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Performance analysis of bacterial self-compacting concrete – workability, mechanical, durability and micro analysis

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ABSTRACT

Concrete may develop micro cracks and contains pores, both of which are extremely undesirable since they allow water and other harmful chemicals to enter the material easily. The Bacterial Self Compacting (BSCC), which continually deposits calcite in concrete, is one efficient method for sealing fissures. Microbiologically Induced Calcite Precipitation, or MICP, is the term used to describe this occurrence. The urease enzyme assists bacteria in the deposition of calcium carbonate (CaCO3). Because it is bio-based, environmentally safe, and long-lasting, the bacterial remediation method outperforms other methods. The high pH of concrete and the mechanical forces that occur during mixing require bacteria to provide resistance. The MICP-induced concrete has become a significant topic of study for high performance building. The utilization of bacteria for the production of bacterial SCC has received very little attention in India, and the durability properties of these mixtures have also received inadequate attention. Bacterial Self-Compacting Concrete (BSCC) of M60 grade, with bacteria as admixture along with flyash and silica fume. This research is to know about the workability, mechanical properties, durability and micro analysis of bacterial self-compacting concrete. The test results shows the bacteria of size 106 shows the best results in bacterial self-compacting concrete.

Keywords: Self-compacting concrete; bacterial self-compacting concrete; workability; durability and micro analysis.

1. INTRODUCTION

Reviews of SCC, which is to be constructed utilising different mineral additives and fibres. Heavy, complex, high-storey constructions are required because of contemporary developments in the construction sector. In such a situation, it is quite challenging to guarantee that a sizeable volume of concrete is fully compacted to the strong reinforcement in order to avoid voids and honeycombs, where the compactions by human, mechanical vibrators are challenging [1]. Self-compacting concrete, a novel variety of concrete, was consequently created. This concrete is extremely fluid and flows easily around the reinforcing bars and into every nook of the formwork, compacting itself by its own weight without the need for vibration. It is sometimes referred to as high performance self-compacting concrete or self-consolidating concrete. There is a time, labor, and energy savings because this concrete mix doesn't need to be compressed [2]. Induction of Bacillus subtilis bacteria in mortar cubes at varying cell concentrations using mixing water. The number of bacteria in the concrete was altered, and two mixtures—M20 and M40—were utilized. The number of cells per milliliter varied from 104 to 107. The bacteria spores experience microbiological activities in contact with oxygen and water during the spread of fractures in a concrete structure [3]. There is a decreased values of chloride ion permeability for numerous types of bacteria added to advanced concrete. The rapid chloride penetration test findings employed in this experiment have so shown that bacterial concrete has higher durability features [4]. The test revealed that specimens' compressive strength had noticeably risen and that any cracks had fully closed. Concrete crack healing and increased strength are shown visually by SEM [5]. Calcite precipitations were produced at the surface cracks. With enrich in average crack width, it became harder to fix the fracture, and microbial healing agents could only be used on specimens with cracks up to 0.8 mm wide. The workable option was suggested to be water cure. The crack healing ratio was significantly low when the age of the cracking was more than 60 days [6].

Flyash substitution give improved resistance to acid, alkali, and sulphate assaults. As the w/c ratio of 0.26 in M70 grade concrete is insufficient to give acceptable workability, superplasticizer is required for

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the formation of HPC. By achieving good particle packing using ultrafine and fine cementitious materials, it is possible to meet the performance requirements for concrete in both its fresh and hardened states [7]. Nanosilica was investigated at replacement rates of 1.5%, 3.5%, 4.5%, 6.5%, 7.5%, and 10% with a constant rate of flyash replacement. The maximum rise in compressive strength occurred at age 7 days at 3% Ns and 10% FA, and it is now 15.86%. The maximum increase in tensile strength occurred at age 28 days at 3% Ns and 10% FA, which was 29.58%. According to the results, 10% Fly ash and 3% Nanosilica strengthened compressive and split tensile strengths of conventional concrete [8]. In reinforced concrete buildings with difficult casting circumstances, self-compacting concrete (SCC) has grown in favour recently. Fresh concrete must have a high degree of fluidity and cohesion for these applications. A lot of fly ash was used in an attempt to create and test SCC, and the first findings are displayed and discussed. In this experiment, nine SCC combinations and one control concrete were both looked at. While the cementitious material's composition (400 kg/m^3) stayed constant, the water to cementitious material ratio fluctuated between 0.35 and 0.45. Class F fly ash replaced 40, 50, and 60% of the cement in the self-compacting mixtures. The study compares the fresh qualities of SCC with commercially available admixture to those of SCC with various concentrations of fly ash [9, 10].

The increasing in restore levels of cement with silica fume enhanced and lowered the axial and flexural strength, and slump of concrete on higher dose. Dosages of 0%, 3%, 6%, 9%, 13%, 18%, and 23% were used. The studies revealed that the highest strength was attained when the dosage was between 3% and 6%, and that over 9%, the results declined and indicated undesirable consequences [11]. The inclusion of SF greatly enhanced axial and split tensile strengths at both early and late ages. This was described as a result of increased pozzolanic activity. It also turned out that introducing silica fume to samples reduced cumulative water volume absorbed and fluid capillary sorptivity, and that the system enhances the ITZ structure, leading in superior strength values [12]. The M35 grade concrete for different degrees of silica fume replacement, 30 numbers of 150 mm cubes, 30 numbers of 300 mm x 100 mm cylinders, and 30 numbers of 150 mm square × 750 mm prisms were used in this investigation. A superplasticizer dose of 0.65% of the total amount of binder was used, and the w/c ratio was kept constant at 0.36. The levels of cement substitution that were selected were 0%, 5%, 10%, 15%, and 20%. For cement's 28-day compressive strength, the study found that an optimal SF replacement amount should be between 10% and 15%. Another finding was that the flexural strength of the samples increased when silica fume replaced cement to the extent of 15% [13, 14]. The partial substitution of cement with SF. The axial strength of concrete samples was investigated using 150mm cubes. In tests on cube samples, SF replacement levels of 5%, 10%, 15%, 20%, and 25% were tested during periods of 3, 7, 14, and 28 days. In this investigation, the mix proportioning was 1:2:4 mix by weight. The findings indicated that cement's strength increased when silica fume replacement levels reached 10%. For all testing ages, i.e., 3, 7, 14 and 28 days, the axial strength was seen to decline as the replacement level rose over 10% to 15% and above [15, 16]. Cement was replaced with GGBS from 20% to 80% in a mix design for SCC. They demonstrated that a combination with a low water to binder ratio and SP doses might be used to generate a high strength SCC. Their findings suggested that SCC mixes with large volumes of GGBS lowered strength whereas concrete with less volumes produced high strengths that limited the amount of cement refill [17]. Tests were used to determine the SSFSCC's stability in the fresh condition in order to guarantee its resistance to segregation and bleeding. The area enclosed between the prefabricated slab installed beyond and the base plate at the bottom was grouted using SSFSCC. There was evidence of the strong link that had been created between the prefabricated slab and the SCC infill, creating a composite plate shape [18].

The characteristics of concrete made using GGBS and coal bottom ash as fine aggregates. In this investigation, both components were employed to make concrete instead of using natural sand. The use of bottom ash and slag reduced the workability of the concrete by 30 to 50%. This result was attributable to the aggregates' high water absorption, porous particles, decreased bulk density, and soundness. When compared to the strength of the reference mix, the concrete with bottom ash and granulated blast furnace slag had a 10 to 22% reduced strength. The use of lighter materials in place of natural sand resulted in concrete having a lower bulk density, which was believed to be the cause of the drop in strength [19].

They deduced that the fly ash's very tiny particle size influenced the concrete's pore size and further decreased water absorption. In the sulphate and chloride penetration test, the concrete mix made with fly ash and limestone performed better. The maximum rise in compressive strength occurred at age 7 days at 3% Ns and 10% FA, and it is now 15.86%. The maximum increase in tensile strength occurred at age 28 days at 3% Ns and 10% FA, which was 29.58%. According to the results, 10% Fly ash and 3% Nanosilica strengthened axial and split tensile strengths of conventional concrete [20]. By achieving good particle packing using ultrafine and fine cementitious materials, it is possible to meet the performance requirements for concrete in both its fresh and hardened states [21].

2. MATERIALS AND METHODS

2.1. Cement

In concrete, cement is essential. The ability of cement to provide enhanced microstructure in concrete serves as the criterion for cement selection. Compressive strength is 37.25, 47.90 and 61.05 MPa at 3, 7 and 28 days curing, specific gravity of 3.15, fineness 321 m^2/kg, heat of hydration 268 @ 7days kj/kg, initial setting time 53 minutes, final setting time of cement 436 minutes with a consistency of 27.5. The bacteria's compatibility with cement must be confirmed as being crucial. The bacteria's compatibility with cement must be confirmed as being crucial [22]. Water that complies with IS: 456-2000 criteria has been proven to be acceptable for manufacturing BC. It is a common belief that water adequate for drinking can be utilised as well to create concrete. For the purposes of this experiment, the water for drinking that corporation provides to Coimbatore City was utilised for BC production and curing.

2.2. Fine aggregate

M-sand, which is readily available in the area, was employed as the fine aggregate in this experiment. The properties of fine aggregate are specific gravity of 2.55, water absorption of 1.45%, fineness modulus of 2.86, moisture content os almost zero and bulk density of 1575 kg/m^3.

2.3. Coarse aggregate

In concrete, the coarse aggregate is both the most durable and the least permeable. Additionally, it has a steady chemical composition [23, 24]. Since moisture is moving about during drying, shrinkage and other dimensional changes are reduced. The properties of coarse aggregate are specific gravity of 2.75, water absorption of 0.482%, fineness modulus of 5.14, crushing value of 32.5%, impact value of 14.4%, abrasion resistance of 19.5%, flaky particles of 9% and elongation particles of 8%. In the scope of this investigation, the research employed a maximum coarse aggregate size of 12 mm. This parameter choice influences the structural properties and overall composition of the studied material.

2.4. Flyash

Using a Le Chatelier flask, the specific gravity and density of fly ash were measured in accordance with the requirements of IS: 4031 (P11) – 1988. With the use of a Blaine type variable air permeability equipment, the fineness of fly ash was determined in accordance with the requirements of IS: 4031 (P2) – 1999. The properties of flyash are specific gravity of 2.11, fineness of 516m^2/kg, bulk modulus of 1135 kg/m^3, physical form is in powder form and color of flyash is dark grey. The incorporation of fly ash in cement significantly enhances various aspects of the concrete mixture, including improved durability, reduced heat generation, increased strength, and enhanced workability.

2.5. Silica fume and GGBS

Silica fume possesses a set of distinctive characteristics. It boasts a specific gravity of 2.26, indicating its density relative to water. Its exceptional fineness, at 20,000m^2/kg, results in an extensive surface area per unit mass, enhancing reactivity. With a bulk modulus of 656 kg/m^3, it exhibits some compressibility, useful in applications requiring flexibility. Typically found in powder form, it readily integrates with various materials. Its light grey color ensures seamless blending with construction components. These properties make silica fume indispensable in construction, especially for enhancing the strength, durability, and performance of concrete, as well as in other industrial applications.

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2.7. Bacteria

Bacillus Megaterium (BM) were found to thrive in this high-alkaline environment under conditions of high pH value up to 13 of the cement-water mixer. They were suspended in a peptone, NaCl, and beef extract-based nutritional broth solution. The acquired bacterial cultures were stored in the refrigerator until use. Figure 1 shows the microscopic image of Bacillus Megaterium.

2.8. Superplasticizer

The addition of superplasticizer has effectively enhanced workability, enabling better fluidity and ease of manipulation during the construction process, leading to improved overall performance.

2.9. Properties of Bacillus Megaterium

Bacillus Megaterium may be found in a wide range of environments. This bacterium has a rod form. Bacillus Megaterium is one of the largest known bacteria, with cells that may reach lengths of up to 4 m and a diameter of 1.5 m. Poly-glutamic acid is a recognised product of B. megaterium. The buildup of the polymer, which mostly consists of L-glutamate (L-isomer concentration up to 95%), is significantly enhanced in a salty (2–10% NaCl) environment. Bacillus Megaterium at least one strain has been shown to grow on up to 15% NaCl, making it a halophyte. Polysaccharides on the cell walls of the cells serve as connectors between the cells, which are frequently found in pairs and chains. The ideal temperature for Bacillus Megaterium growth is between 30°C and 45°C. Because of its enormous size—about 100 times that of E. coli—Bacillus Megaterium is known as the "big beast." Since the 1950s, Bacillus Megaterium, which is around 60 micrometres cubed in size, has been used to research the structure, protein localization, and membranes of bacteria.

2.10. Mix design

Cement = 381.5 kg/m^3

Flyash content = 54.5 kg/m^3

Silica fume = 54.5 kg/m^3

GGBS = 54.5 kg/m^3

Water = 150 kg/m^3

Superplastizer = 4.36 kg/m^3

Fine aggregate = 687.5 kg/m^3

Coarse aggregate = 1017 kg/m^3

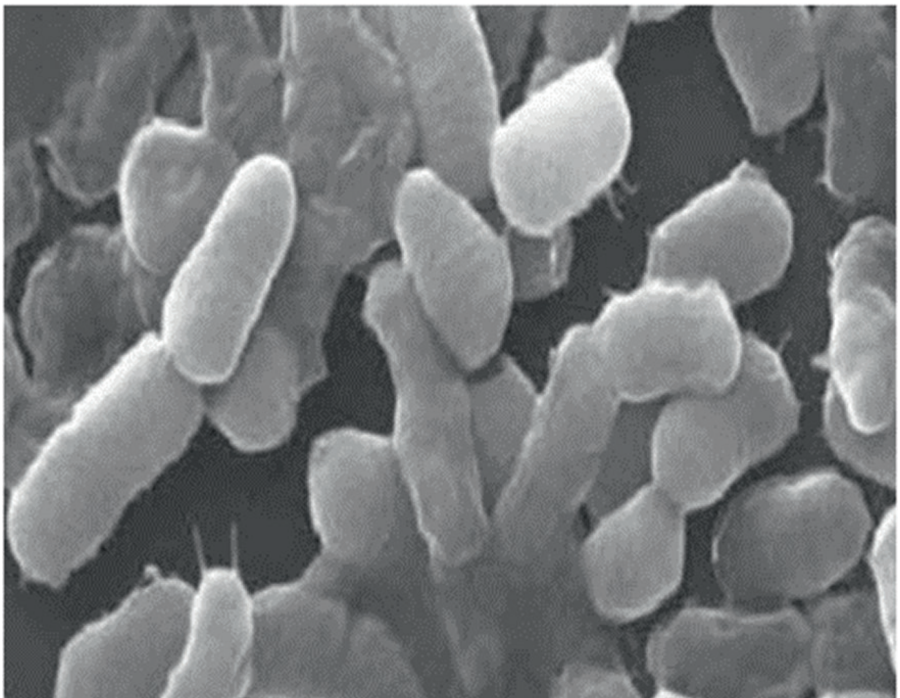

Figure 1: Microstructure of Bacillus Megaterium.

3. RESULTS AND DISCUSSION

3.1. Slump cone test

The slump cone was filled with about six litres of prepared SCC mix up to the top level without compacting it, and any extra concrete was then taken out. For the concrete to subside, the cone was raised vertically. A stop-watch was also started at this time to time how long it took the concrete to complete a circle with a 500 mm diameter. The slump value enrich with enrich in cell concentration of bacteria. Figure 2 shows the linear variation of slump flow for conventional SCC and SC bacterial concrete.

3.2. L box

To divide the parts, a mobile gate that could be moved was installed next to the reinforcing bars. Without compacting it, around 14 liters of concrete were poured into the vertical part, allowing it to remain there for a full minute. The gate was then opened, allowing the concrete to flow between the vertical and horizontal sections through the reinforcing bars. Measurements were made of the height of the concrete in sections H1 and H2. Figure 3 shows the linear variation of test results of L box for conventional SCC and SC bacterial concrete.

3.3. T5 min

Subsequently, place a bucket. Do not compress or tap the concrete once it has been entirely poured into the device; instead, use the trowel to simply strike off the top level of concrete. After the second fill of the funnel, wait five minutes before opening the trapdoor and letting the concrete drain out naturally. Figure 4 shows the linear variation of test results of T5 min for conventional SCC and SC bacterial concrete.

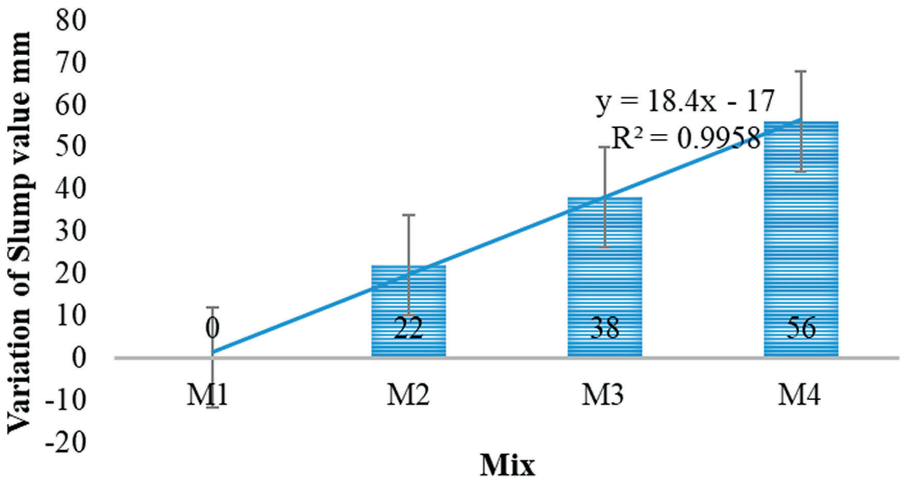

Figure 2: Linear variation of Slump value.

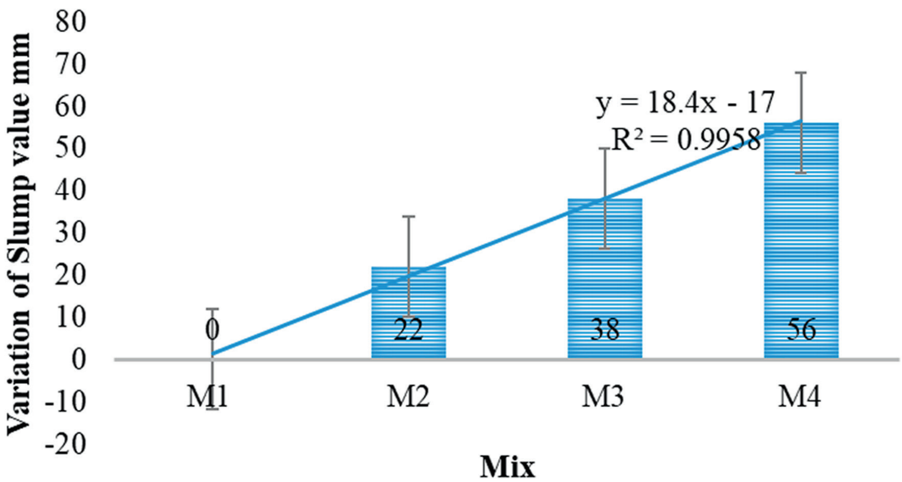

Figure 3: Linear variation of blocking ratio.

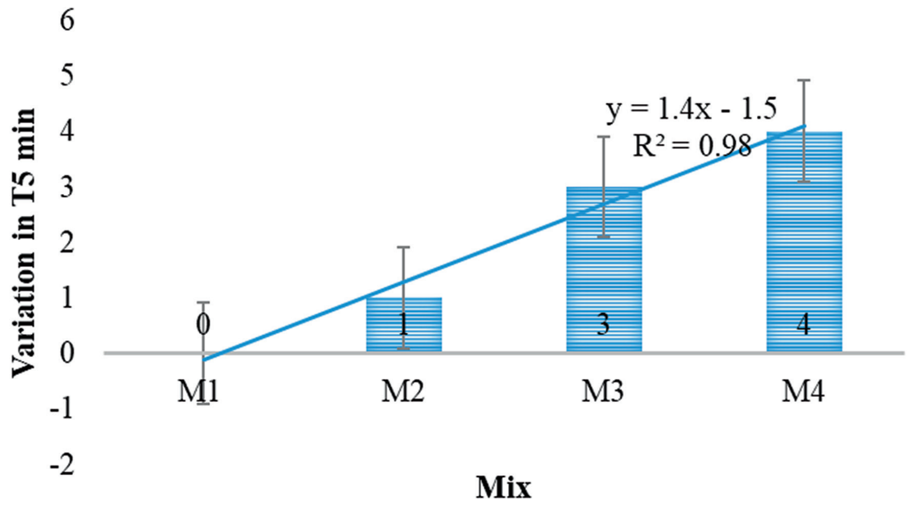

Figure 4: Linear variation of T5 min.

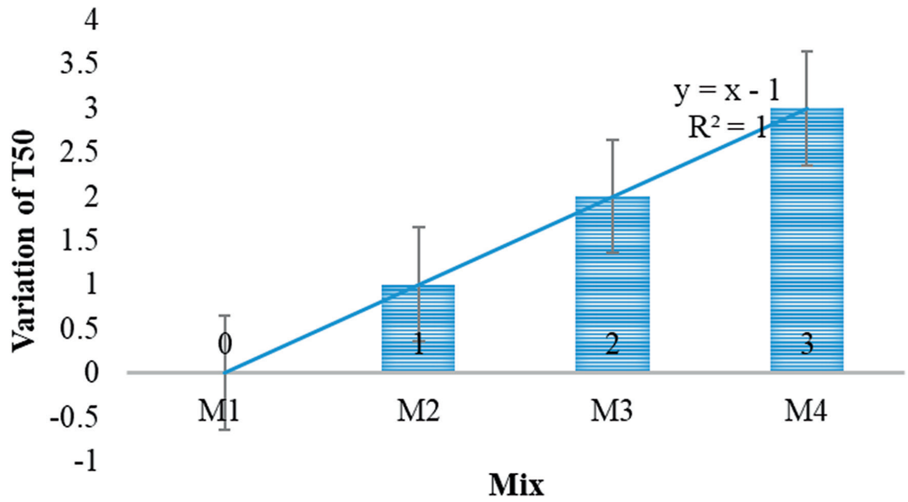

Figure 5: Linear variation of T50.

3.4. T 50

The amount of time needed for the concrete to flow completely was noted as V-funnel T50. Figure 5 shows the linear variation of test results of T50 for conventional SCC and SC bacterial concrete.

3.5. V Funnel test

Without compacting the concrete, 12 liters of mixed concrete were poured into the V-funnel to know about the time duration for flow. Blocking of the SC bacterial concrete is at low with a cell concentration of 106. Figure 6 shows the linear variation of test results of V funnel for conventional SCC and SC bacterial concrete.

3.6. Compression strength test

Following specimen centering in the testing apparatus, tests were conducted at a uniform stress of 140 kg/cm^2/minute. The dial gauge needle was just beginning to move in the other way as the loading progressed. The direction of the needle's motion changing indicates that the specimen has failed. It was noted the current reading on the dial gauge, which represented the maximum load. The axial strength of the ultimate cube relates to the ultimate load divided by the specimen's cross-sectional area. Table 1 shows the results of compression strength test for conventional SCC and bacterial SCC. At 7 days, M1 demonstrates a compression strength of 54.2 MPa, serving as the baseline for comparison. As the cell concentration increases in M2, the strength is slightly reduced to 40.2 MPa. In M3, the strength increases to 43.7 MPa, and in M4, it reaches 46.1 MPa at 7 days. The trend of increasing strength with higher cell concentrations continues at 14 days, 28 days, 56 days, and 90 days.

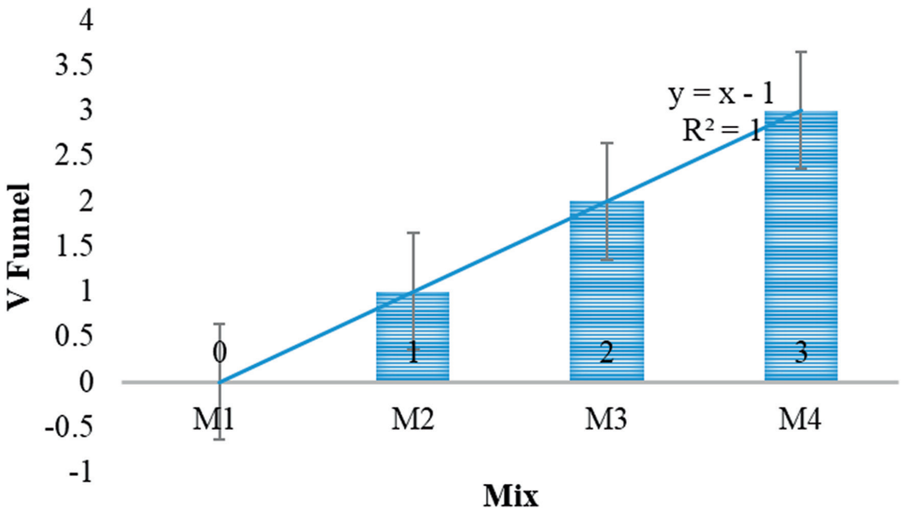

Figure 6: Linear variation of V-funnel test.

Table 1: Compression strength test of conventional and bacaterial SCC.

SI. NO.	MIX	CELL CONCENTRATION	COMPRESSION STRENGTH IN MPa				
			7 DAYS	14 DAYS	28 DAYS	56 DAYS	90 DAYS
1.	M1	Conventional SCC	37.6	54.2	61.8	68.2	72.4
2.	M2	10^4	40.2	57.6	64.3	73.4	77.7
3.	M3	10^5	43.7	61.0	68.9	77.1	81.6
4.	M4	10^6	46.1	64.1	72.5	80.3	85.2

Table 2: Split Tensile Strength of conventional and bacaterial SCC.

SI. NO.	MIX	CELL CONCENTRATION	SPLIT TENSILE STRENGTH IN MPa				
			7 DAYS	14 DAYS	28 DAYS	56 DAYS	90 DAYS
1.	M1	Conventional SCC	3.37	4.05	4.61	5.21	5.38
2.	M2	10^4	3.79	4.31	5.26	6.08	5.98
3.	M3	10^5	4.26	4.63	5.71	6.79	6.74
4.	M4	10^6	4.85	4.99	6.38	7.31	7.79

3.7. Split tensile strength

The cylinders were tested in accordance with the IS: 5816-1999 specifications after curing. In the 2000 kN capacity axial testing machine, the cylinders were laid out horizontally. The load was gradually added, and the cylinder failure load was recorded. The comparison of the test results with linear variation is incorporated for conventional SCC and bacterial SCC for various concentration. The experimental test results for the splitting tensile strength test is depicted in Table 2. At 7 days, M1 exhibits a split tensile strength of 3.37 MPa, serving as the baseline. As the cell concentration increases in M2, the strength improves to 3.79 MPa. In M3, with a cell concentration of 105, the strength further increases to 4.26 MPa, and in M4, it reaches 4.85 MPa at 7 days. This trend of increasing split tensile strength with higher cell concentrations continues at 14 days, 28 days, 56 days, and 90 days.

3.8. Flexure strength test

Prisms were taken from the curing tank after water curing and evaluated in the flexural testing equipment with a two-point load at a loading rate of 400 kg/min according to IS: 516 – 1959. The comparison of the test results with linear variation is incorporated for conventional SCC and bacterial SCC for various concentration. The experimental results of flexural strength test is shown in Table 3. At 28 days, M1 exhibits a flexural strength of 8.14 MPa, serving as the baseline. As the cell concentration increases in M2, the strength improves to 8.94 MPa. In M3, with a cell concentration of 105, the strength further increases to 9.58 MPa, and in M4, it reaches 10.08 MPa at 28 days. This trend of increasing flexural strength with higher cell concentrations continues at 56 days and 90 days.

3.9. Impact strength

The specimens were grease-coated and set on the base plate after undergoing a 28-day water cure. The specimen with a height of 457 mm was repeatedly struck with a steel ball that was 63.5 mm in diameter and 4.54 kg in weight. The comparison of the test results with linear variation is incorporated for conventional SCC and bacterial SCC for various concentration. The cylindrical concrete examples were cast and submerged in water for 28 days to cure. The experimental test results for the impact tensile strength test is depicted in Table 4. At 28 days, M1 exhibits an impact strength of 65 MPa for the first crack and 69 MPa for the final crack. As the cell concentration increases in M2, the impact strength improves to 68 MPa for the first crack and 72 MPa for the final crack. In M3, with a cell concentration of 10^5, the impact strength further increases to 70 MPa for the first crack and 76 MPa for the final crack. M4, with the highest cell concentration, records an impact strength of 75 MPa for the first crack and 79 MPa for the final crack at 28 days.

3.10. Saturated water absorption

Until the mass difference between two following measurements conducted at 24-hour intervals substantially corresponded, the drying process was maintained. Before being immersed in water, the dried samples were cooled to room temperature. The samples were taken out at regular intervals, dried on the surface using a clean towel, and weighed. By continuing this method, the weights were kept constant (fully saturated). Table 5

Table 3: Flexural Strength of conventional and bacaterial SCC.

SI. NO.	MIX	CELL CONCENTRATION	FLEXURAL STRENGTH IN MPa		
			28 DAYS	56 DAYS	90 DAYS
1.	M1	Conventional SCC	8.14	9.29	9.69
2.	M2	10^4	8.94	9.98	10.78
3.	M3	10^5	9.58	10.64	11.64
4.	M4	10^6	10.08	11.33	12.03

Table 4: Impact Strength of conventional and bacaterial SCC.

SI. NO.	MIX	CELL CONCENTRATION	IMPACT STRENGTH IN MPa					
			28 DAYS		56 DAYS		90 DAYS	
			FIRST CRACK	FINAL CRACK	FIRST CRACK	FINAL CRACK	FIRST CRACK	FINAL CRACK
1.	M1	Conventional SCC	65	69	74	80	79	85
2.	M2	10^4	68	72	76	81	80	86
3.	M3	10^5	70	76	80	85	84	90
4.	M4	10^6	75	79	84	89	86	93

Table 5: Saturated Water Absorption of conventional and bacaterial SCC.

SI. NO.	MIX	CELL CONCENTRATION	SATURATED WATER ABSORPTION IN %		
			28 DAYS	56 DAYS	90 DAYS
1.	M1	Conventional SCC	2.32	2.13	2.01
2.	M2	10^4	1.99	1.72	1.58
3.	M3	10^5	1.78	1.61	1.38
4.	M4	10^6	1.51	1.37	1.25

displays the experimental findings of saturated water absorption test. At 28 days, M1 exhibits a saturated water absorption of 2.32%. As the cell concentration increases in M2, the absorption decreases to 1.99%. In M3, with a cell concentration of 105, the absorption further reduces to 1.78%. M4, with the highest cell concentration, records the lowest absorption of 1.51% at 28 days.

3.11. Porosity

Effective porosity is the porosity measured using absorption testing. The amount of water lost when a specimen that is saturated with water is dried in the oven at 105°C to constant mass is used to calculate the volume of the voids. The variation between the specimen's mass in air and its mass when submerged in water determines the specimen's bulk volume. The comparison of the test results with linear variation is incorporated for conventional SCC and bacterial SCC for various concentration. The variation between the specimen's mass in air and its mass when submerged in water determines the specimen's bulk volume. The comparison of the test results with linear variation is incorporated for conventional SCC and bacterial SCC for various concentration. The difference between the specimen's mass in air and its mass when submerged in water determines the specimen's bulk volume. The experimental results of porosity test is shown in Table 6. At 28 days, M1 exhibits a porosity of 3.01%. As the cell concentration increases in M2, the porosity significantly decreases to 1.03%. In M3, with a cell concentration of 105, the porosity remains low at 1.09%. M4, with the highest cell concentration, records the lowest porosity of 1.15% at 28 days.

3.12. Acid resistance

The pH of the HCl solution was kept at 3 and it was five percent of 0.01 normalcy. The pH of the H2SO4 solution was held constant at 2 and it was five percent of 0.01 normalcy. The cubes' surfaces were then cleaned once the specimens had been removed from the acidic water. The specimens' compressive strengths and weight loss were then calculated. Additionally, the specimens' compressive strengths and average weight loss percentages were computed. The comparison of the test results with linear variation is incorporated for conventional SCC and bacterial SCC for various concentration. The experimental results for the acid resistance test is shown in Table 7. The specimen's dimensions, measuring 10 × 10 × 5 mm, crucially influence scanning electron microscopy (SEM) analysis by determining resolution, sample representation, and instrument compatibility for accurate surface morphology visualization. At 28 days, M1 exhibits a weight loss of 2.96%. As the cell concentration increases in M2, the weight loss significantly decreases to 0.98%. In M3, with a cell concentration of 105, the weight loss remains low at 1.04%. M4, with the highest cell concentration, records the lowest weight loss of 1.1% at 28 days.

3.13. Scanning Electron Microscope (SEM) Analysis

From cube specimens whose compressive strength had been tested for 28 days, samples measuring 10 × 10 × 5 mm were collected. A SEM was used to study the concrete samples' microstructures and fracture width.

Table 6: Porosity of conventional and bacaterial SCC.

SI. NO.	MIX	CELL CONCENTRATION	POROSITY		
			28 DAYS	56 DAYS	90 DAYS
1.	M1	Conventional SCC	3.01	2.75	2.45
2.	M2	10^4	1.03	0.98	0.91
3.	M3	10^5	1.09	1.01	0.93
4.	M4	10^6	1.15	1.04	0.95

Table 7: Acid resistance test of conventional and bacaterial SCC.

SI. NO.	MIX	CELL CONCENTRATION	% OF LOSS OF WEIGHT		
			28 DAYS	56 DAYS	90 DAYS
1.	M1	Conventional SCC	2.96	2.7	2.41
2.	M2	10^4	0.98	0.93	0.87
3.	M3	10^5	1.04	0.96	0.89
4.	M4	10^6	1.1	0.99	0.91

A focused beam of electrons is moved across the sample while utilising a scanning electron microscope, and various signals are then detected as a result of the electron beam's interactions with the sample. Figures 7 and 8 shows the SEM images of 28 days conventional SCC and bacterial SCC. Using SEM, it was possible to identify different calcite crystals embedded in concrete in the bacterial SCC specimens. The presence of calcite in the form of CaCO3 owing to bacteria was verified by the high calcium content in it. Calcite deposition increases impermeability by acting as a barrier to hazardous substances.

3.14. X- Ray Diffraction (XRD)

X-ray diffraction analysis may be used to check for the presence of calcite and calcite-silicate-hydrate (C-S-H) gels in bacterial concrete samples. The existence of calcite peaks will demonstrate that bacterial precipitation

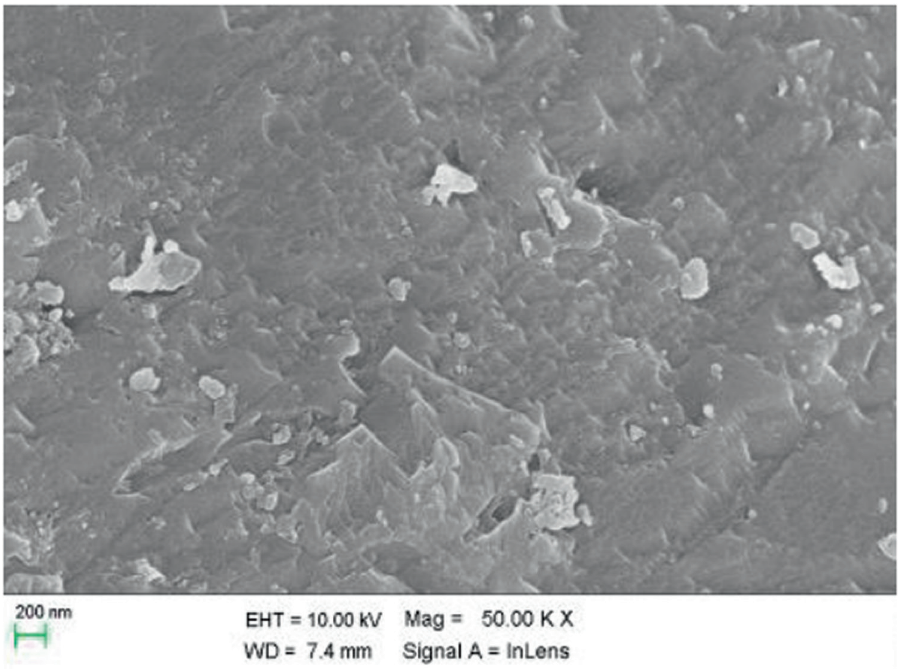

Figure 7: SEM image conventional self-compacting concrete.

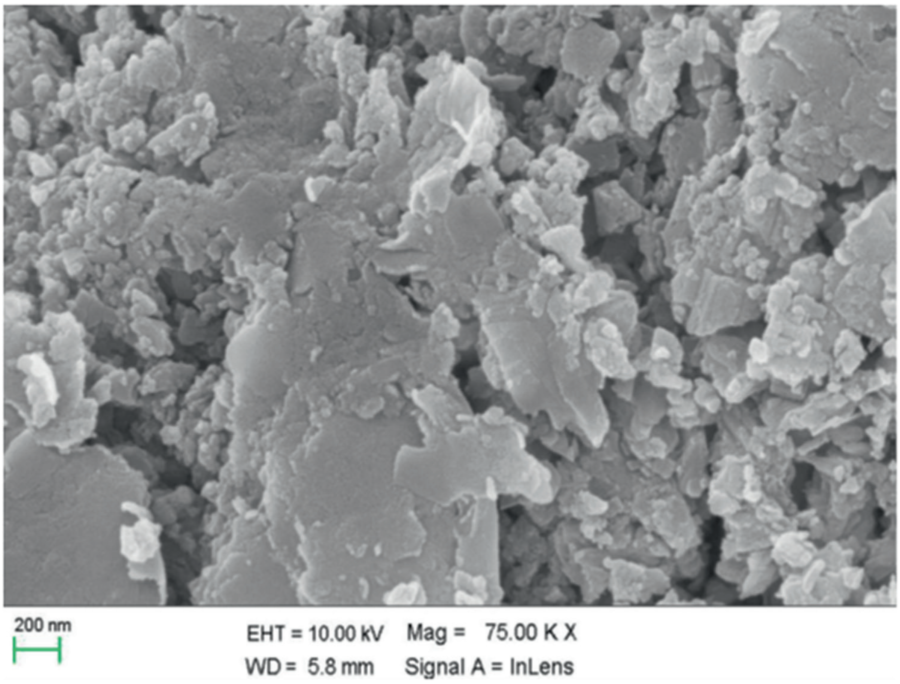

Figure 8: SEM image bacterial self-compacting concrete.

of calcite, which increases the strength and durability of concrete, has taken place. The evolution of concrete's strength will be explained by the existence of C-S-H peaks. Using a pestle and mortar, broken cube specimen fragments from the compressive strength test were collected and ground into powder. The portion that made it through a sieve with a 5 mm opening was examined using XRD analysis. Figures 9 and 10 shows the XRD images of 28 days conventional SCC and bacterial SCC.

4. CONCLUSION

The conclusions drawn from this study are explained below:

- The inclusion of bacteria increases the impermeability of concrete by acting as micro-pore fillers, reducing the size of the pores, and producing tiny and discontinuous pore architectures.
- At ages of 28 days and 90 days, it was discovered that the permeability of the bacterial SCC specimens was lower than that of the control SCC specimen thus increasing the strength and durability of the concrete.

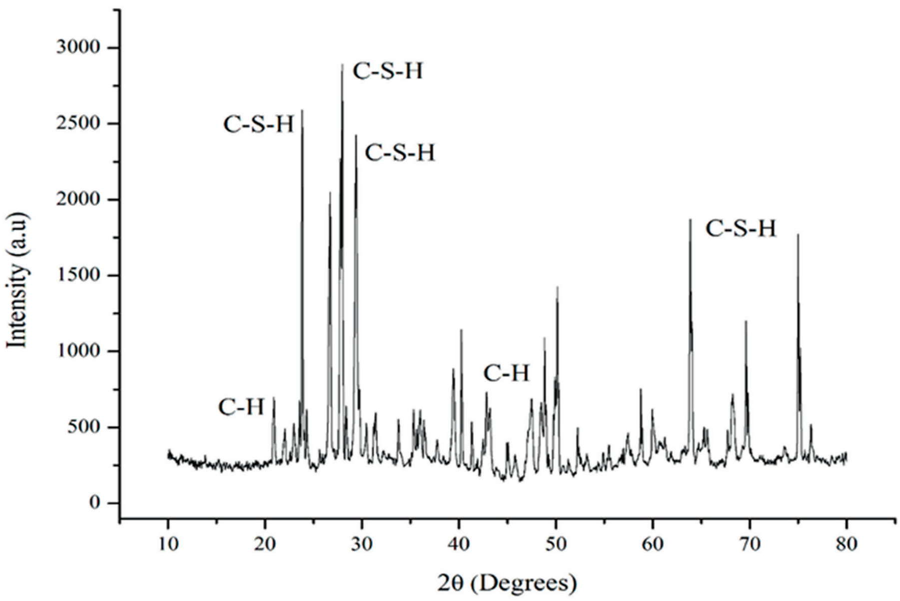

Figure 9: XRD image conventional self-compacting concrete.

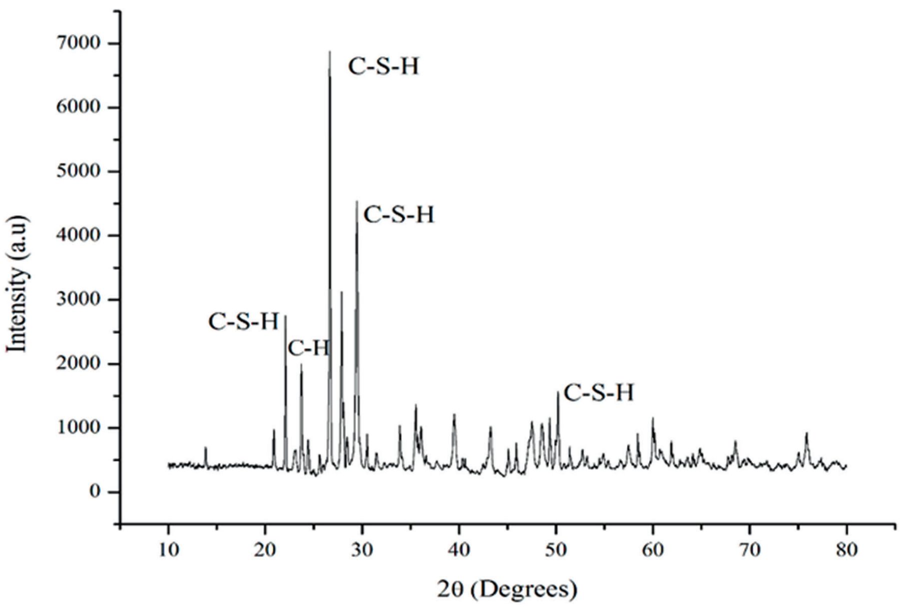

Figure 10: XRD image bacterial self-compacting concrete.

- The outcomes of experiments on saturated water absorption and porosity have shown that bacterial SCC has higher durability qualities. This is because the presence of bacteria-induced Microbiologically Induced Calcite Precipitation (MICP), which results in tiny and discontinuous pore structure, improves the microstructure in the cement paste matrix.
- As the dose of bacterial cell concentration rises, so does the degree of chloride ion penetrability. Thus, it demonstrates that adding bacteria to SCC mixtures as an additive improves the material's resistance to deterioration and longevity, which makes it particularly useful in marine situations.
- The buildup of pores inside the bacterial SCC-induced CaCO3 precipitate is what causes the rise in binding strength.
- Using SEM, it was possible to identify different calcite crystals embedded in concrete in the bacterial SCC specimens. The presence of calcite in the form of CaCO3 owing to bacteria was verified by the high calcium content in it. Calcite deposition increases impermeability by acting as a barrier to hazardous substances.

5. BIBLIOGRAPHY

[1] BARLUENGA, G., PUENTES, J., PALOMAR, I., "Early age monitoring of self-compacting concrete with mineral additions", *Construction & Building Materials*, v. 77, pp. 66–73, 2015. doi: http://dx.doi.org/10.1016/j.conbuildmat.2014.12.033

[2] GUNEYISI, E., GESOGLU, M., FAHMI, M., IPEK, S., "Mechanical and fracture properties of carbon fiber reinforced self-compacting concrete composites", In: *Proceedings of the 10th International Conference on Composite Science and Technology*, Lisboa, Portugal, 2015.

[3] LAKSHMI, L., MEERA, C.M., ELDHOSE, C., "Durability and self-healing behavior of bacterial impregnated concrete", *International Journal of Innovative Research in Science, Engineering and Technology*, v. 5, n. 8, pp. 14887–14892, 2016.

[4] ARULSIVANANTHAM, P., GOKULAN, R., "A review on self-compacting concrete", *International Journal of Chemtech Research*, v. 10, pp. 62–68, 2018.

[5] ANUSHA, P., HAFSA, M., SESHAGIRI RAO, M.V., *et al*., "Bioengineered concrete: a sustainable self-healing construction material", *Research Journal of Engineering Sciences*, v. 2, n. 6, pp. 45–51, 2013.

[6] BARIYA, A., PATEL, I., GOHIL, G., *et al*., "Experimental study of advanced concrete", *International Journal of Advance Research in Engineering, Science & Technology*, v. 4, n. 5, pp. 100–105, 2017.

[7] SILVA, P., BRITO, J., "Experimental study of the porosity and microstructure of self-compacting concrete (SCC) with binary and ternary mixes of fly ash and limestone filler", *Construction & Building Materials*, v. 86, pp. 101–112, 2015. doi: http://dx.doi.org/10.1016/j.conbuildmat.2015.03.110

[8] KRISHNAPRIYA, S., PRINCE ARULRAJ, G., VENKATESH BABU, D.L., "Isolation and identification of bacteria to improve the strength of concrete", *Microbiological Research*, v. 174, pp. 48–55, 2015. doi: http://dx.doi.org/10.1016/j.micres.2015.03.009. PubMed PMID: 25946328

[9] LUO, M., QIAN, C., LI, R., "Factors affecting crack repairing capacity of bacteria-based self-healing concrete", *Construction & Building Materials*, v. 87, pp. 1–7, 2015. doi: http://dx.doi.org/10.1016/j.conbuildmat.2015.03.117

[10] SUJAY, H.M., NAIR, N.A., SUDARSANA RAO, H., *et al*., "Experimental study on durability characteristics of composite fiber reinforced high-performance concrete incorporating nanosilica and ultra fine fly ash", *Construction & Building Materials*, v. 262, pp. 120738, 2020. doi: http://dx.doi.org/10.1016/j.conbuildmat.2020.120738

[11] GAGARE, S.B., KAWADE, U.R., "Enhancing properties of concrete by using nano-silica as a partial replacement of cement", *International Journal of Advance Research and Innovative Ideas in Education*, v. 2, n. 5, pp. 29–34, 2016.

[12] DASARATHY, A.K., TAMIL SELVI, M., LEELA, D., *et al*., "Self compacting concrete: an analysis of properties using fly ash", *IACSIT International Journal of Engineering and Technology*, v. 7, n. 2.24, pp. 135–139, 2018. doi: http://dx.doi.org/10.14419/ijet.v7i2.24.12018

[13] AKSHANA, V., NAVEEN ARASU, A., KARTHIGAISELVI, P., "Experimental study on concrete by partial replacement cement with silica fume", *Journal of Critical Reviews*, v. 7, n. 17, pp. 3801–3805, 2020.

[14] ZHANG, H.Y., LIU, X.Y., WEI, D.F., "Influence of silica fume content on performance of high performance concrete", *E3S Web of Conferences*, v. 237, pp. 03039, 2021. doi: http://dx.doi.org/10.1051/e3sconf/202123703039

[15] WU, W., WANG, R., ZHU, C., *et al*., "The effect of flyash and silica fume on mechanical properties and durability of coral aggregate concrete", *Construction & Building Materials*, v. 185, pp. 69–78, 2018. doi: http://dx.doi.org/10.1016/j.conbuildmat.2018.06.097

[16] NAVEEN ARASU, N., NATARAJAN, M., BALASUNDARAM, N., *et al*., "Utilizing recycled nanomaterials as a partial replacement for cement to create high performance concrete", *Global NEST Journal*, v. 6, n. 25, pp. 89–92, 2023.

[17] FASEYEMI, V.A., "Investigations on microsilica (silica fume) as partial cement replacement in concrete", *Global Journal of Researches in Engineering Civil and Structural Engineering.*, v. 12, n. 1, pp. 17–23, 2012.

[18] NAVEEN ARASU, A., NATARAJAN, M., BALASUNDARAM, N., *et al*., "Optimization of jigh performance concrete composites b using nano materials", *Research on Engineering Structures and Materials*, 2023.

[19] DINAKAR, P., MANU, S.N., "Concrete mix design for high strength self-compacting concrete using metakaolin", *Materials & Design*, v. 60, pp. 661–668, 2014. doi: http://dx.doi.org/10.1016/j.matdes.2014.03.053

[20] YUAN, Q., LONG, G., LIU, Z., *et al*., "Sealed-space-filling SCC: a special SCC applied in high-speed rail of China", *Construction & Building Materials*, v. 124, pp. 167–176, 2016. doi: http://dx.doi.org/10.1016/j.conbuildmat.2016.07.093

[21] YÜKSEL, I., GENÇ, A., "Properties of concrete containing nonground ash and slag as fine aggregate", *ACI Materials Journal*, v. 104, n. 4, pp. 397–403, 2007.

[22] PALANIAPPAN, S.M., GOVINDASAMY, V., JABAR, A.B., "Experimental investigation on flexural performance of functionally graded concrete beams using flyash and red mud", *Matéria*, v. 26, n. 1, e12913, 2021. doi: http://dx.doi.org/10.1590/s1517-707620210001.1213

[23] MATOS, P.R.D., SAKATA, R.D., FOIATO, M., *et al*., "Workability maintenance of water-reducing admixtures in high-performance pastes produced with different types of Portland cement", *Matéria*, v. 26, n. 1, e12925, 2021. doi: http://dx.doi.org/10.1590/s1517-707620210001.1225

[24] SCHIAVON, J.Z., BORGES, P.M., SILVA, S.R.D., *et al*., "Analysis of mechanical and microstructural properties of high performance concretes containing nanosilica and silica fume", *Matéria*, v. 26, n. 4, e13104, 2022. doi:http://doi.org/10.1590/S1517-707620210004.1304