at 28 Days. The B0.5 mix concrete also shows increased in strength than the conventional concrete. The increase of tensile strength is due to calcite formation which acts as a fibre material to fill the pores in concrete. The split tensile strength of B2 concrete i.e., is 2% bacterial concrete shows very lower tensile strength than the conventional concrete. This is due the bacterial influence is greater in B2 concrete. The concentration of bacteria is greater in B2 than other two bacterial proportions which shows less calcite formation.

3.3 SCANNING ELECTRON MICROSCOPY (SEM)

In order to study the microstructure of concrete Scanning Electron microscopy analysis was carried out for samples of control mix concrete and 0.5% bacteria in wastewater concrete of 28 Days. Calcium carbonate crystals are confirmed through SEM and EDX analysis in bacterial concrete. Figure 5– Scanning electron microscopy analysis images of 28 Days control mix concrete and 0.5% bacteria in wastewater concrete i.e., B0.5. The pores are identified in control mix concrete. In bacterial concrete the voids are filled with mineral precipitates and the compressive strength of bacterial concrete are found to be increased than conventional concrete. The healing of concrete was confirmed through EDAX analysis by confirming the presence of calcite minerals in concrete.



a)

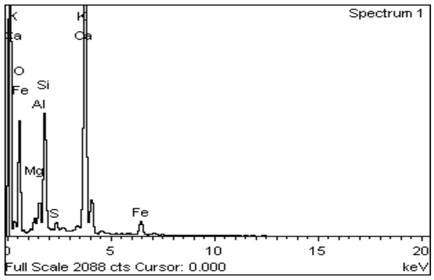


b)

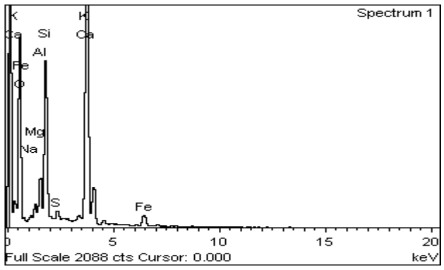
Fig. 5 SEM images of a) control mix 28 Days b) 0.5% bacteria 28 days

EDAX (Energy Dispersive Spectroscopy)

The mineral composition of concrete specimen is identified using EDAX analysis. The presence of calcium carbonate in the bacterial concrete confirms the self-healing process occurred in bacterial concrete. Wiktor and Jonkers founded that the bacterial products contain C, O and Ca minerals. According to this, calcium carbonate ($CaCO_3$) is mineral precipitate of bacterial activity. The calcium composition is greater in bacterial concrete compared to control mix concrete. This confirms the calcium carbonate crystals are composed in 0.5% bacterial concrete. It helps in healing micro cracks. When the micro cracks are healed, then the propagation of cracks due to constant loading was healed and this could increase the life of concrete. In fig.6 the presence of calcium Ca mineral in the bacterial concrete confirms the self-Healing process of the concrete that had achieved.



a)



b)

Fig. 6 EDAX spectrum of (a) control mix concrete (b)0.5% bacterial concrete.

CONCLUSION

The strength and durability properties of self-healing concrete were compared with conventional concrete in this experimental investigation. The wastewater from treatment plant was used as a replacement of water in concrete and the self-healing properties were tested by adding bacteria to the wastewater. The following were the conclusion of this experimental investigation.

- At earlier stage, wastewater concrete (WW) shows greater strength than conventional concrete without adding any chemical admixtures.
- Bacterial concrete (B0.5) mixes possess 30.5 MPa compressive strength at 28 days.
- Split tensile strength of bacterial concrete is 3.14 MPa which indicates that tensile strength of wastewater concrete is greater than conventional mix.
- Bacterial concrete shows reduction in strength properties when the proportion of bacteria increases and thus the bacterial concrete B0.5 is the optimal proportions for wastewater concrete than B1 and B2 concrete proportions.

- Self-healing properties of bacterial concrete are confirmed through calcite formation in cracks which can be verified through SEM images and EDAX results.
- Wastewater from the treatment plant can be effectively used as the replacement of water which creates demand in future.

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