

“An Experimental Investigation of Sustainable Bacterial Concrete by Incorporating Ceramic Tiles Waste”Uvesh A. Marfani¹, Chetankumar G. Solanki², Kishor B. Vaghela³¹Student, M.E. Structural Engineering, Darshan Institute of Engineering & Technology, Rajkot²Assistant Professor, Department of Civil Engineering, Darshan Institute of Engineering & Technology, Rajkot³Assistant Professor, Department of Civil Engineering, Government Engineering College, Rajkot**HIGHLIGHTS:**

- Effect of bacteria on strength of concrete is presented
- Calcite producing bacteria improved strength of CTWP concrete
- CTWP acts primarily as a filler rather than pozzolanic material

Abstract -- Influence of bacteria on strength characteristics in concrete incorporating ceramic tiles waste powder (CTWP) as partial replacement of cement has been investigated in this study. For this purpose, control concrete was designed to have 28-d strength of 25 and 50 Mpa. In the control concrete cement was partially replaced with (0, 5, 10, and 15% by weight). Then, bacterium *Bacillus megaterium* (10^5 cells/mL) was mixed in water during making of concrete. Test were performed for compressive strength, split tensile strength, and flexural strength, at age of 28 d for CTWP mixtures with and without bacteria.

Keywords -- Bacteria, Bacterial Concrete, Ceramic Tiles Waste Powder (CTWP), Strength.

I. INTRODUCTION

Approximately, yearly production of concrete is 10 billion cubic meters. Cement is very important constituent of concrete, and approximately 4180 million tons of cement were produced in 2014 globally. Production of one tone of cement releases approximately one ton of CO₂ which makes up 7% of all CO₂ emissions produced globally. Hence, there is necessity to use supplementary cementitious materials (SCMs) as partial replacement of cement in concrete. Utilization of SCMs which reduces the consumption of ordinary Portland cement, and thereby reduces the energy consumption and greenhouse gas emissions associated with cement production.

This paper investigates the possibility of utilizing ceramic tiles waste powder (CTWP) as partial replacement of cement in bacterial concrete. In India ceramic production is 100 million tons per year. The tiles industry has about 15 to 30% waste material generated from the total production. The tiles waste which is dumped in land filling and pit or vacant spaces causes the environmental pollution which is dangerous for human health. Hence these ceramic tiles waste is converted into powder form and use as cement replacement. The use of ceramic tiles waste in the form of powder is better than using it as fine or coarse aggregate. CTWP due to its fine size mainly serves as a micro-filler, pozzolanic, and viscosity modifier in concrete. CTWP behaves as a reactive pozzolanic material because of its extreme surface fineness and high silica content. Utilization of CTWP between 8 to 40% no pozzolanic activity was observed at early stages, while good pozzolanic activity was observed at 28 days. CTWP react with calcium hydroxide and produce additional CSH gel. Supplementary Cementitious material improves the strength of concrete however, the micro-cracks remained the main cause of concrete cracks. Various available traditional repair systems are chemical based which are expansive and hazardous to environment and health. For the last 10-15 years, the interaction between microorganisms (particularly bacteria) and concrete structure is gaining ground in research for improvement in the cracks of concrete. Several researchers have proposed bacterial induced calcite precipitation (BICP) as an alternative approach to self-healing of concrete cracks by incorporating dormant but viable spores of alkali-resistant urease producing bacteria that convert organic compound to inorganic mineral precipitates i.e. calcite.

Several studies have been reported on the use of CTWP as partial replacement to cement in the production of concrete and use of calcite producing bacteria for remediation of concrete cracks but no such works have been reported on the use of bacteria on concrete containing CTWP as partial replacement to cement to find effect on strength parameters. The calcite producing bacterium has been used in this research work to study its effect on strength concrete. The calcite produced by the bacteria in the concrete pores, densifies the matrix which results not only in improvement of compressive strength but also reduces the pore size, thereby, improving the permeation properties. Therefore, the present study was conducted to provide technical data about the strength properties of concrete containing CTWP and calcite producing bacteria.

II. EXPERIMENTAL PROGRAM

2.1. Bacteria and its revival process:

- Storage of received culture: Store freeze-dried culture at 2°C to 8°C in refrigerator until use
 - How to prepare N- broth (culture media):
Sterilize all required equipment. Prepare N-broth as a culture media for cultivation of bacteria. Take 28 gm of N-broth and 1000 ml distilled water in conical flask, and apply heat to properly dissolved it. Then put conical flask in auto clave at 121 °C and 15lbs for 15 minutes for sterilization of medium. After sterilization completed allow it to cool down. Dispense the medium in petri plates and store at required temperature. Now culture media is ready to use
 - Revival process:
Take Pasteur pipette and shortly heat it. take suspension using wire pipette and drop into culture medium. Petry plate is put in incubator for incubation at 37°C for 24-48 hours. Next day observed the result and note down colony characteristics.
 - Gram straining:
 - Objective of gram straining:
Perform gram straining for conformation and identification of culture media and bacteria. Gram straining method is used to differentiate between gram positive and gram-negative bacteria. Gram positive bacteria have much thicker cell wall (20 - 80 nm) compare to gram negative (7-8 nm). Gram positive bacteria capable to resist pressure during mixing.
 - Methodology:
Take a clean and grease free glass slide and clean it with 75% ethyl alcohol and then sterilize inoculation loop. Apply thin film of bacteria to clean glass slide using inoculation loop and allow it to dry. Heat fix the smear (5-6 times passing out burner), and apply crystal violet 2-3 drops and leave it for a 1 minute, then wash it with tap water. Add gram iodine for 1 minute which is work as a mordant and wash it with tap water. Add decolorized (drop wise) for 10-15 seconds and rinse with sterile water. Add safranin 2-3 drops for 45 seconds and wash it with tap water and allow it to dry. Put one drop of oil and observed under oil immersion lens in light microscope. Gram positive shown purple or violet and gram negative shown red or pink.
 - Endospore formation method:
 - Prepare 3 different flask having 300 ml sterile N- broth
 - Inoculate bacterial culture in every flask in aseptic condition add pinch of antibiotics (powder form
 - Incubate flask at 37°C for 24-72 hours.
 - To check endospore by performing endospore staining. (Schaffer Fulton method)
 - Count endospore with the help of haemocytometer
 - Maintain the endospore number approx. 10^5 , 10^6 and 10^7 endospore per ml using N-Broth & sterile distilled water.
 - Important of endospore formation
 - Endospore can survive without nutrient and also resist ultraviolet radiation, desiccation, high temperature, extreme freezing and chemical disinfectants. Endospores enable bacteria to lie dormant for extended periods, even centuries. When the environment becomes more favourable, the endospore can reactivate itself to the vegetative state
 - How to apply bacteria in concrete?
1. Direct application:
In this method, bacteria are added into concrete directly when concrete mixing is done.
 2. Encapsulation:
In this method the bacteria and its food i.e. calcium acetate, are placed inside treated clay pellets and concrete is mixed. About 6% of the clay pellets are added for making concrete with bacteria

2.2. Materials:

- a) Cement
Ordinary Portland cement of 53 grade cement was used in this study. The cement used was fresh and without lumps.
- b) Ceramic tiles powder

Waste of ceramic tiles is collected **industrial area of Morbi** and crushed in the powder form which size is less than 90 microns. Physical and chemical properties of ceramic tiles waste powder are carried at **YOR LAB** (NABL approved), its results are as per below:

Test description	Obtain value	Unit
CaO	0.66	%
SiO ₂	65.04	%
Al ₂ O ₃	22.56	%
MgO	2.88	%
Fe ₂ O ₃	2.12	%
SO ₃	0.10	%
Specific gravity	1.217	gm/cm ³
Moisture content	0.19	%
Water absorption	19	%
Fineness	75	micron

from Table 1 Chemical composition of ceramic tiles waste powder

c) Fine Aggregate

One of the most important factors for producing workable concrete is a good gradation of fine aggregates. Good grading implies that a sample fraction of aggregates in required proportion such that the sample contains minimum voids. Samples of the well graded aggregate containing minimum voids require minimum paste to fill up the voids in the aggregates. The properties of fine aggregate taken are as follows.

d) Coarse Aggregate

These coarse aggregates having the maximum size of 10mm and 20mm were used in the present work. As per blending of aggregate, used 30% 20mm sized aggregate and 70% 10 mm size aggregate. The properties of coarse aggregate like Specific gravity, water absorption, bulk density, aggregate crushing value, aggregate impact value and fineness are as follows.

Sr. No	material	Water absorption (%)	Specific gravity
1	Coarse aggregate	0.5	2.74
2	Fine aggregate	1.0	2.65

Table 2 Physical properties of fine and coarse aggregate

e) GGBS

Ground granulated blast furnace slag is used to making workable concrete in M50 grade. Specific gravity of GGBFS is 2.89, which is 30% replaced with total cementitious material content.

f) Water

Water is the key ingredient, which when mixed with cement, forms a paste that binds the aggregate together. The water causes the hardening of concrete through a process called hydration. Hydration is a chemical reaction in which the major compounds in cement form chemical bonds with water molecules and become hydrates or hydration products.

g) Super Plasticizer

Conplast SP430 is a chloride free, super plasticising admixture based on selected sulphonated naphthalene polymers is used for M25 grade concrete. It appears as brown liquid which reduces the water content in design mix. The amount of admixture used is 1.2% of cement. For M50 grade concrete used Redwop Procreate R20 which is poly carboxylic ether-based admixture for such a high strength concrete, and its amount is 1.5% of cement.

Specific gravity: 1.107

Appearance: Brown liquid

2.3. Mix composition:

Control concrete mix having 28-d compressive strength of 25 MPa and 50 MPa was designed as per BIS: 10262-2019. Ceramic tiles waste powder (5, 10 and 15% by weight) was used as partial replacement of cement. Constant concentration of bacillus megaterium culture (10⁵ cfu/mL of water) was used in all the bacterial concrete mixes. The bacterial growth curve was prepared by observing optical density at 600 nm and cell concentration was determined from it. Mixes proportion details are presented in Table 3 & 4. The addition of bacteria has no major effect on the slump value of concrete. As such slump results of bacterial concrete are presented in the Table 3.

MIX PROPORTION FOR M25								
MIXTURE	W/C RATIO	WATER	CEMENT	CTWP	SAND	COARSE AGGREGETE	BACTERIAL CONTENT (cells/mL)	SLUMP
CONTROL (C0)	0.43	171.4	366.8	0	811.3	1098.7	-	100
C5	0.43	174.7	348.5	18.3	801	1084.7	-	110
C10	0.43	178.1	330.1	36.7	790.6	1070.7	-	115
C15	0.43	181.4	311.8	55.0	780.3	1056.7	-	120
BC0	0.43	171.4	366.8	0	811.3	1098.7	10 ⁵	95
BC5	0.43	174.7	348.5	18.3	801	1084.7	10 ⁵	108
BC10	0.43	178.1	330.1	36.7	790.6	1070.7	10 ⁵	115
BC15	0.43	181.4	311.8	55.0	780.3	1056.7	10 ⁵	122

Table 3 MIX PROPORTION FOR M25 grade concrete

MIX PROPORTION FOR M50									
MIXTURE	W/C RATIO	WATER	CEMENT	CTWP	SAND	COARSE AGGREGETE	GGBS	BACTERIAL CONTENT (cells/mL)	SLUMP
CONTROL (C0)	0.28	156.4	395.8	0	711.39	1043.79	169.6	0	90
C5	0.28	159.9	376	19.8	700.54	1027.86	169.6	0	110
C10	0.28	163.5	356.2	39.6	689.68	1011.93	169.6	0	120
C15	0.28	167.1	336.4	59.4	678.83	996	169.6	0	130
BC0	0.28	156.4	395.8	0	711.39	1043.79	169.6	10 ⁵	85
BC5	0.28	160	376	16.03	700.54	1027.86	169.6	10 ⁵	115
BC10	0.28	163.5	356.2	32.06	689.68	1011.93	169.6	10 ⁵	118
BC15	0.28	167.1	336.4	48.09	678.83	996	169.6	10 ⁵	125

Table 4 MIX PROPORTION FOR M50

2.4. Casting, curing and testing of specimens

Cubes (150x150 mm) were cast for compressive strength measurement as per BIS: 516-1959. Beam (500x100x100 mm) were cast for flexural strength and cylinder (150x300 mm) were cast for split tensile strength test. All experiments were done in triplicate.

III.RESULTS AND DISCUSSIONS

3.1 compressive strength test

Compressive strength results of CTWP concrete and bacterial concrete mixtures are shown in fig 1 & 2. at early age, compressive strength of concrete mixtures containing CTWP increased with increase in CTWP content up to 10% as cement replacement and concrete mixture C15 displayed lower compressive strength than the control concrete. The concrete mixture containing 10% CTWP as replacement of cement displayed optimum increase in compressive strength at all the ages. The increase in compressive strength of concrete mixture C10 was by 3.43% & 6.49 % in M25 grade and 4.58 % & 5.02 % in M50 grade with respect to control concrete at the ages of 7, and 28d respectively. the increase strength of CTWP concrete mixtures was due to fineness of CTWP and reactive silica content that reacted with hydration products of cement and produced secondary calcium silicate hydrate (CSH) gel. concrete mixture containing 15% CTWP displayed - 1.39% & -0.26 % lower compressive strength in M25 grade where -6.65 % & -5.97 % in M50 grade concrete at age of 7 and 28d. The addition of bacterial cells in control and CTWP concrete mixtures resulted in increase in compressive strength. Comparison to control concrete, concrete mixtures containing 10% CTWP and bacterial cells displayed 12.39 % and 13.39 % higher compressive strength in M25 grade where 12.79% & 11.99 % in M50 grade concrete at 7, and 28d, respectively, where 15% CTWP in bacterium concrete displayed 12.12% and 5.12 % higher compressive strength in M25 grade where 4.36 % & 3.98 % in M50 grade concrete at 7, and 28d. Increase in strength in bacterial concrete was due to formation of calcite within pores of the cement sand matrix with concentration 10⁵ cells/ml.

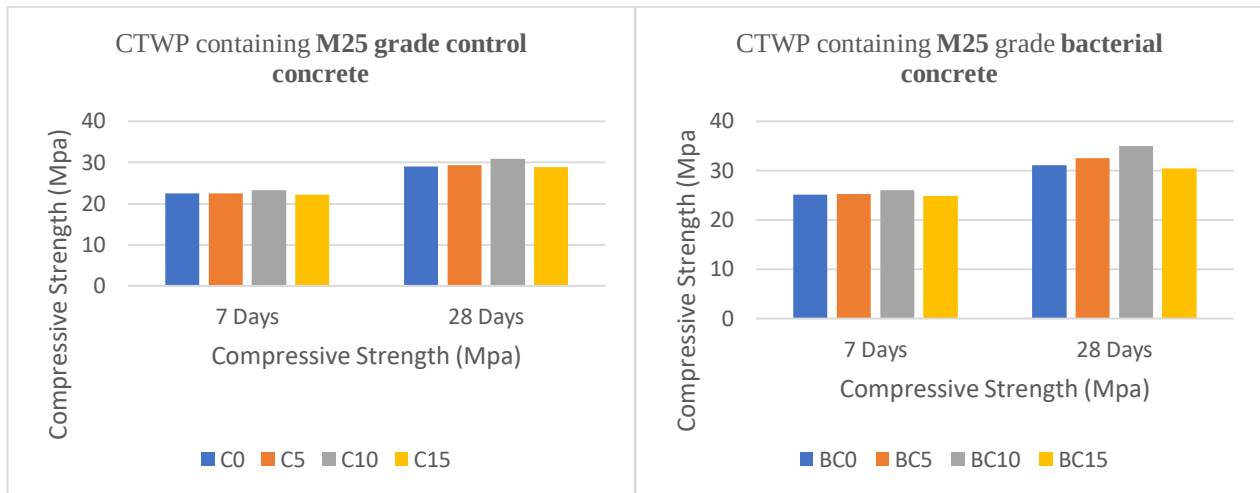


Figure 1 Compressive strength of M25 grade control and bacterial concrete

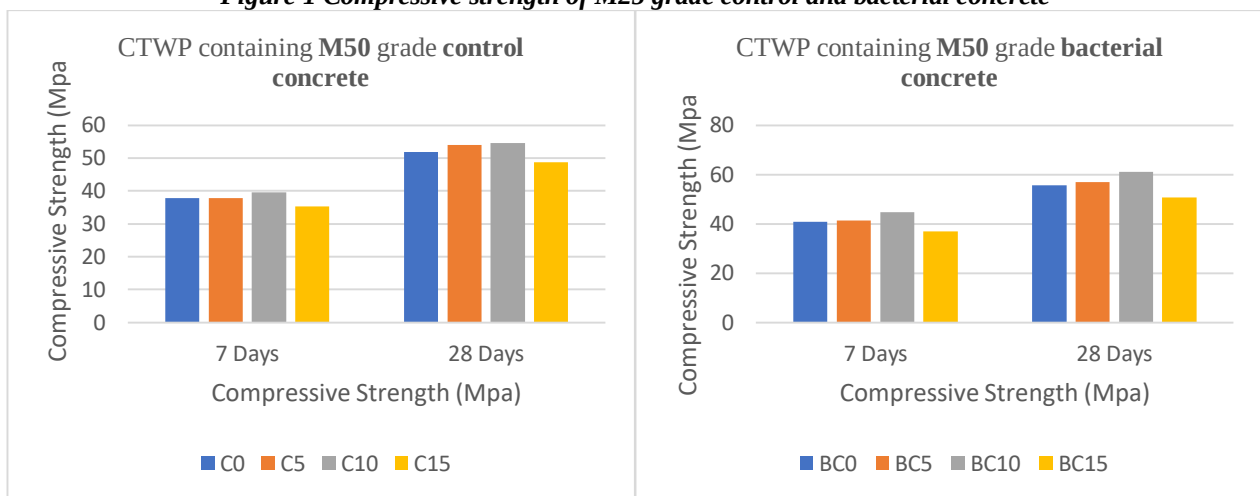


Figure 2 Compressive strength of M50 grade control and bacterial concrete

3.2 Flexural strength test

Flexural strength results of CTWP concrete and bacterial concrete mixtures are shown in fig 3 & 4. Flexural strength of concrete mixtures containing CTWP increased with increase in CTWP content up to 10% as cement replacement and concrete mixture 15% CTWP displayed lower flexural strength than the control concrete. The concrete mixture containing 10% CTWP as replacement of cement displayed optimum increase in compressive strength at all the ages. The increase in flexural strength of concrete mixture C10 was by 3.73 % in M25 grade where 8.6 1% in M50 grade with respect to control concrete and at C15 flexural strength was reduced – 2.24 % and - 1.32 % in M25 and M50 grade concrete with respect to control concrete at the age of 28 d. bacterial concrete mixtures containing 10% CTWP displayed 8.63 % and 10.37 % higher flexural strength in M25 and M50 grade concrete , where at 15% CTWP displayed 2.29 % and 6.71 % higher flexural strength in M25 and M50 grade concrete at 28d.

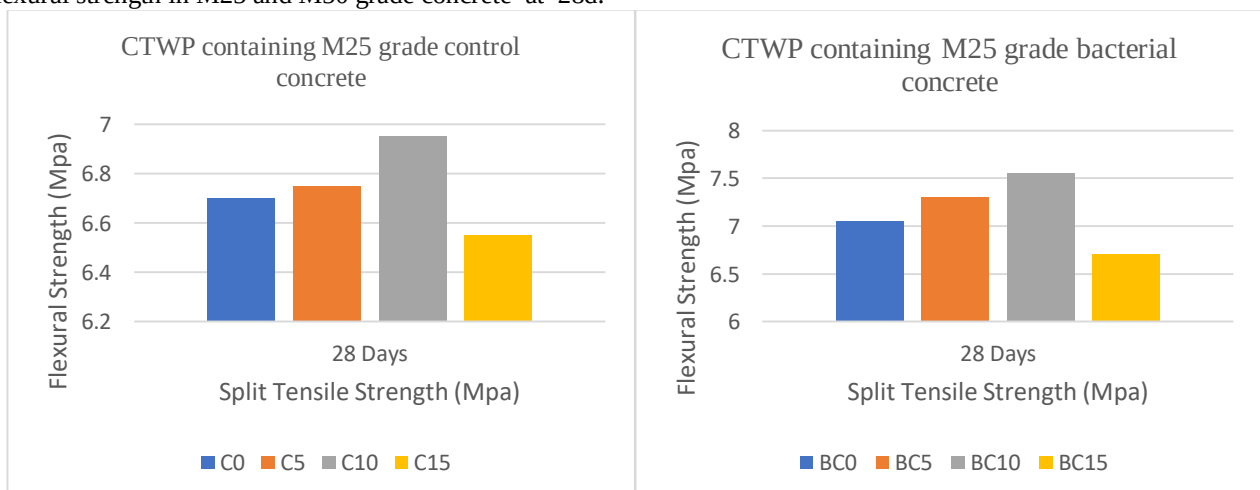


Figure 3 Flexural strength test of M25 grade control and bacterial concrete

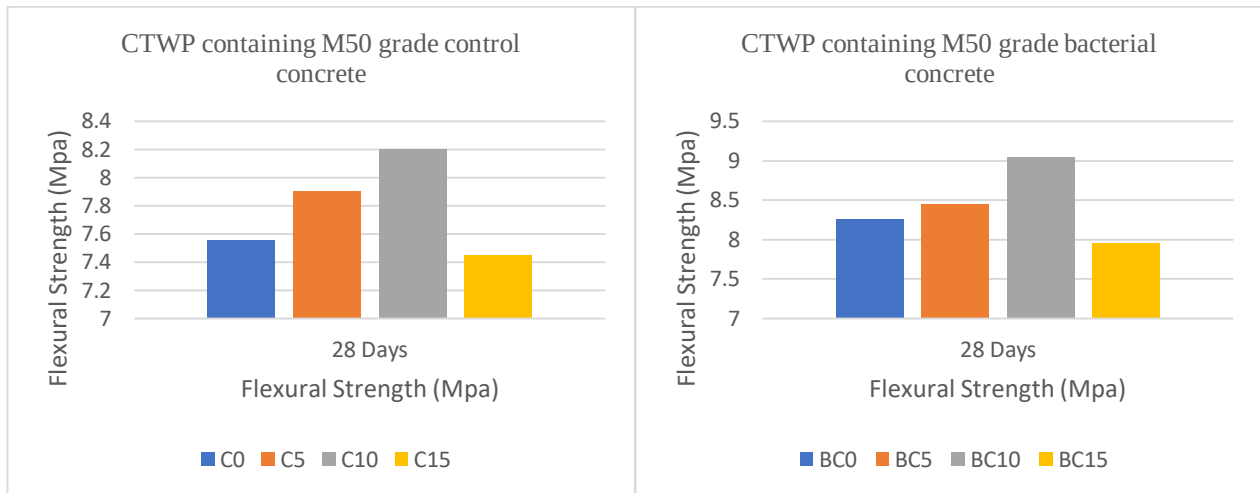


Figure 4 Flexural strength of M50 grade control and bacterial concrete

3.3 Split tensile strength test

Tensile strength results of CTWP concrete and bacterial concrete mixtures are shown in fig.5 & 6. Tensile strength of concrete mixtures containing CTWP increased with increase in CTWP content up to 10% as cement replacement and concrete mixture 15% CTWP displayed lower tensile strength than the control concrete. The concrete mixture containing 10% CTWP as replacement of cement displayed optimum increase in tensile strength at all the ages. The increase in tensile strength of concrete mixture C10 was by 7.77% in M25 grade where 3.23 % in M50 grade with respect to control concrete and at C15 tensile strength was reduced -1.55 % and -1.21 % in M25 and M50 grade concrete with respect to control concrete at the age of 28 d. bacterial concrete mixtures containing 10% CTWP displayed 11.30 % and 11.33 % higher tensile strength in M25 and M50 grade concrete, where at 15% CTWP displayed 8.95 % and 1.63 % higher tensile strength in M25 and M50 grade concrete at 28d.

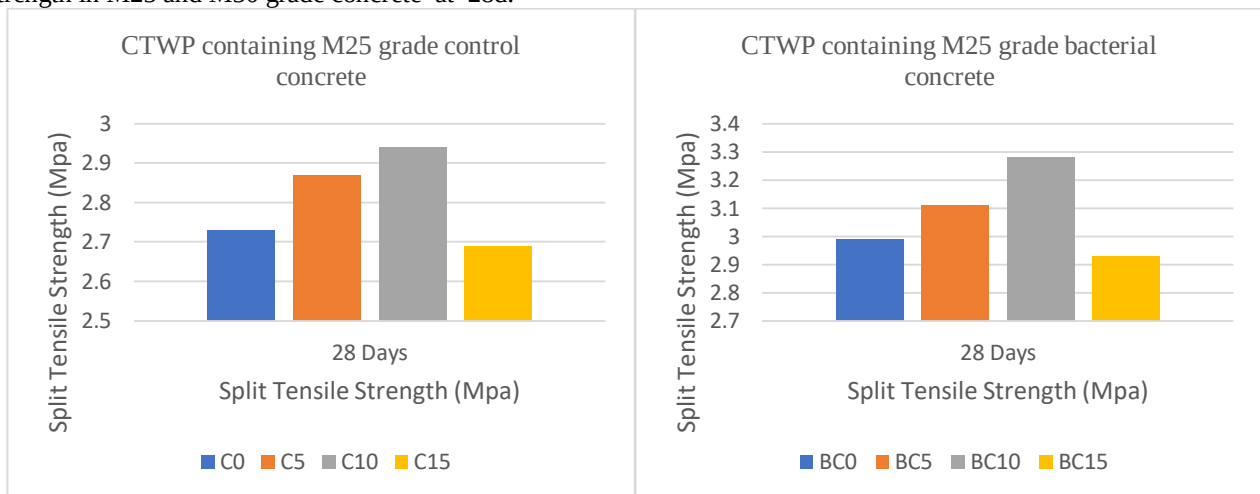


Figure 5 Tensile strength of M25 grade control and bacterial concrete

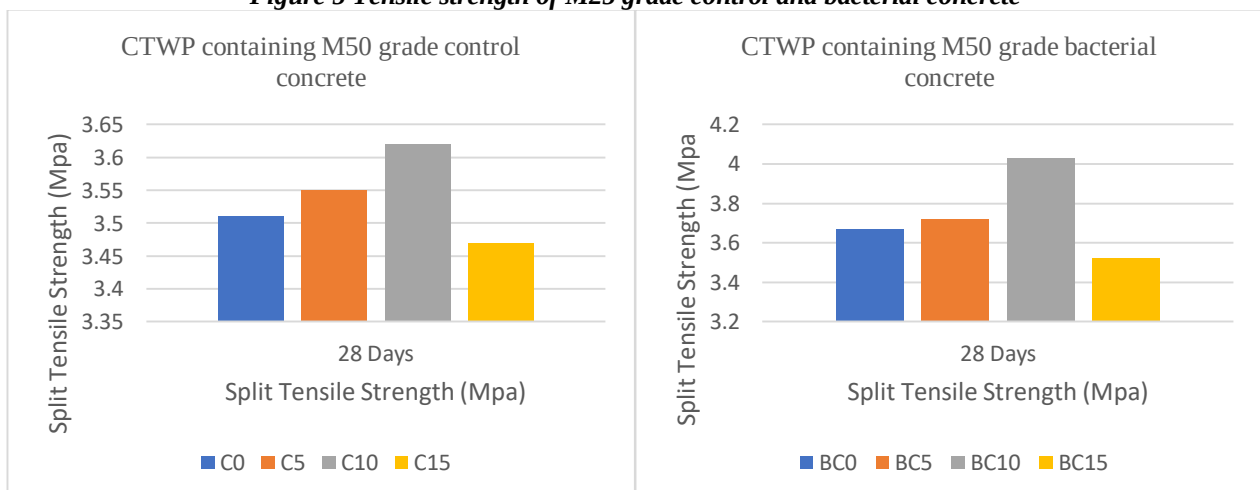


Figure 6 Tensile strength of M50 grade control and bacterial concrete

IV. CONCLUSIONS

- Bacteria cells addition in CTWP concrete further improved its strength. Optimum dosages of CTWP as cement replacement in concrete was 10%. The compressive strength of concrete decrease, when the addition of dosage is more than 10%. The result show if 15% replacement of cement by ceramic tile powder will decrease the strength of concrete
- On replacing cement with **10% tile powder** in **M25 grade bacterial concrete** displayed, increase in **compressive, split tensile & flexural strength** is **13.39 % 11.30 % & 8.63 %** respectively, where on replacing cement with **10% tile powder** in **M50 grade bacterial concrete** displayed increase in **compressive, split tensile & flexural strength** is **11.99 % 11.33 % & 10.37%** respectively at age of 28 days.
- On replacing cement with **10% tile powder** in **M25 grade control concrete** displayed **6.49 % 7.77 % & 3.73 %** increment in **compressive, split tensile, & flexural strength** respectively. Where on replacing cement with **10% tile powder** in **M50 grade control concrete** displayed **5.02 %, 3.23 % & 8.63 %** increment in **compressive, split tensile, & flexural strength** respectively
- It is found that addition of bacillus megaterium bacteria had a positive effect on high strength structural concrete. Therefore, the bacterial concrete made using B. megaterium can be recommended to be used as a green building material in the construction industry
- By doing this project we could gave a contribution to the society by making the environment eco-friendlier by utilizing the ceramic tile waste scientifically.
- Thus, by adopting replacement method we can overcome problems such as waste disposal crisis. Utilization of tile powder and its application for the sustainable development of the construction industry is the most efficient solution and also address the high value application of such waste

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