*International Journal of Recent Research and Review, Vol. XVII, Issue 2, June 2024*
ISSN 2277 – 8322

# A STUDY OF SELF-HEALING CONCRETE PREPARED WITH BACTERIA TO PREVENT CRACKS

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***Abstract:*** The use of self-healing concrete provides an alternative method to repair cracks that form over time as a result of environmental impacts, heavy traffic, and defects in the material. This distinctive range of concrete contains microorganisms, including bacteria and fungi, along with nutrients and healing substances. These microbes are activated when water enters the cracks and begins to heal the concrete. They produce calcium carbonate, a material that fills up the cracks in the concrete and helps it restore its strength. This process is known as "self-healing" because it parallels the way our bones heal themselves. Self-healing concrete extends the life of structures, including bridges, buildings, and roads, while likewise improving their durability and lowering maintenance costs. This makes infrastructure more durable and resilient since it can tolerate degradation over time. In this research work consider M30 grade of concrete to perform experimental work. For this work use Bacillus subtilis, that is a type of bacteria and use silica fume and fly ash as replacement materials concrete mix. 0, 5, 10 and 15% Silica-fume and fly-ash are replacing with cement. Major goal of this work to find out optimum concentration of bacteria for concrete and after that prepared concrete mix with one combination is optimum solution of bacteria and silica fume second combination is optimum solution of bacteria and fly ash.

**Keyword:** Self-healing Concrete, Fly ash, Silica fume and Bacillus subtilis etc.

## I. INTRODUCTION

As concrete isn't especially resilient under tension, cracks in it are an ongoing issue. When these cracks bring in potentially risky liquids and gases, the durability of the concrete may be degraded. Longer cracks that eventually reach an internal metal reinforcement can corrode the material, producing even more damage. But a specific type of bacteria that may help to heal these cracks is identified as Bacillus subtilis. The strength and longevity of concrete structures or components can be increased by adding Bacillus subtilis to the concrete mixture. In addition, because Bacillus subtilis is not toxic or dangerous, it is safe for both humans and the environment. Concrete may heal itself with the addition of Bacillus subtilis microbes. A crack in the concrete surface causes water to enter and react with bacteria to make calcium carbonate ($CaCO_3$), a key component in lime. They pick calcium lactate as a chemical reactant that helps carry out the function since the bacteria require nutrition to survive.

Concrete, an essential material in the construction industry, has long been lauded for its durability and versatility. However, despite its widespread use, concrete structures are prone to damage over time, primarily due to cracking due to distinct factors like environmental situations, loading stresses, and material imperfections. These cracks affect not just the structural stability but also suffer substantial maintenance and repair costs, posing significant challenges for sustainable development and infrastructure resilience.The technique of self-healing concrete has gained popularity as an option for the common issue of crack development and growth in concrete structures. The function of self-healing mechanisms is to automatically fill up cracks in concrete, improving the durability of infrastructure and lowering the rate of repairs that are needed. Integrating bacteria-mediated healing processes into self-healing concrete is one of the innovative methods that has gained a lot of attention since it has a chance to entirely change the building materials industry.

### Engineering bacteria

Engineering bacteria, also known as genetic engineering of bacteria, involves manipulating the genetic material of bacterial cells to introduce specific traits or functionalities. This process typically entails modifying the bacterium's DNA using molecular biology techniques to achieve desired outcomes, such as enhancing its ability to produce certain compounds, tolerate environmental stresses, or perform specific tasks. The engineering of bacteria has numerous applications across various fields, including biotechnology, medicine, environmental science, and industrial processes. In the context of self-healing concrete, engineering bacteria involves designing strains that possess the capability to promote bio-mineralization, a process where minerals such as calcium carbonate are precipitated to fill cracks in concrete.

**Self-Healing Concrete**

An novel concept known as self-healing concrete was developed to repair cracks in concrete structures that occur over the years. Conventional concrete is strong, but it can break because of things like temperature changes, mechanical stress, chemical reactions, and shrinkage. The cracks not only affect the concrete's structural stability but also let pollutants and moisture in, increasing the harm. Several techniques are used by self-healing concrete to lessen cracking while supporting the self-healing of already present cracks. An essential method that develops when cracks form is the integration of industries, or healing sectors, into the business network.Several kinds of this treatment are available, such as:

- Microcapsules
- Self-activating Materials
- Bacteria
- Vascular Systems

**Figure 1 Self-healing concrete**

**Effect of Silica fume in bacteria mix concrete**

Concrete's mechanical features, like its flexural strength, resistance to abrasion, and compressive strength, have been found to be improved by silica fume. Additionally, enhancing the strength and durability of concrete mixes is achieved through the use of silica fume combined with bacterial enhancements. This is especially useful at times when more durable, high-performance concrete is needed. Due to its micro-particle size, silica fume can fill the pores and gaps in the framework of concrete, more effectively than conventional cement particles. This results in a denser microstructure and reduced permeability, which can help inhibit the ingress of moisture, aggressive chemicals, and harmful agents that could potentially affect the activity of bacteria in self-healing concrete. The workability and rheological features of fresh concrete can be affected by the integration of silica fume into concrete compositions. While silica fume tends to increase the viscosity and reduce the slump of concrete mixes, proper modifications in mix design and water-cementitious materials ratio can help maintain the desired workability and ease of placement, attempt to assure that the bacteria are distributed equally across the concrete composition.

**Effect of fly ash in bacteria mix concrete**

Fly ash particles are typically very fine, which can improve the workability and cohesiveness of fresh concrete mixtures. This can be advantageous in bacterial concrete applications, as it facilitates the uniform distribution of bacteria throughout the concrete composition during mixing and placement. The heat of hydration, which occurs throughout the process of hydration, will be reduced by mixing fly ash into the concrete mixture. This is particularly beneficial in significant concrete casts where excessive heat development may result in steel cracking and affect the structure's strength. Whenever fly ash and calcium hydroxide interact with water, extra-hydrated calcium silicate gel (C-S-H) forms. This gel helps a structure become stronger and more resilient. Compressive, flexural strength, affordability over chemical and sulfate exposure, and total material manufacturing knowledge are all increased when fly ash is added to bacterial concrete mixtures. By fixing the pores and spaces in the concrete structure, fly ash can help lower the permeation rate of concrete. This can strengthen the bacterial concrete's resistance to moisture surveillance, toxic compounds, and other dangerous substances that might otherwise compromise bacterial activity and the efficiency of self-healing mechanisms.

## II. OBJECTIVES

- To find out optimized concentration of bacteria into self-healing concrete.
- To identify the best mix percentage for fly ash and optimized bacteria.
- To identify the best mix percentage for silica fumes and optimized bacteria.

- To enhance the self-healing and durability of concrete together.
- To utilize waste material to prepared green concrete.

## III. PROBLEM STATEMENT

Concrete is one of the most utilized construction materials globally, owing to its resilience and strength. However, one common issue with concrete structures is the formation of cracks over time due to various factors such as shrinkage, structural loads, and environmental conditions. Some cracks not only settlement the structural integrity of the concrete but also increase maintenance costs and shorten the lifespan of the structure. To address this challenge, researchers have been exploring innovative solutions such as self-healing concrete. To heal micro-cracks easily that occur within the material, self-healing concrete has the ability, thereby prolonging its service life and reducing the need for costly repairs. One promising approach involves incorporating bacteria into the concrete mixture, which can produce calcite (calcium carbonate) in response to crack formation, effectively sealing the cracks and restoring the material's integrity. In this research work consider M30 grade of concrete to perform experimental work. For this work use Bacillus subtilis that is a type of bacteria and also use silica fume and fly ash as replacement materials concrete mix. 0%, 5%, 10% and 15% Silica fume and fly ash are replacing with cement. Major goal of this work to find out optimum concentration of bacteria for concrete and after that prepared concrete mix with one combination is optimum solution of bacteria and silica fume second combination is optimum solution of bacteria and fly ash.

## IV. METHODOLOGY

Bacterial-infused concrete is a novel solution designed to naturally generate limestone for the purpose of repairing cracks in concrete structures. During the mixing process, specific strains of Bacillus bacteria, alongside calcium lactate, a calcium-based nutrient, as well as nitrogen and phosphorus, are incorporated into the concrete ingredients. These self-healing agents remain inactive within the concrete for up to two centuries. Upon encountering moisture and nutrients from water infiltration through concrete cracks, the bacterial spores germinate and become active. They then metabolize the calcium lactate, triggered by this activation. When microbes consume the calcium lactate, they absorb oxygen and convert the resoluble calcium lactate into insoluble limestone. This newly formed limestone hardens at the cracked surface, effectively sealing the cracks. This process mimics the natural bone healing mechanism in humans, where osteoblast cells mineralize to repair fractures. Additionally, the utilization of oxygen during bacterial activity serves an added benefit by reducing the presence of oxygen, which is a key component in steel corrosion. This contributes to the enhanced durability of steel-reinforced concrete structures.

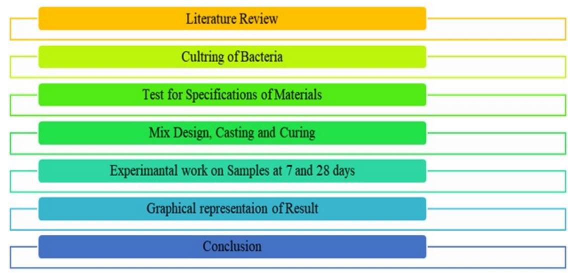


**Figure 2 Research Flow Start**

### Composition of Concrete

**Table 1 Source of Concrete Composite**

| S No. | Composites | Source |
|---|---|---|
| 1 | Cement | Bhawani Materials & Supplier, Jaipur |
| 2 | Fine Aggregate | Bhawani Materials & Supplier, Jaipur |
| 3 | Coarse Aggregate | Bhawani Materials & Supplier, Jaipur |
| 4 | Fly ash | Chitransh Traders, Mansarover, Jaipur |
| 5 | Silica fume | Dalton Mines & Minerals Private Limited, Jaipur |
| 6 | Bacillus subtilis | Nihit Medicos, Jaipur |


**Figure 3 Concrete Composite Materials**

### Experimental Work

- Initial Setting Time of cement
- Final Setting Time of Cement'
- Slump Cone Test
- Compressive Strength Test (IS) 516:1959
- Split Tensile Test
- Acid Attack of concrete
- Flexural Strength Test


**Figure 4 Different test Evaluated**

## V. RESULT AND DISCUSSION

In this section of study results collected from experimental work of concrete for slump, compressive, split tensile and acid attack. To get optimum concentration of bacterial (OCB) solution perform compressive strength test and find out highest strength as OCB solution for further experiments with fly ash and silica fume.

### Examine Optimum Concentrations of Bacteria

**Table 4.1 Compressive Strength of Concrete Mix**

| Mixtures | Cells Per ml Solution (OCB) | Compressive Strength N/mm$^2$ | |
|---|---|---|---|
| | | 7Days | 28Days |
| Standard | $10^0$ | 19.87 | 30.12 |
| Mix-1 | $10^3$ | 20.91 | 32.47 |
| Mix-2 | $10^6$ | 22.59 | 35.08 |
| Mix-3 | $10^9$ | 24.14 | 37.49 |

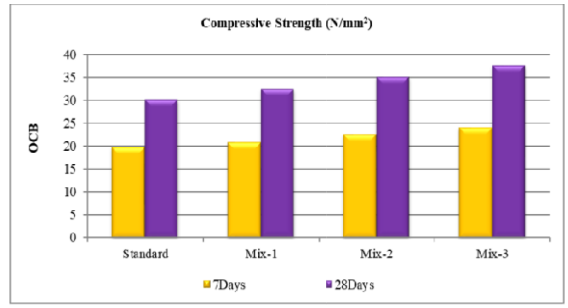


**Figure 5 Compressive Strength of Concrete Mix at 7 & 28Days**

**Table 4.2 Slump Value of Concrete with Bacteria and Fly Ash**

| Mixtures | Cells Per ml Solution (OCB) | Cement | Fly Ash | Slump (mm) |
|---|---|---|---|---|
| Standard | $10^0$ | 100% | 0% | 76 |
| OCB | $10^9$ | 100% | 0% | 82 |
| $B_9$-$FA_5$ | $10^9$ | 95% | 5% | 78 |
| $B_9$-$FA_{10}$ | $10^9$ | 90% | 10 % | 71 |
| $B_9$-$FA_{15}$ | $10^9$ | 85% | 15 % | 73 |

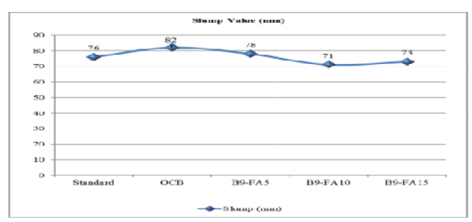


**Figure 6 Slump Value of Concrete with Bacteria and Fly Ash**

### Table 4.3 Slump Value of Concrete with Bacteria and Silica Fume

| Mixtures | Cells Per ml Solution (OCB) | Cement | Silica Fume | Slump (mm) |
|---|---|---|---|---|
| Standard | $10^0$ | 100% | 0% | 76 |
| OCB | $10^9$ | 100% | 0% | 82 |
| $B_9$-$SF_5$ | $10^9$ | 95% | 5% | 80 |
| $B_9$-$SF_{10}$ | $10^9$ | 90% | 10% | 76 |
| $B_9$-$SF_{15}$ | $10^9$ | 85% | 15% | 72 |

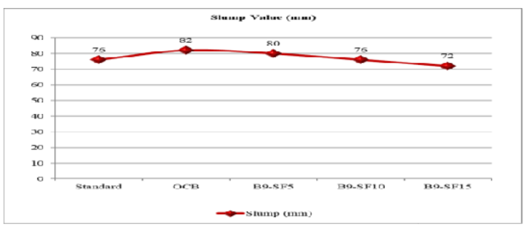


**Figure 7 Slump Value of Concrete with Bacteria and Silica Fume**

### Table 4.4 Compressive Strength of Concrete Cube with Bacteria and Fly Ash

| Mixtures | Cells Per ml Solution (OCB) | Cement | Fly Ash | Compressive Strength N/mm² | |
|---|---|---|---|---|---|
| | | | | 7Days | 28Days |
| Standard | 100 | 100% | 0% | 19.87 | 30.12 |
| OCB | $10^9$ | 100% | 0% | 24.14 | 37.49 |
| $B_9$-$FA_5$ | $10^9$ | 95% | 5% | 27.76 | 40.45 |
| $B_9$-$FA_{10}$ | $10^9$ | 90% | 10 % | 29.05 | 43.26 |
| $B_9$-$FA_{15}$ | $10^9$ | 85% | 15 % | 30.13 | 42.07 |

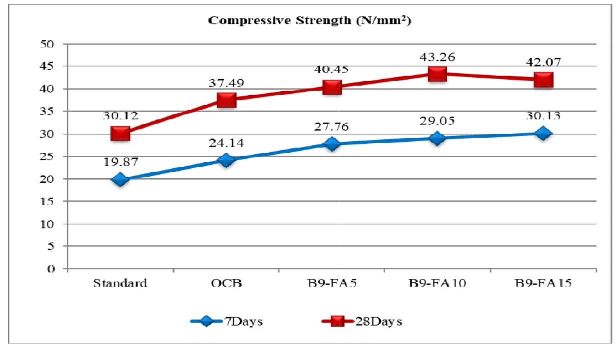


**Figure 8 Compressive Strength of Concrete Cube with Bacteria and Fly Ash**

### Table 4.5 Compressive Strength of Concrete Cube with Bacteria and Silica Fume

| Mixtures | Cells Per ml Solution (OCB) | Cement | Silica Fume | Compressive Strength N/mm² | |
|---|---|---|---|---|---|
| | | | | 7Days | 28Days |
| Standard | 100 | 100% | 0% | 19.87 | 30.12 |
| OCB | $10^9$ | 100% | 0% | 24.14 | 37.49 |
| $B_9$-$SF_5$ | $10^9$ | 95% | 5% | 28.01 | 40.97 |
| $B_9$-$SF_{10}$ | $10^9$ | 90% | 10% | 30.57 | 42.31 |
| $B_9$-$SF_{15}$ | $10^9$ | 85% | 15% | 31.83 | 44.72 |

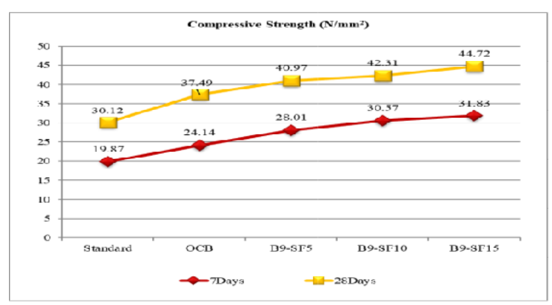


**Figure 9 Compressive Strength of Concrete Cube with Bacteria and Silica Fume**

### Table 4.6 Split tensile strength of Concrete Cylinder with Bacteria and Fly Ash

| Mixtures | Cells Per ml Solution (OCB) | Cement | Fly Ash | Split tensile strength N/mm² 28Days |
|---|---|---|---|---|
| Standard | 100 | 100% | 0% | 2.71 |
| OCB | $10^9$ | 100% | 0% | 3.36 |
| $B_9$-$FA_5$ | $10^9$ | 95% | 5% | 3.62 |
| $B_9$-$FA_{10}$ | $10^9$ | 90% | 10% | 3.87 |
| $B_9$-$FA_{15}$ | $10^9$ | 85% | 15% | 3.77 |

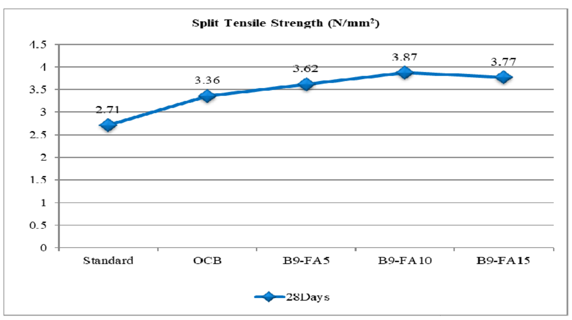


**Figure 10 Split tensile strength of Concrete Cylinder with Bacteria and Fly Ash**

### Table 4.7 Split tensile strength of Concrete Cylinder with Bacteria and Silica Fume

| Mixtures | Cells Per ml Solution (OCB) | Cement | Silica Fume | Split tensile strength N/mm² 28Days |
|---|---|---|---|---|
| Standard | 100 | 100% | 0% | 2.71 |
| OCB | $10^9$ | 100% | 0% | 3.36 |
| $B_9$-$SF_5$ | $10^9$ | 95% | 5% | 3.67 |
| $B_9$-$SF_{10}$ | $10^9$ | 90% | 10% | 3.79 |
| $B_9$-$SF_{15}$ | $10^9$ | 85% | 15% | 4.01 |

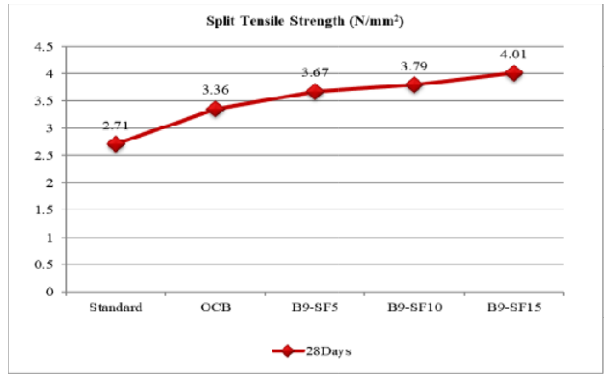


**Figure 11 Split tensile strength of Concrete Cylinder with Bacteria and Silica Fume**

### Table 4.8 Acid Attack on Concrete specimens with Bacteria and Fly Ash

| Mixtures | Cells Per ml Solution (OCB) | Cement | Fly Ash | Acid Attack (%) |
|---|---|---|---|---|
| Standard | 100 | 100% | 0% | 10.3 |
| OCB | $10^9$ | 100% | 0% | 12.7 |
| $B_9$-$FA_5$ | $10^9$ | 95% | 5% | 11.2 |
| $B_9$-$FA_{10}$ | $10^9$ | 90% | 10 % | 9.8 |
| $B_9$-$FA_{15}$ | $10^9$ | 85% | 15 % | 9.5 |

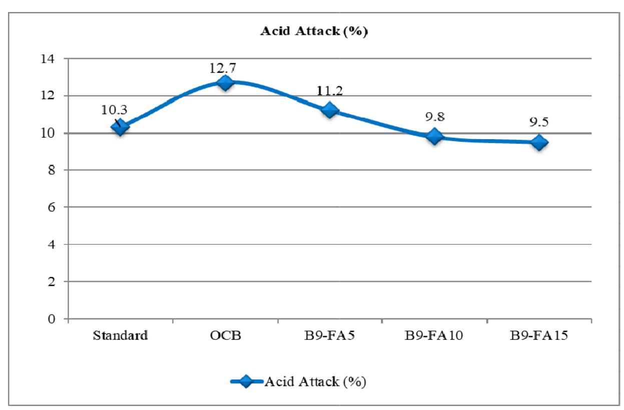


**Figure 12 Acid Attack on Concrete specimens with Bacteria and Fly Ash**

**Table 4.9 Acid Attack on Concrete specimens with Bacteria and Silica Fume**

| Mixtures | Cells Per ml Solution (OCB) | Cement | Silica Fume | Acid Attack (%) |
|---|---|---|---|---|
| Standard | 100 | 100% | 0% | 10.3 |
| OCB | $10^9$ | 100% | 0% | 12.7 |
| $B_9$-$SF_5$ | $10^9$ | 95% | 5% | 10.3 |
| $B_9$-$SF_{10}$ | $10^9$ | 90% | 10% | 9.6 |
| $B_9$-$SF_{15}$ | $10^9$ | 85% | 15% | 9.1 |

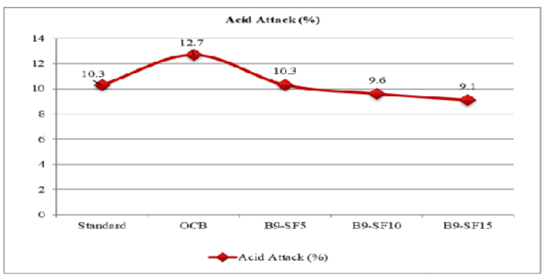


**Figure 13 Acid Attack on Concrete specimens with Bacteria and Silica Fume**

**Table 4.10** Flexural strength **of Concrete mix with Bacteria and Fly Ash**

| Mixtures | Cells Per ml Solution (OCB) | Cement | Fly Ash | Flexural strength $N/mm^2$ 28Days |
|---|---|---|---|---|
| Standard | 100 | 100% | 0% | 6.183 |
| OCB | $10^9$ | 100% | 0% | 6.795 |
| $B_9$-$FA_5$ | $10^9$ | 95% | 5% | 7.032 |
| $B_9$-$FA_{10}$ | $10^9$ | 90% | 10 % | 7.249 |
| $B_9$-$FA_{15}$ | $10^9$ | 85% | 15 % | 7.168 |

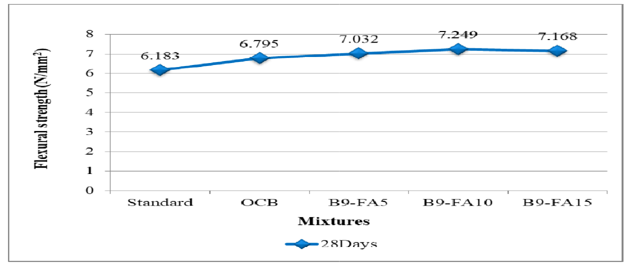


**Figure 14** Flexural strength **of Concrete Cube with Bacteria and Fly Ash**

**Table 4.11** Flexural strength **of Concrete mix with Bacteria and Silica Fume**

| Mixtures | Cells Per ml Solution (OCB) | Cement | Silica Fume | Flexural strength $N/mm^2$ 28Days |
|---|---|---|---|---|
| Standard | 100 | 100% | 0% | 6.183 |
| OCB | $10^9$ | 100% | 0% | 6.795 |
| $B_9$-$SF_5$ | $10^9$ | 95% | 5% | 7.073 |
| $B_9$-$SF_{10}$ | $10^9$ | 90% | 10% | 7.177 |
| $B_9$-$SF_{15}$ | $10^9$ | 85% | 15% | 7.369 |

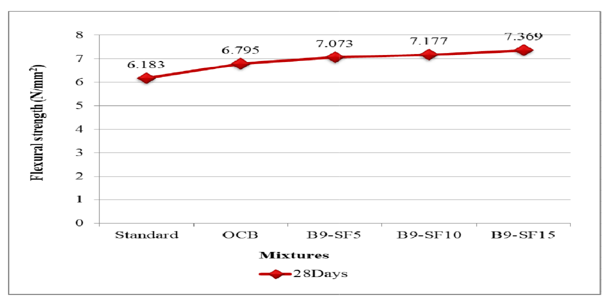


**Figure 15** Flexural strength **of Concrete Cube with Bacteria and Silica Fume**

## VI. CONCLUSION

The compressive strength of M30 grade concrete at 7 days was 19.87 N/mm² and increased to 30.12 N/mm² at 28 days. Introducing a bacterial solution at a concentration of $10^3$ cells per ml resulted in compressive strengths of 20.91 N/mm² at 7 days and 32.47 N/mm² at 28 days. Increasing the bacterial concentration to $10^6$ cells per ml yielded compressive strengths of 22.59 N/mm² at 7 days and 35.08 N/mm² at 28 days. Further increasing the concentration to $10^9$ cells per ml led to compressive strengths of 24.14 N/mm² at 7 days and 37.49 N/mm² at 28 days. The most significant increase in compressive strength was observed at the concentration of $10^9$ cells per ml. Consequently, this concentration was deemed the optimal bacteria cell concentration.

The initial maximum slump of the standard concrete sample was 76mm. After treating the concrete with optimum bacteria, the slump value increased to 82mm. When incorporating fly ash into the bacteria-mixed concrete, the slump value decreased by up to 10%. However, with further additions of fly ash, the slump value slightly increased again. The overall percentage change in slump value due to the combination of fly ash and bacteria-mixed concrete was 6.57%.

Similarly, in another scenario where the optimum bacteria-mixed concrete was prepared with silica fume, the slump value decreased by up to 10% with the addition of silica fume up to 10%. However, with further additions of silica fume, the slump value slightly increased again. The total percentage change in slump value due to the combination of silica fume and bacteria-mixed concrete was 2.63%.

The initial maximum compressive strength of the standard concrete sample at 7days and 28 days was 19.87N/mm$^2$ and 30.12N/mm$^2$ respectively. After treating the concrete with optimum bacteria, the compressive strength value increased to 24.14N/mm$^2$ at 7days and 37.49N/mm$^2$ at 28dyas. When incorporating fly ash into the bacteria-mixed concrete, the compressive strength increased by up to 15% at 7days test result and 10% at 28 days.

However, with further additions of fly ash, the compressive strength at 28 days slightly decreased again. The overall percentage change in compressive strength due to the combination of fly ash and bacteria-mixed concrete was 55.25% at 7days and 43.62% at 28 days.When incorporating fly ash into the bacteria-mixed concrete, the compressive strength increased by up to 15% at 7days test result and 10% at 28 days. However, with further additions of fly ash, the compressive strength at 28 days slightly decreased again. The overall percentage change in compressive strength due to the combination of fly ash and bacteria-mixed concrete was 55.25% at 7days and 43.62% at 28 days.

The initial maximum split tensile strength of the standard concrete sample at 28 days was 2.71N/mm$^2$. After treating the concrete with optimum bacteria, the split tensile strength value increased to 3.36N/mm$^2$ at 28dyas. When incorporating fly ash into the bacteria-mixed concrete, the split tensile strength increased by up to 10% at test result at 28 days. However, with further additions of fly ash, the split tensile strength at 28 days slightly decreased again. The overall percentage change in split tensile strength due to the combination of fly ash and bacteria-mixed concrete was 39.11% at 28days.

When incorporating silica fume into the bacteria-mixed concrete, the Split Tensile strength increased by up to 15% at 28 days. However, with further additions of silica fume, the split tensile strength at 28 days slightly increased again. The overall percentage change in split tensile strength due to the combination of silica fume and bacteria-mixed concrete was 47.97% at 28 days.

The initial maximum weight loss of the standard concrete sample at 28 days was 10.3%. After treating the concrete with optimum bacteria, the weight loss value increased to 12.7% at 28dyas. When incorporating fly ash into the bacteria-mixed concrete, the weight loss reduced up to 9.5% at test result at 28 days. When incorporating silica fume into the bacteria-mixed concrete, the weight loss reduced up to 15% at 28 days.

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