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STRENGTH PARAMETERS OF CONCRETE BY USING BIO-CEMENT

Praveen Suvarna[1], Athmadev B.[1]

[1]Department of Civil Engineering, P. A. College of Engineering, Mangaluru, Karnataka, India.

*Corresponding Author: Dr. Praveen Suvarna Email:praveen_civil@pace.edu.in

Abstract:

Concrete is the most consumed artificial cementitious material because of rapid urbanization. Modern concrete is not sustainable and is one of the biggest causes of anthropogenic greenhouse gas emissions. A possible technique to imitate nature's sustainability methods is through microbial precipitation of $CaCO_3$. In the present work, an attempt is made to create concrete using Bacteria by Microbial induced Calcite Precipitation (MICP) method. By using a certain species of bacteria from the order of Bacillales. In the present study, Bacillus Cohnii bacteria is used. The test results indicate that in the presence of Bacillus Cohnii bacteria media is insufficient to create concrete only using GGBS and fly ash. The study indicates a minimum use of 30% of cement is obvious for making concrete using Bacillus Cohnii bacteria. The compressive test results shows Bacillus cohnii bacterial may contribute 2% to 4% increase in compressive strength of concrete. The compressive strength of the mixture with 30% cement, 50 % GGBS, and 20% Fly ash is nearly in the range of concrete using 100% cement.

Key Words: Bio-Cement, Microbial induced Calcite Precipitation, Bacillus Cohnii.

1. Introduction

Around the world, the building sector has a significant impact on social and economic growth. However, it has a significant carbon footprint because it uses a lot of energy during every stage of manufacturing, from gathering raw materials to building structures. This quickens the process of global warming, ice cap melting, and the subsequent rise in sea levels. The population of the world is suffering because of this environmental issue. The building materials that release the most carbon dioxide (CO_2) during the production of burnt clay brick, concrete, and cement mortar. The traditional binding powder for the creation of mortar and

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concrete is cement. Cement production contributes significantly to the world's CO_2 emissions, accounting for about 2.4 percent of all CO_2 emissions from energy and industrial sources. Calcium plays an important role in the concrete. In the present study, the Microbially induced calcium carbonate precipitation method is used to produce calcium. MICP is the use of microbial metabolism to induce the production of calcium carbonate ($CaCO_3$) by mineralization. Microbially induced calcium carbonate precipitation (MICP), enzyme-induced calcium carbonate precipitation (EICP), and microalgae-induced calcium carbonate precipitation are the three fundamental construction biotechnology approaches (MAICP). All the methods use urea and $CaCl_2$ as common ingredients and bacteria, urease enzymes, or microalgae for MICP, EICP, and MAICP, respectively, to produce calcium carbonate ($CaCO_3$) precipitation. The bio-cementation method makes use of the calcium carbonate that is deposited by specific organisms. One of the essential components for accomplishing bio-cementation and accelerating bio-mineralization is urease. Therefore, the bio-cementation technique can be divided into Microbially Induced Carbonate Precipitation (MICP) and Enzymatically Induced Carbonate Precipitation (EICP) depending on various urease sources. The bacteria used in the project is Bacillus Cohnii. Hence, the present study is focused on finding the use of bacteria in the process of production of cement.

Many researchers like Achal et al. (2009) [1], Muynck et al. (2010) [2], and Kaur et al. (2013) [3] worked on the use of bacteria in concrete. They concluded that the presence of bacteria will increase the compressive strength of concrete. Karunagaran (2014) [4] and Azadi et al. (2017) [5] worked on the use of bacteria in the making of soil bricks and soil stabilizations respectively. Qian et al. (2018) [6], Chandrasiri et al. (2019) [7], Irfan et al. (2019) [8], and Nething et al. (2020) [9] explore the use of bacteria for the creation of bio-cement.

Nething et al. (2020) [9], have studied that that a new sustainable technology is the replacement of Portland cement used in the manufacture of building materials with bio-cement made from microorganisms. Bricks and other bio-cemented building materials have been manufactured in molds where bacteria-containing aggregates solidify when treated with a cementing solution, limiting the size of the component. These restrictions may be removed with the aid of additive manufacturing techniques. In the current work, an automated method for creating spatial structures has been devised. Sand and calcium carbonate powder that is urease active were placed in certain locations inside a print volume and then treated with a cementing solution. In the powder-containing sections, this technique created the right circumstances for calcite

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precipitation. The 3D-printed construction had well defined limits and was geometrically stable. Testing for compressive strength on cylinder specimens revealed that the powder-sand mixture utilized may produce high-strength bio-cemented materials. The current work shows how bio cement can be used in an additive manufacturing method to create building components that are resource-efficient and sustainable.

Kala and Lakshmi (2022) [10] have studied that concrete by its nature contains microcracks, which weaken structures. The toxicity and other shortcomings of the techniques utilized to manage microcracks prevent them from being fully effective. When bacteria are utilized in fresh concrete, calcite precipitates in the voids, increasing the strength and decreasing the permeability of the concrete. Bacillus pasteurii 5%, urea, and calcium lactate 95% are the ingredients that make up bio-cement. In this investigation, compressive strength and flexural strength values for M25 grade concrete were measured after 7 and 28 days of curing by adding 0, 0.5, 1, and 2% Bio-cement by weight of cement.

Wang et al. (2022) [11] Due to its high compressibility and poor strength, calcareous sand is commonly found in coastal areas all over the world and is typically regarded as a weak and unstable material. A method for enhancing soil is microbial-induced calcium carbonate precipitation (MICP). The widely used bio-augmented MICP method is less natural soil environment friendly than other approaches, nevertheless. Therefore, the bio-stimulated MICP technique is the main focus of this investigation since it is thought to be more effective and is likely to prolong the dominance of ureolytic bacteria. This paper's main goal is to examine the compressibility of calcareous sand that has been treated using a bio-stimulated MICP technique. A series of one-dimension compression tests on bio-cemented sand made through bio-stimulation with various initial relative densities were carried out in the current study.

2. OBJECTIVE

The objectives of this study are,

1. To determine the effect of using calcium and urea for the formation of bio concrete.
2. To determine the effect of the curing period on the compressive strength of bio-concrete.

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3. METHODOLOGY

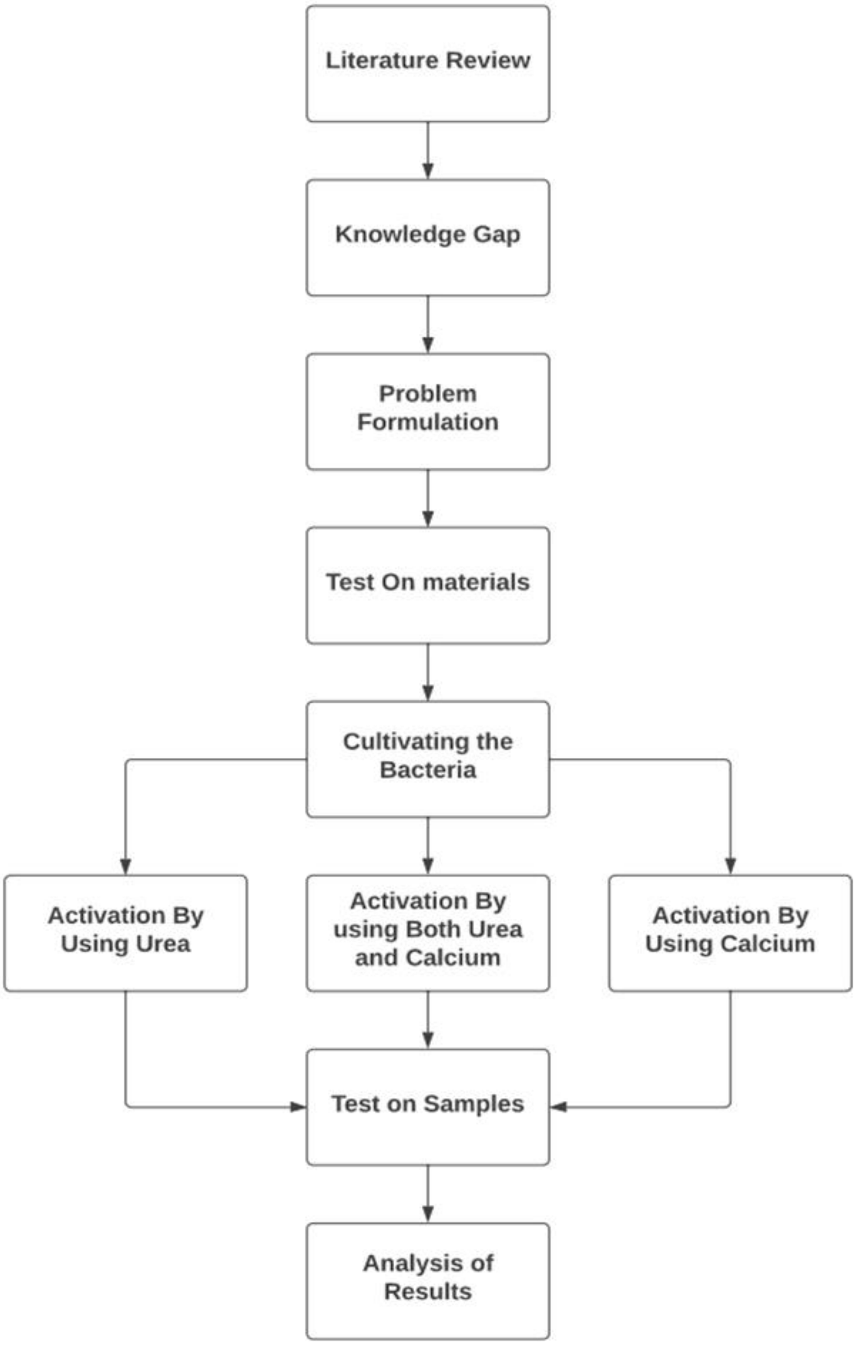

Figure 1: Methodology

4. RESULT AND DISCUSSIONS

4.1 MATERIALS

- Bacteria: Bacillus Cohnii.
- Fine Aggregate (Sand): Passing through 4.75mm sieve.

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- Coarse Aggregate: Passing through 20mm sieve.
- Ground Granulated Blast-furnace Slag.
- Fly Ash.

4.2 BACTERIA

- Full Scientific Name: Bacillus Cohnii Spanka and Fritze 1993
- Species: Bacillus Cohnii
- Domain: Bacteria
- Phylum: Firmicutes
- Class: Bacilli
- Order: Bacillales
- Family: Bacillaceae
- Genus: Bacillus

4.3 BACTERIA MEDIA

- Culture Medium: Alkaline Nutrient Agar
- Culture Medium Composition: Alkaline Nutrient Agar . After sterilization add sterile 1M Na-sesquicarbonate solution (1 ml in 10 ml) to achieve a pH of 9.7 Na-sesquicarbonate solution: $NaCHO_3$ anhydrous 5.3g Distilled water 100ml
- Temperature: 30° (optimum)
- Temperature Range: Mesophilic

4.4 PROCESS OF MEDIA PREPARATION

The media (liquid) considered for the culturing the bacteria was constituted by adding 5.00 g of peptone to 3.95 g of calcium acetate and 3.00 g of meat extract in 1 litre of distilled water. The resultant mixture constituted the liquid medium per stock culture.

Sterilization of the mixture was carried out by autoclaving at a temperature of 121°C.This was done for 20 minutes. This mixture was then cooled to room temperature. The media (liquid) considered for the culturing the bacteria was constituted by adding 5.00 g of peptone to 3.95 g of calcium acetate and 3.00 g of meat extract in 1 litre of distilled water. The resultant mixture constituted the liquid medium per stock culture. Sterilization of the mixture

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4.5 PREPARATION OF LIQUID CULTURE

Bacillus cohnii bacterial culture was transferred to 50 mL falcon tubes (Fig 10). Each falcon tube was centrifuged at 10,000 rpm for 10 min to separate bacterial cells, the supernatant was disposed of, and bacterial cells (pellets) were harvested for re-suspension in physiological solution (NaCl, 9 g/L). The required concentration of 105 cells/mL was adjusted by checking with a calorimeter at 600nm. Then, the bacterial cells were suspended in a nutrient solution containing calcium nitrate (20 g/L), urea (20 g/L) and yeast extract (2 g/L) of cement mass. The solution was then mixed to avoid precipitation. The concentrations of calcium nitrate, urea, and yeast extract were 2%,2%, and 0.2%, respectively.

5. EXPERIMENTAL WORK

An experimental investigation was performed to find the effect of using Bacillus Cohnii to produce concrete. In the present work, concrete cubes are cast using a mold of size 150×150×150 mm. To find the effect of bacteria and its related strength experiments are conducted in seven different trials. The each trial had varying quantities of GGBS, Fly ash, and Bacteria. Variation for bacteria was taken as 50% and 10%. For compression, a trail mix of 1:1.5:3 was adopted. The water and (GGBS+ Fly ash) ratio was taken as 0.5.

5.1 PHASE 1

An initial trial was conducted by using sand and coarse aggregate without any GGBS, Fly ash or Cement. Sand and coarse aggregate were taken in equal proportions. The liquid culture was added to the mixture of the sand and coarse aggregate and subjected to curing.

After 7 days of curing, it was observed that there was no bonding between the fine and coarse aggregate. Hence, the initial trial failed to achieve any bonding between the aggregated and the bacteria did not show any signs of bonding or calcium precipitation.

5.2 PHASE 2

Since phase 1 fails to achieve desired compression strength. The phase 2 is performed using GGBS and Fly ash. In each trial, an attempt is made to use 10% and 50% of bacteria. The percentage of the materials used is given in the table below.

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Table 1: Trail mix for Phase 2

	GGBS (%)	FLYASH (%)
TRAIL A	30	70
TRAIL B	70	30
TRAIL C	50	50

After the cubes were cast with 10 and 50% bacteria the cubes were left to cure. There were 18 cubes (9 with 10% bacteria and 9 with 50% bacteria) cast for each trial. After 7 days it was observed that the cubes failed to create any bonding between the ingredients. Hence, the cube crumbled as it was being removed from the mold resulting in zero compressive strength.

From this phase, it can be concluded that the GGBS and Fly ash did not have any bonding strength nor did the bacteria have any effect on it.

5.3 PHASE 3

As phases 1 and 2 were failed, it was decided to use a small portion of cement to create initial bonding between the aggregates. The percentage of Fly ash was set as 20%. In the Phase 3 10% and 50% of bacteria was used. The cubes were cast and cured for 7 and 14 days and was tested for compressive strength.

Table 6.2 shows the proportions of the materials taken for the current setup.

Table 2: Trail mix for Phase 3

	GGBS (%)	FLYASH (%)	CEMENT (%)
TRAIL D	50	20	30
TRAIL E	30	20	50
TRAIL F	0	0	100

The following are the results of the test conducted on the cubes that were casted.

Table 3: Seven days of curing and 10% bacteria

SAMPLE	AVERAGE COMPRESSIVE LOAD (KN)	STRENGTH (N/mm2)
D1	430	19.111
E1	420	18.667

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F1	440	19.556

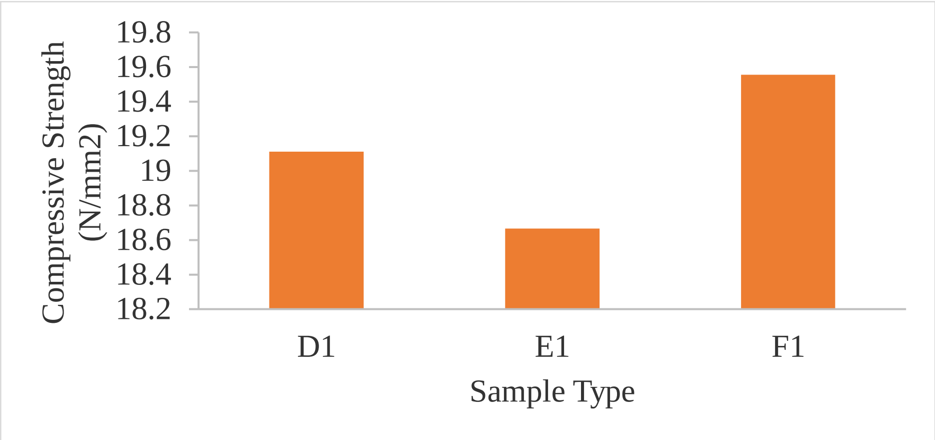

Figure 2: 7 days of compression strength with 10% bacteria – Phase 3

Table 4: Fourteen days of curing and 10% bacteria

SAMPLE	AVERAGE COMPRESSIVE LOAD (KN)	STRENGTH (N/mm2)
D1	460	20.444
E1	450	20
F1	470	20.889

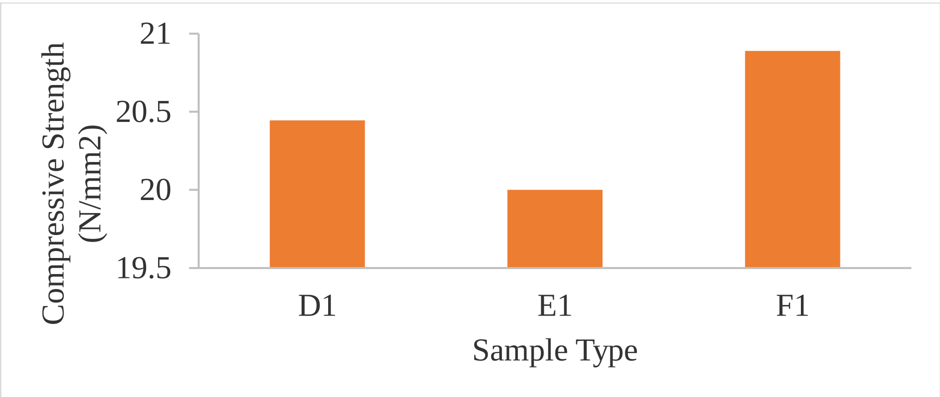

Figure 3: 14 days of compression strength with 10% bacteria - Phase 3

Table 5: Seven days of curing and 50% bacteria

SAMPLE	AVERAGE COMPRESSIVE LOAD (KN)	STRENGTH (N/mm2)
D1	440	19.556
E1	430	19.111

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F1	450	20

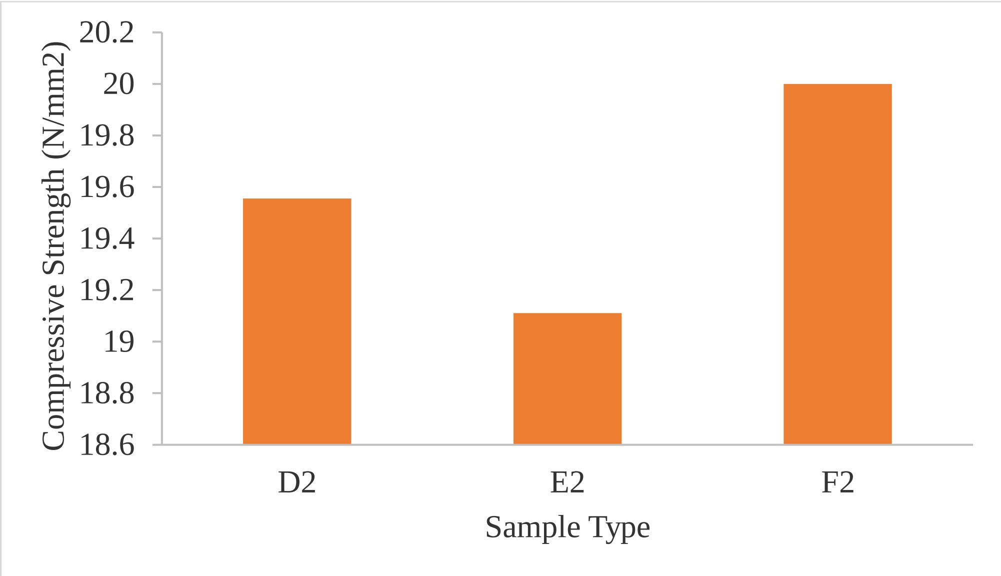

Figure 4: 7 days of compression strength with 50% bacteria - Phase 3

Table 6: Fourteen days of curing and 50% bacteria

SAMPLE	AVERAGE COMPRESSIVE LOAD (KN)	STRENGTH (N/mm2)
D1	480	21.333
E1	460	20.444
F1	490	21.778

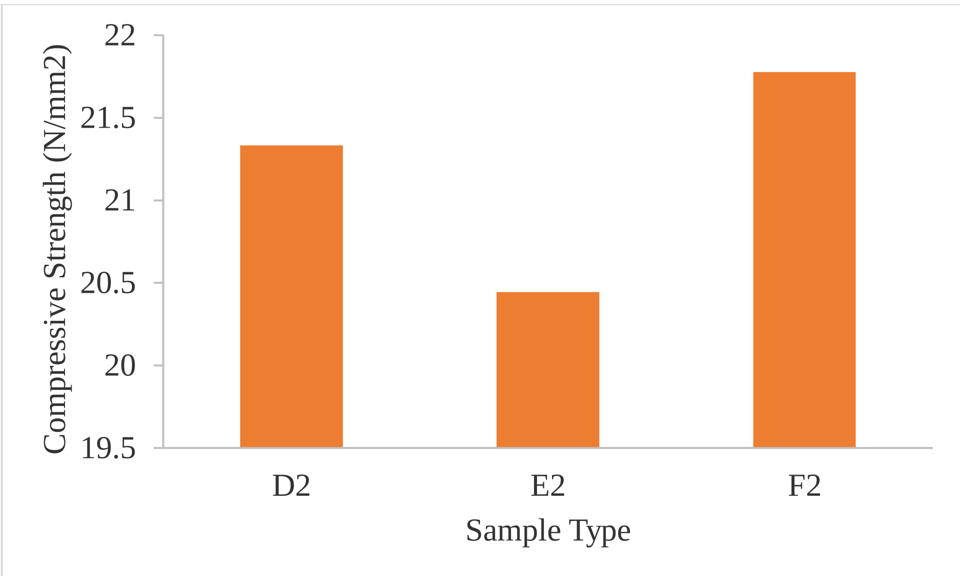

Figure 5: 14 days of compression strength with 50% bacteria - Phase 3

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5.4 COMPARISION

The following are the figures representing the compressive strengths of the cubes with 10% and 50% of bacteria used.

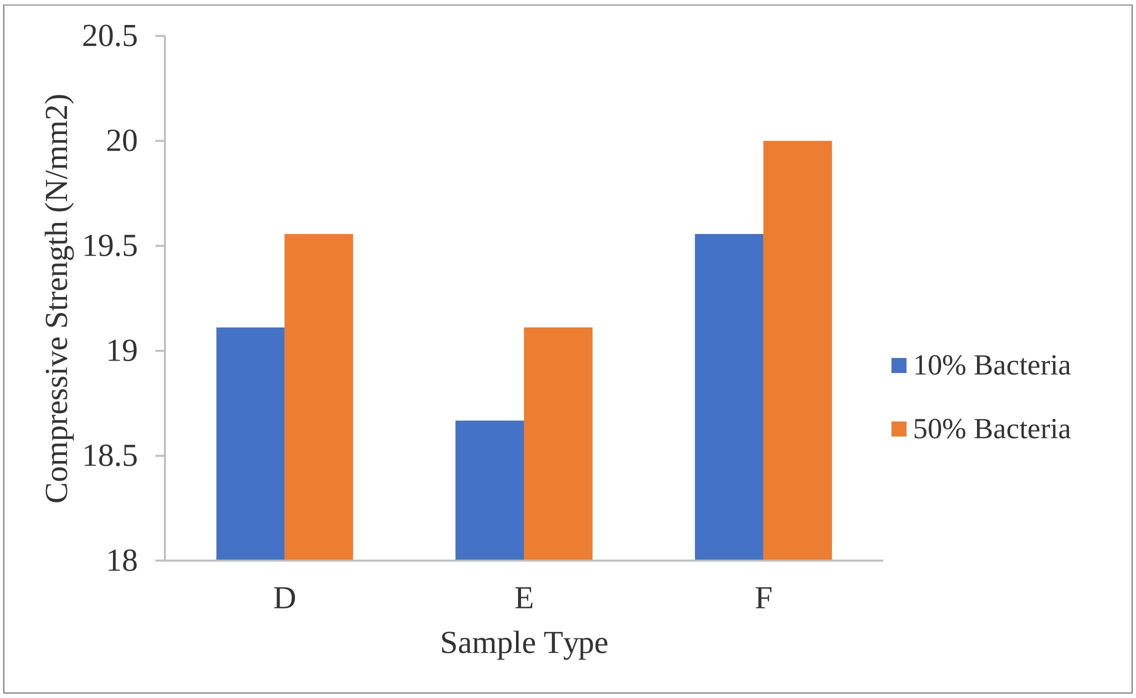

Figure 6: Effect of bacteria on 7 days compression strength

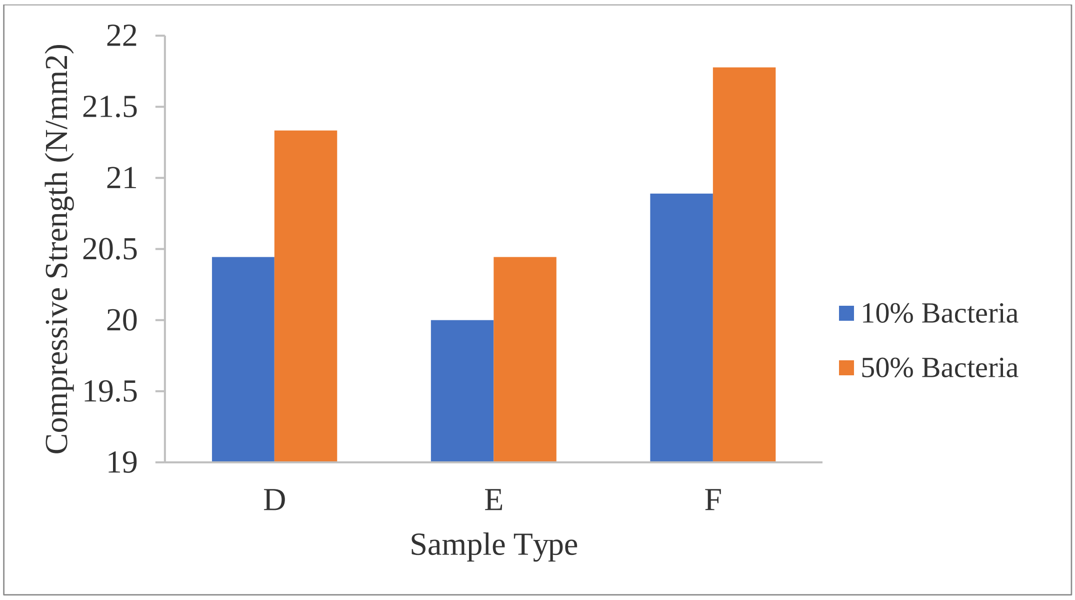

Figure 7: Effect of bacteria on 14 days compression strength

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6. CONCLUSION

Based on the present study following conclusions were made,

- There was no effect of bacteria on cubes cast using GGBS and Fly ash.
- A minimum of 30% cement is required to act as binding material.
- Bacillus cohnii bacterial may contribute 2% to 4% increase in compressive strength.
- The compressive strength of the mixture with 30% cement, 50 % GGBS, and 20% Fly ash is nearly in the range of concrete using 100% cement.

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