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Experimental Evaluation of Strength in Bacterial Concrete Mixtures

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Abstract

The incorporation of bacteria into concrete, through the process of Microbiologically Induced Calcite Precipitation (MICP), offers a promising approach to enhancing the mechanical properties and durability of concrete. This research explores the effect of bacterial addition on the compressive strength, split tensile strength, flexural strength, and workability of concrete. Specifically, three bacterial strains—Bacillus megaterium, Bacillus subtilis, and Pseudomonas aeruginosa—were used in varying concentrations (10^4, 10^5, and 10^6 cells/ml) and incorporated into M20 grade concrete. The findings demonstrate that the addition of bacteria results improved workability without additional water demand, with bacterial concrete exhibiting better finishing characteristics. At 28 days, cube compressive strength increased by 24%, 19%, and 21% for Bacillus Megaterium, Bacillus Subtilis, and Pseudomonas Aeruginosa, respectively. Similarly, splitting tensile strength rose by 25%, 21.5%, and 23.6%, while flexural strength improved by 27%, 22.4%, and 24.4% for the same bacteria. Additionally, the study highlights the potential for improved performance due to bacterial activity within the concrete matrix, with possible applications for more sustainable and long-lasting construction materials.

Keywords: Bacterial concrete, bacillus megaterium, bacillus subtilis, pseudomonas aeruginosa, micp, compressive strength, tensile strength, flexural strength, sustainable concrete

INTRODUCTION

Bacterial concrete is an innovative material developed by incorporating bacteria capable of consistently precipitating calcite into the concrete mix. This process, known as Microbiologically Induced Calcite Precipitation (MICP), enhances the strength and durability of concrete by filling voids, cracks, and pores within the structure [1–5].

MICP relies on specific microorganisms, biochemical pathways, and environmental conditions to deposit calcium carbonate ($CaCO_3$). This bio-based repair mechanism effectively plugs micro-cracks and pores, offering a sustainable, eco-friendly, cost-effective, and durable alternative to traditional repair techniques. Urease-positive bacteria play a crucial role in this process by utilizing the urease enzyme to hydrolyze urea into CO_2 and ammonia, which increases pH levels and facilitates calcite precipitation. The calcium carbonate crystals are deposited on bacterial cell walls through heterogeneous nucleation, leading to a dense and impermeable concrete microstructure [6-9].

Under optimal conditions, calcite formation activated by bacteria enhances concrete durability, reduces maintenance costs, and minimizes crack

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formation and propagation. Research by Guang Ye et al. (2017) highlights that bacterial concrete mitigates the effects of corrosive ions in pore water, which degrade traditional concrete. The self-healing properties of bacterial concrete have made it a promising material for addressing durability issues in concrete structures [10-13].

Bacterial concrete operates through MICP, producing calcite crystals that seal pores and cracks, improving concrete's impermeability to fluids and gases like water, chlorides, sulfates, and oxygen. Studies by Srinivasa Reddy et al. (2013) and Ramana Reddy et al. (2017) demonstrate that bacterial concrete exhibits superior strength, durability, and reduced permeability compared to conventional cement concrete [14-17].

The concept of bacterial concrete was pioneered by V. Ramakrishnan et al. (2005) to repair cracks and fissures in concrete using MICP. Their research revealed the effectiveness of $CaCO_3$ as a microbial sealant, showcasing its capability to consolidate fractures and surface fissures, supported by microscopic observations of bacterial activity around calcite crystals [18-20]

Objectives

The main objectives of this research on bacterial concrete are as follows:

- *To evaluate the effect of bacterial addition on the mechanical properties* of concrete, specifically compressive strength, split tensile strength, and flexural strength, at different curing ages (7, 14, 28, 56, and 90 days).
- *To assess the workability of bacterial concrete mixes* by performing standard tests such as slump test, compaction factor test, and Vee-Bee consistometer test, and to determine how bacterial incorporation influences the handling and compaction of concrete.

Material

The materials used in this study were selected based on their compatibility with bacterial activities. Ordinary Portland Cement (OPC) was used as the binder material, while locally sourced aggregates and potable water were employed for mixing the concrete. The bacterial strains used in this study were *Bacillus megaterium* (BM), *Bacillus subtilis* (BS), and *Pseudomonas aeruginosa* (PA), with concentrations of 10^4, 10^5, and 10^6 cells/ml. [21-25]

Mix Design

The mix design for M20 grade concrete was carried out according to IS: 10262-2009, with a water-cement ratio of 0.45. The control mix was prepared without bacteria, and bacterial concrete mixes were prepared by adding each bacterial strain at three different concentrations (10^4, 10^5, and 10^6 cells/ml) in the mixing water. A total of 10 different mixes were prepared, including the control specimen and nine bacterial concrete mixes [26-32].

RESULTS

Workability

The workability of concrete mixtures was measured using standard tests such as the slump test, compaction factor test, and Vee-Bee consistometer test. The results indicated that bacterial incorporation improved the workability of the mix, with higher bacterial concentrations generally leading to greater ease of handling and compaction.

Cube Compressive Strength

The compressive strength results for control concrete and bacterial concrete mixes at 7, 14, 28, 56, and 90 days are presented in Table 2. The strength development for M20-grade bacterial concrete, containing various bacterium types and concentrations, is depicted graphically in Figures 1 to 4.

Table 1. Shows the workability measurements for M20-grade bacterial concrete mixes.

Mix ID	**Bacteria Type**	**Cell Density (cells/ml)**	**Workability**		
			Slump (mm)	***Compaction Rate***	***Vee-Bee (sec)***
CS	Control Sample	-	98	0.9	8
BM1	Bacillus Megaterium	10^4	95	0.97	7
BM2	Bacillus Megaterium	10^5	105	0.92	7
BM3	Bacillus Megaterium	10^6	102	0.94	8
BS1	Bacillus Subtilis	10^4	98	0.96	8
BS2	Bacillus Subtilis	10^5	105	0.92	7
BS3	Bacillus Subtilis	10^6	109	0.93	8
PA1	Pseudomonas Aeruginosa	10^4	94	0.94	8
PA2	Pseudomonas Aeruginosa	10^5	107	0.92	7
PA3	Pseudomonas Aeruginosa	10^6	111	0.95	8

Test results indicate that at all ages, bacterial concrete specimens exhibit higher compressive strength compared to control concrete. The maximum compressive strengths at 28 days were achieved by bacterial mixes BM1, BS2, and PA2, with values of 34.97 MPa, 33.78 MPa, and 33.95 MPa, respectively. The optimal cell concentrations for achieving these strengths were found to be 10^4cells/ml for *Bacillus Megaterium*, and 10^5cells/ml for both *Bacillus Subtilis* and *Pseudomonas Aeruginosa*.

At 28 days, bacterial concrete showed an increase in compressive strength of approximately 24%, 19%, and 21% for Bacillus Megaterium, Bacillus Subtilis, and Pseudomonas Aeruginosa, respectively, compared to the control concrete. Among these, Bacillus Megaterium achieved the highest improvement in compressive strength (24%).

Table 2. Presents the cube compressive strength values for M20-grade bacterial concrete mixes.

Mix ID	**Bacteria Type**	**Cell Density (cells/ml)**	**Cube Compressive Strength**				
			7 Days	***14 Days***	***28 Days***	***56 Days***	***90 Days***
CS	Control Sample	-	19.22	23.46	28.64	29.49	30.1
BM1	Bacillus Megaterium	10^4	23.54	28.66	34.97	36.34	37.76
BM2	Bacillus Megaterium	10^5	22.33	27.64	33.75	35.07	36.11
BM3	Bacillus Megaterium	10^6	22.28	27.38	33.26	34.48	35.72
BS1	Bacillus Subtilis	10^4	21.71	26.54	32.36	33.39	34.92
BS2	Bacillus Subtilis	10^5	22.52	27.62	33.78	35.22	36.38
BS3	Bacillus Subtilis	10^6	21.86	26.68	32.53	34	35.07
PA1	Pseudomonas Aeruginosa	10^4	22.13	27.15	33.15	34.69	36.3
PA2	Pseudomonas Aeruginosa	10^5	22.63	27.85	33.95	35.67	36.87
PA3	Pseudomonas Aeruginosa	10^6	21.8	26.6	32.52	33.47	34.85

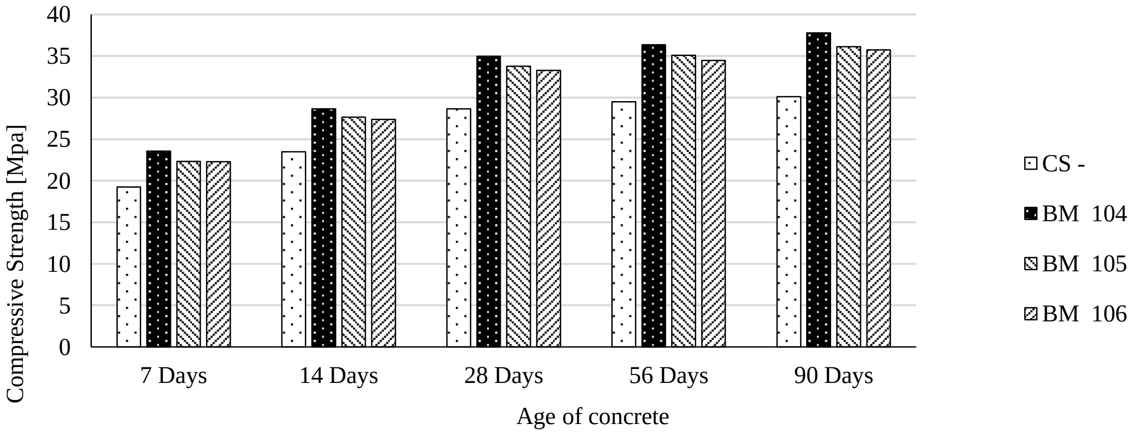

Figure 1. Illustrates the effect of BM bacteria on the compressive strength of M20-grade bacterial concrete mixes at different ages.

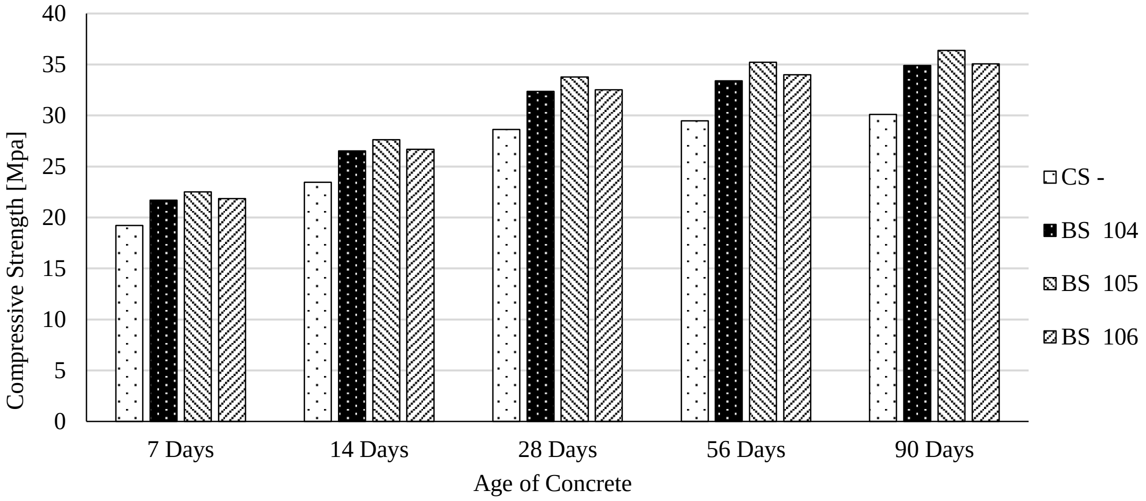

Figure 2. Depicts the influence of BS bacteria on the compressive strength of M20-grade bacterial concrete mixes across various ages.

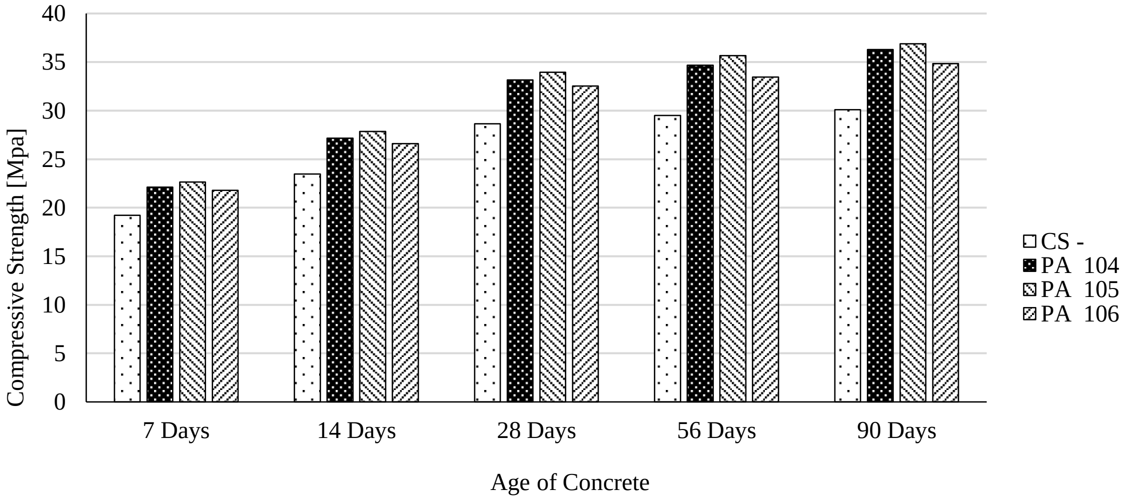

Figure 3. Demonstrates the impact of PA bacteria on the compressive strength of M20-grade bacterial concrete mixes over time.

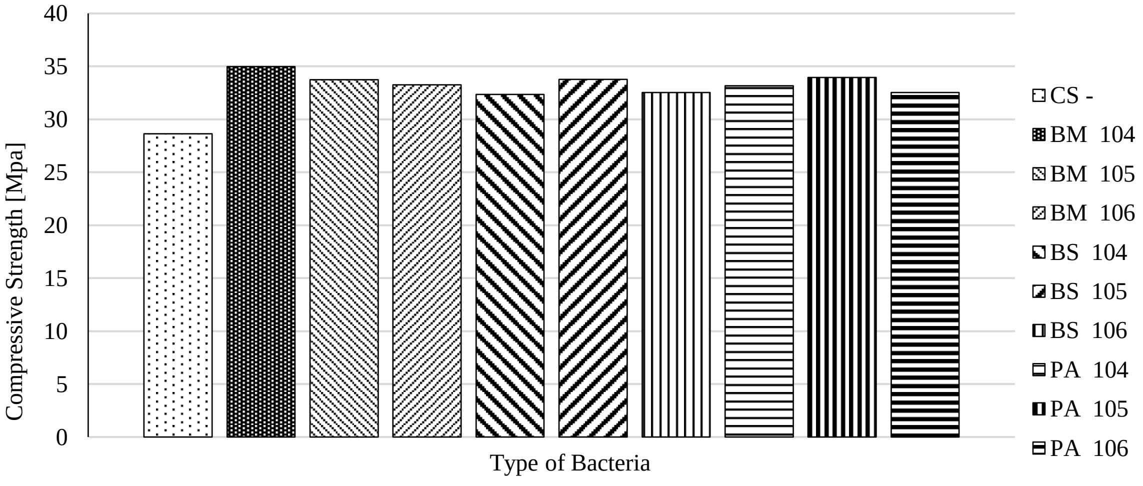

Figure 4. Highlights the optimum cell concentration of different bacteria types for achieving maximum compressive strength at 28 days.

Splitting Tensile Strength

The splitting tensile strength results for M20-grade control concrete and bacterial concrete mixes at 7 and 28 days are presented in Table 3. The variation in tensile strength influenced by different bacterium types and cell concentrations is illustrated graphically in Figures 6 and 7.

Test results reveal that the splitting tensile strength of all bacterial concrete specimens was higher than that of the control mix. At 28 days, the maximum tensile strengths were recorded for bacterial mixes BM1, BS2, and PA2, with values of 2.90 MPa, 2.79 MPa, and 2.86 MPa, respectively. The optimal cell concentrations for achieving these strengths were 10^4 cells/ml for Bacillus Megaterium and 10^5 cells/ml for both Bacillus Subtilis and Pseudomonas Aeruginosa.

The bacterial concrete mixes showed tensile strength increases of approximately 25%, 21.5%, and 23.6% for Bacillus Megaterium, Bacillus Subtilis, and Pseudomonas Aeruginosa, respectively, compared to the control concrete. Among these, Bacillus Megaterium achieved the highest tensile strength of 2.90 MPa.

Table 3. Summarizes the splitting tensile strength results for M20-grade bacterial concrete mixes.

Mix ID	Bacteria Type	Cell Density (cells/ml)	Mean Split Tensile Strength 7 days [Mpa]	Mean Split Tensile Strength 28 days [Mpa]
CS	Control Sample	-	1.56	2.33
BM1	Bacillus Megaterium	10^4	1.95	2.90
BM2	Bacillus Megaterium	10^5	1.80	2.74
BM3	Bacillus Megaterium	10^6	1.74	2.70
BS1	Bacillus Subtilis	10^4	1.71	2.59
BS2	Bacillus Subtilis	10^5	1.85	2.79
BS3	Bacillus Subtilis	10^6	1.78	2.63
PA1	Pseudomonas Aeruginosa	10^4	1.76	2.65
PA2	Pseudomonas Aeruginosa	10^5	1.90	2.86
PA3	Pseudomonas Aeruginosa	10^6	1.73	2.61

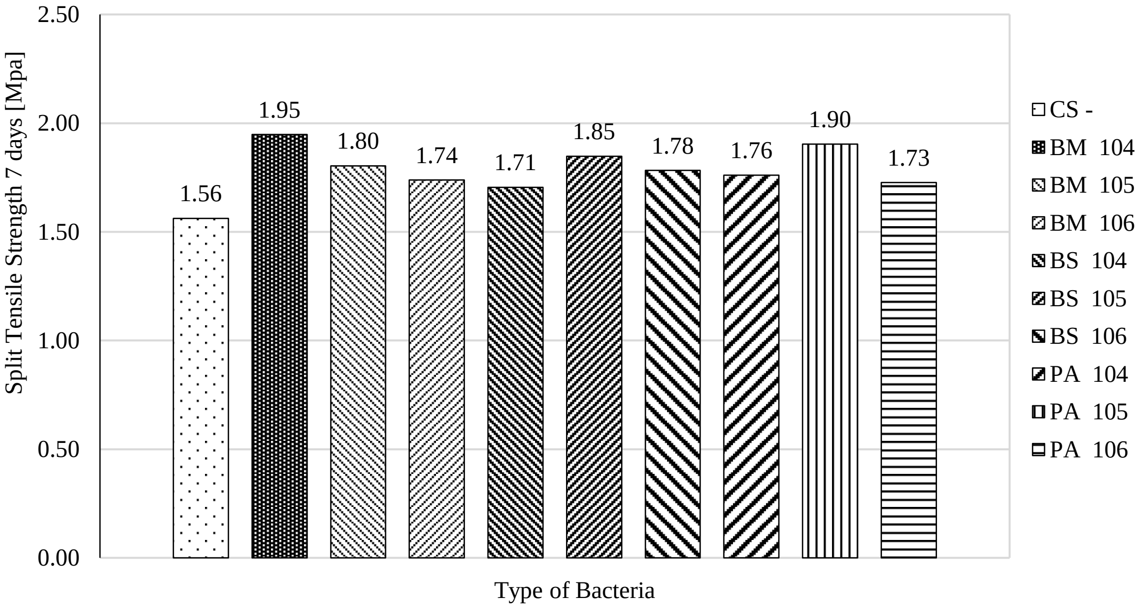

Figure 5. Displays the effect of various bacteria types on the splitting tensile strength of M20-grade bacterial concrete mixes at 7 days.

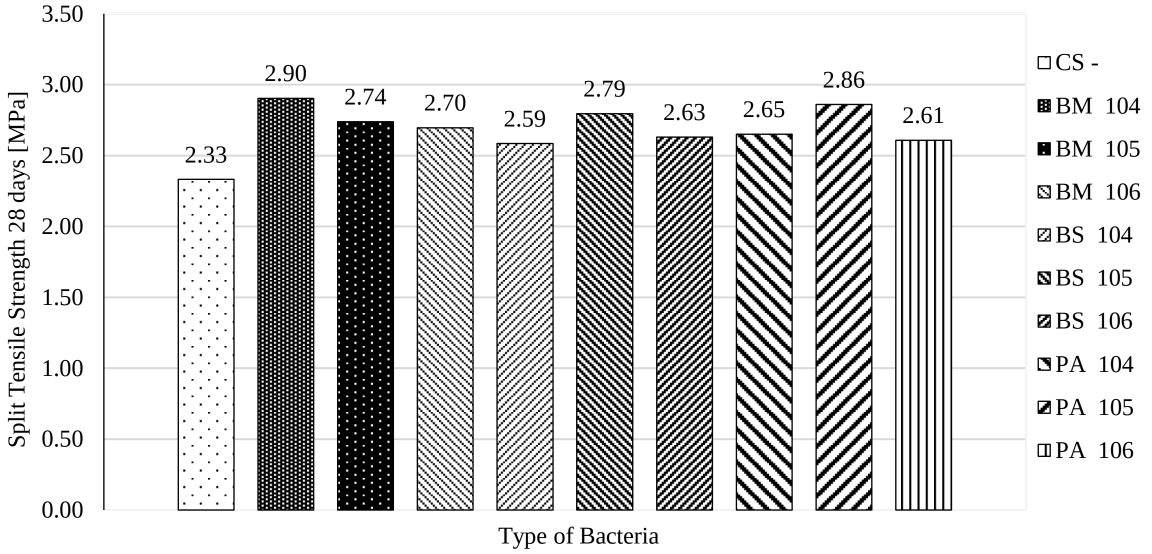

Figure 6. Shows the influence of different bacteria on the splitting tensile strength of M20-grade bacterial concrete mixes at 28 days.

Flexural Strength

The flexural strength results of M20-grade control and bacterial concrete mixes at 28 days are presented in Table 4, with the variation in strength due to bacteria and cell concentrations illustrated in Figure 7.

Test results reveal that the flexural strength of all bacterial concrete specimens exceeded that of the control mix. The maximum flexural strengths were recorded for bacterial mixes BM1, BS2, and PA2, with values of 5.18 MPa, 4.98 MPa, and 5.04 MPa, respectively, at 28 days. Optimal cell concentrations for maximum flexural strength were found to be 10^4 cells/ml for Bacillus Megaterium and 10^5 cells/ml for both Bacillus Subtilis and Pseudomonas Aeruginosa.

Compared to the control concrete, bacterial concrete showed flexural strength improvements of approximately 27%, 22.4%, and 24.4% for Bacillus Megaterium, Bacillus Subtilis, and Pseudomonas Aeruginosa, respectively. Among these, Bacillus Megaterium yielded the highest flexural strength at 5.18 MPa.

Table 4. Outlines the flexural strength results for M20-grade bacterial concrete mixes.

Mix ID	Bacteria Type	Cell Density (cells/ml)	Mean Flexural Strength 7 days [Mpa]
CS	Control Sample	-	4.12
BM1	Bacillus Megaterium	10^4	5.18
BM2	Bacillus Megaterium	10^5	4.94
BM3	Bacillus Megaterium	10^6	4.90
BS1	Bacillus Subtilis	10^4	4.78
BS2	Bacillus Subtilis	10^5	4.98
BS3	Bacillus Subtilis	10^6	4.82
PA1	Pseudomonas Aeruginosa	10^4	4.85
PA2	Pseudomonas Aeruginosa	10^5	5.04
PA3	Pseudomonas Aeruginosa	10^6	4.81

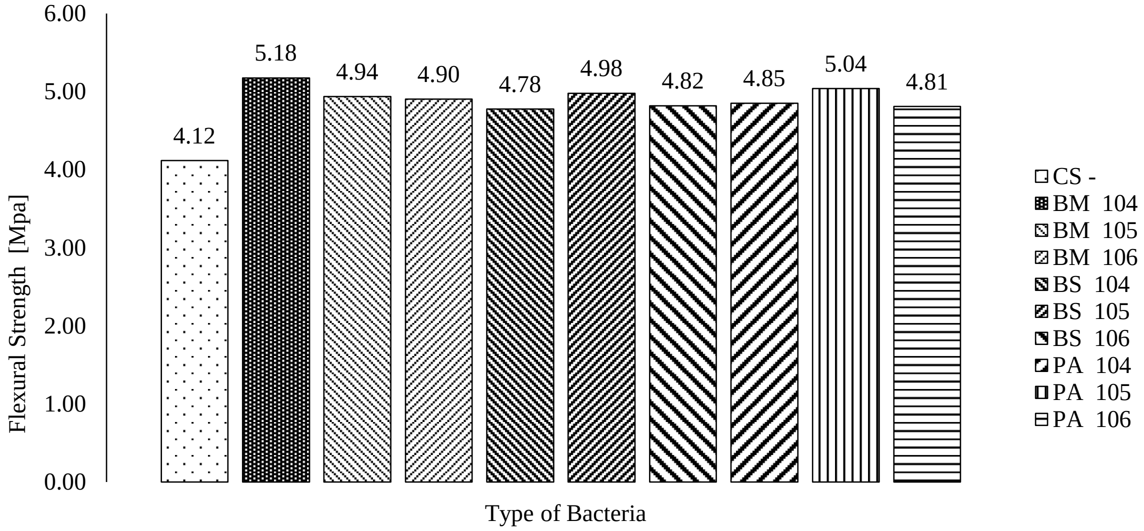

Figure 7. Presents the impact of various bacteria types on the flexural strength of M20-grade bacterial concrete mixes at 28 days.

CONCLUSIONS

The incorporation of bacteria such as Bacillus Megaterium, Bacillus Subtilis, and Pseudomonas Aeruginosa into concrete has proven to significantly enhance its mechanical properties. The key conclusions from this study are:

- *Workability:* Bacterial concrete exhibited improved workability without requiring additional water, demonstrating better finishing characteristics.
- *Compressive Strength:* Cube compressive strength increased by 24%, 19%, and 21% for Bacillus Megaterium, Bacillus Subtilis, and Pseudomonas Aeruginosa, respectively, compared to control concrete.
- *Tensile and Flexural Strength:* Splitting tensile and flexural strengths showed improvements of 21–27% due to bacterial inclusion, with the modulus of rupture being about 15% of the compressive strength.

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