International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 02 Issue: 06 June 2024
Page No: 1725- 1732
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2024.0238

An Experimental Study on Properties of Microbial Blended Concrete

C. Venkata Sai Nagendra[1], N. Jayaramappa[2], Veena[3]
[1]Research Scholar, Department of Civil Engineering, UVCE, Bangalore University, Bangalore, Karnataka, India.
[2]Professor, Department of Civil Engineering, UVCE, Bangalore University, Bangalore, Karnataka, India.
[3]PG Student, Department of Civil Engineering, UVCE, Bangalore University, Bangalore, Karnataka, India.
Email ID: *Chintalanagendra25@gmail.com[1], jakasauj@gamil.com[2], veenanaik480@gmail.com[3]*

Abstract
Several efforts are being made by researchers to turn concrete into a more sustainable material. Various research are being carried out to substitute cement in concrete, either whole or in part. The current work uses mineral admixtures like metakaolin and GGBS (blended concrete) to partially substitute cement in concrete. Concrete prone to cracking due to structural and Non-structural conditions. All kinds of fissures have the potential to harm concrete by letting water and other substances pass through them, which weakens and distorts the material while also compromising the reinforcing. To repair the concrete cracks, a certain type of treatment and routine upkeep are required, and they will be very costly. So, the current research is to study the impact of Bacteria (microbes) on crack healing as well as on properties of blended concrete. Different mixes of M25-grade concrete were done by using M-sand as fine aggregate to obtain the optimum percentage of GGBS used as supplementary cementitious material (0, 5%, 10%, 15%, 20%, 25%, and 30%), and the same percentage was used in blended concrete, which included metakaolin at different percentages (0, 5%, 10%, 15%, 20%, and 25%).Among different mixes, the proportions of blended concrete with enhanced mechanical properties were considered, and bacteria were induced at a constant percentage in that mix. The results indicated that the microbial blended concrete mix has significantly improved mechanical and durability properties, when compared to conventional and blended concrete mixes.
Keywords: *Bacteria; GGBS; Metakaolin; Blended Concrete & Cracks.*

1. Introduction
Concrete is the most widely used building material. Many factors contribute to its widespread use, such as its low cost, adaptability, fair durability, and capacity to take on any shape or size. However, even before to being exposed to external influences, concrete naturally contains fractures. Human aid is needed if the fracture is large; if it is small, it is advised to seal the breach by introducing chemicals or other external agents into the concrete. Bacteria are one of the many types of external agents available on the market. Bacteria aids in the healing of cracks while also improving the characteristics of concrete. When added to concrete, a type of bacteria called Bacillus subtilis improves crack healing and improves concrete's properties. M. V. Seshagiri Rao [1]. The term "self-healing property" refers to a substance's ability to restore its desirable mechanical properties following loss or degradation with little to no help from outside sources. A sustainable method that incorporates microorganisms into the concrete's design is biologically repaired concrete[2]P.Jagannathan et.al.,[3] investigated on Bacillus sphaericus and bacillus pasteurii, which are two bacterial species that are utilized independently in concrete and in addition to bacteria, flyash is utilised as a partial substitute of cement. In comparison to the mixes with bacillus pasteurii and flyash, the mixes with bacillus sphaericus and flyash around 10% showed highest strength. Elzy Abraham et.al.,[4] research have looked in to the influence of bacteria on waste foundry sand (WFS) based concrete. The concrete mix with combination of bacteria and partial replacement of fine aggregate (M-sand) with WFS

shown significant improvement in both mechanical and durability characteristics. Meera CM et. al., [5], studied about the evaluation of the strength and durability of bacteria-based self-healing concrete. This paper examines the impact of Bacillus subtilis JC3 on the durability and strength of concrete. Cubes were examined for varying bacterial concentrations at 7 and 28 days in order to evaluate their strength. It was found that when mixing water was added at a cell concentration of 10^5, the compressive strength of the concrete increased significantly by 42%. According to Sandip Mondala et.al.,[6], Bacillus subtilis and Bacillus cereus can be used to improve the properties of concrete at ideal concentrations of 10^5 and 10^3 cells/ml, respectively. N. Iswaryaa et.al., [7] investigation focused on concrete specimens containing bacillus subtilis JC3 bacteria solution (15ml, 25ml, 35ml, and 45ml) and various amounts of aluminium powder (0.25, 0.35, 0.45, and 0.55 percent by weight of cement). Among all the mixes, the specimens cast with 25ml bacteria and 0.35 percent aluminium powder exhibited the maximum strength and the lowest amount of water absorption.Encapsulation-based self-healing has the potential to raise the quality of the self-healing by allowing for a wider range of crack widths to be repaired and a faster reaction to matrix cracking [8]. SakinaNajmuddinSaifee et.al.,[9] explained about the various kinds of bacteria and how they are used in concrete. The bacterial concrete is particularly helpful in repairing limestone monuments, sealing concrete cracks to create extremely durable cracks, and extending the life of cementious materials. Additionally, it helps avoid erosion of loose sands, develop high-strength buildings with greater bearing capacity, and construct affordable, permanent homes. Sadath et.al.,[10] Investigated on M20 grade of concrete using bacteria of different concentrations 10^4, 10^5, 10^6, 10^7 cells/ml. Different mixes were casted using different concentrations of bacteria including conventional mix to determine the mechanical properties and calcite formation. Results shown that the strength in compression of concrete is maximum for the mix with the addition of Bacillus subtilis JC3 at 10^5 cells/ml concentration.Ternary blended concrete made of silica fume and waste glass powder can be used as alternate for conventional concrete and suitable for structural applications [11]. The ternary blended concrete mix has a higher compressive strength than a conventional mix. The development of strong cementing agents such as calcium aluminum silicates and calcium silicate hydrates is what gives the blended mix its increased compressive strength. 30% fly ash and 7.5% silica fume made up the ternary mixture that had the maximum compressive strength. [12]. Prasad et.al.,[13] An ternary blended concrete mix consisting of powdered eggshell and fly ash. When compared to a standard mix of 100% cement, a significant improvement in strength was observed at a proportion of 20% fly ash, 10% eggshell powder, and 70% OPC cement. According to Khalid et.al.,[14] In addition to improving the properties of geopolymer concrete, extra cementitious elements such GGBS and Metakaolin combination provide ecologically friendly geopolymer blended concrete. In the current study, Metakaolin and GGBS were used to develop blended concrete, and the influence of Bacillus subtilis bacteria on the properties of the blended concrete was investigated.

2. Material

2.1. Cement

Throughout the experimental program, OPC of 43 grade Zuari cement that complied with IS 8112-2013 was used as the cement. Table 1 provides a list of cement's physical qualities.

2.2. Fine aggregate

Locally available Manufactured sand confirming to zone II of IS:383-1970. Table 2 shows physical properties of fine aggregate.

Table 1 Properties of Cement

S. No.	Property	Values
1	Normal Consistency	30 %
2	Specific Gravity	3.12
3	Setting time i)Initial Setting time ii)Final Setting Time	56 minutes 245 minutes
4	Fineness	5 %
5	Soundness	1.2 mm

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Table 2 Characteristics of Fine Aggregate

S. No.	Property	Values
1	Specific Gravity	2.61
2	Density i) Loose ii)Rodded	 1440 kg/m^3 1632 kg/m^3
3	Bulking of Sand	4 %
4	Fineness Modulus	2.80

2.3. Coarse Aggregate

Coarse aggregates of 20 mm downsize was considered for the complete experimental study which obtained local market and the properties conforming to as per IS 383-1970 & IS 2386-1963 and are shown in Table 3.

Table 3 Properties of Coarse Aggregate

S. No.	Property	Values
1	Specific Gravity	2.68
2	Density i) Loose ii)Rodded	 1421 kg/m^3 1594 kg/m^3
3	Water absorption	0.485 %

2.4. Water

In the process of mixing concrete, the required amount of water was measured and added to the dry mixture using a graduated jar. Fresh potable water that complied with IS: 456-2000 requirements was utilized (tap water from the university laboratory).

2.5. Metakaolin

Metakaolin is a naturally occurring Pozzolanic substance that is produced under strict supervision by thermally activating kaolinite clay between 650 and 700 °C. For the current study, metakaolin is obtained from Astrra chemicals, Chennai and the specific gravity for the material obtained was 2.46.

2.6. GGBS

Granulated blast furnace slag is a non-metallic substance composed of several bases, including aluminates and calcium silicates. The chemical structure is similar to cement clinker. The GGBS utilized in this investigation was purchased locally in Bangalore and had a specific gravity of 2.82.

2.7. Bacteria

Bacillus subtilis JC3 at 10^5 cells/ml concentration was employed in this investigation, and nutrient broth was made using ingredients such as peptone, yeast extract, and NaCl and a pinch of bacteria is added to broth to obtain bacterial solution as shown in fig1 & 2. Calcium lactate is a dietary supplement that is added to the mix at a constant proportion of around 0.5. In this case, a bacterial solution was introduced at a percentage of cement of around 2% while mixing and at the same time adjusting the water content to maintain the same workability of the concrete.

Figure 1 Nutrient Broth

Figure 2 Cultured Bacillus Subtilis

Mix Design and Details of Mixes

M25grade concrete was designed as per IS 10262-2019 and IS 456-2000. In this investigation, cement partially substituted with Metakaolin and GGBS, with GGBS kept constant. Then, concrete cubes with varied metakaolin percentages and optimal GGBS percentages are formed to determine the ideal blended concrete mixture. Afterwards, bacteria solution is introduced to the optimum blended concrete mixture to determine the change in characteristics of blended concrete. Table 4 & 5 illustrates the proportion of materials obtained from mix design and Notations for all the mixes with material percentages.

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Table 4 Mix Proportions (With SP-0.80%)

Proportions	Water	Cement	Fine Aggregate	Coarse Aggregate
By Weight (kg)	157	342	822	1089
By Ratio	0.46	1	2.40	3.18

Table 5 Mix Details

S.No.	Mix	C* %	G* %	M* %	BS* Cells/ml	CL* %
1	C	100	0	0	0	0
2	CG1	95	5	0	0	0
3	CG2	90	10	0	0	0
4	CG3	85	15	0	0	0
5	CG4	80	20	0	0	0
6	CG5	75	25	0	0	0
7	CG6	70	30	0	0	0
8	CGM1	85	15	5	0	0
9	CGM2	80	15	10	0	0
10	CGM3	75	15	15	0	0
11	CGM4	70	15	20	0	0
12	CGM5	65	15	25	0	0
13	MBC	80	15	10	10^5	0.5

* C-Cement; *G- GGBS; *M-Metakaolin
*BS-Bacillus Subtilis; *CL- Calcium Lactate

3. Results & Discussions

3.1. Result

3.1.1. Compressive strength

For varying quantities of concrete mix, Compression testing was performed on cube specimens of 150mm x 150mm x 150mm using CTM after 7, 14, 28, and 56 days of curing. Table 6 represents the average of three specimens for each percentage. The variation of compressive strength of concrete with different percentages of metakaolin and GGBS and microbial blended concrete mix (MBC) in all the mix proportions are shown in the above results.

Table 6 Compressive strength Test Results

Concrete Mix	Compressive strength (MPa)			
	7 Days	14 Days	28 Days	56 Days
C	17.33	22.46	27.32	32.45
CG1	21.25	26.38	30.89	34.36
CG2	23.38	27.00	30.93	35.01
CG3	**24.72**	**28.26**	**32.67**	**36.38**
CG4	20.39	23.45	29.98	33.04
CG5	20.16	22.74	28.52	30.24
CG6	19.34	22.51	27.59	30.16
CGM1	24.11	28.97	31.83	35.75
CGM2	**24.98**	**31.37**	**34.32**	**37.93**
CGM3	20.04	23.16	27.45	32.72
CGM4	18.21	22.18	27.41	31.38
CGM5	18.00	21.34	25.89	29.49
MBC	**28.14**	**34.28**	**38.59**	**40.56**

It is observed that there is considerable increase in strength when GGBS is added as a partial replacement of cement. But, as the percentage increases, the strength decreased and the optimum percentage of GGBS which enhanced the strength properties is about 15%. Blended concrete mix was developed using metakaolin of different percentages and GGBS 15% and the mix with metakaolin of 10% shown maximum strength compared to other mixes. Finally, microbial blended concrete mix of metakaolin (10%), GGBS (15%), bacteria (10^5 cells/ml) and calcium lactate (0.5%) shown maximum strength of about 38.59 MPa and 40.56 MPa at 28 days and 56 days respectively compared to all other mixes.

3.1.2. Split Tensile Strength

Several cylindrical specimens underwent split tensile strength testing at the age of 28 days. (150mm dia x 300mm height). A cylindrical specimen is inserted horizontally between the loading surfaces of a compression testing machine, which has an operating limit of 200 tonnes, and a load is applied until the cylinder fails along the vertical diameter. The split tensile strength of specimens at 7 and 28 days is shown in Figure 3.

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https://doi.org/10.47392/IRJAEH.2024.0238

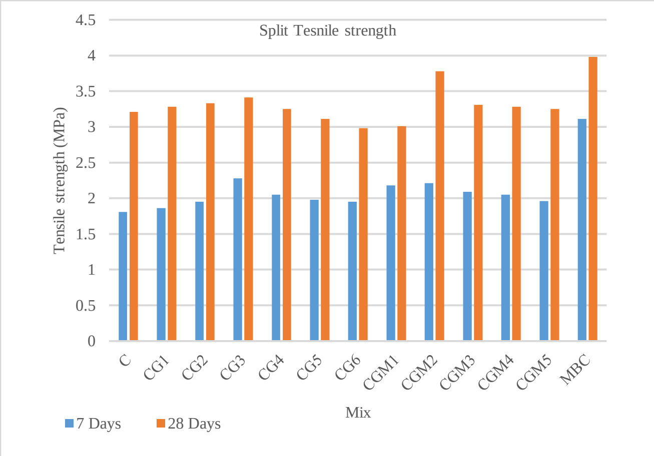

Figure 3 Split Tensile Strength Test Results

Split tensile strength variation for different percentages of metakaolin and GGBS at 7 and 28 days are shown in fig 3. It is observed that microbially blended concrete (Bacteria + GGBS + Metakaolin) mix exhibits a maximum tensile strength of about 3.98 MPa at 28 days.

3.1.3. Flexural Strength

Concrete was tested for flexural strength on various prisms of size 100 x 100 x 500 at the age of 7 and 28 days. Two-point loading is applied for the prisms and the failure load was considered to determine the flexural strength of concrete prisms and the test results obtained are shown in fig 4.

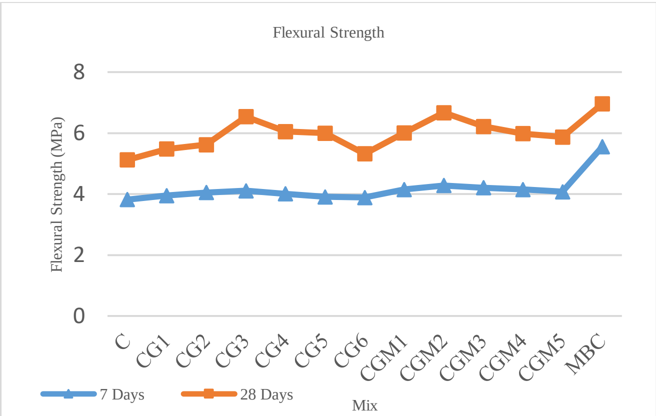

Figure 4 Flexural Strength Test Results

Flexural strength test results for various combinations at 7 and 28 days are shown in Fig. 4. According to test results, the mix of GGBS 15% alone shown maximum strength in comparison to other GGBS mix percentages, and the blended mix of metakaolin 10% and GGBS 15% showed high strength of about 6.67 MPa at 28 days in comparison to all other blended mixes. In comparison to all other mixes, the microbial blended concrete mix attained a maximum strength of roughly 6.96 MPa.

3.1.4. Water Absorption

One of the most important qualities of high-quality concrete is low permeability, particularly in concrete that is resistant to freezing and thawing. At the age of 28 days, the water absorption test is done in line with ASTMC642-11 standard practice. Prior to the water absorption test, 150x150x150 mm cubes are dried in an oven set at 100°C for at least 24 hours. Each specimen should be removed from the oven and allowed to cool in dry air to a temperature of 20° to 25° C before being weighed Continue until any two successive numbers diverge by no more than 0.5% of the lowest value achieved. The specimens should be put back in the oven for a further 24 hours of drying if the difference between values obtained from two subsequent mass values exceeds 0.5% of the smaller value. For all percentages of concrete cube specimens, the same process will be followed. Lastly, it is determined how much the specimen weighs while submerged in water. Weight percent rise is a measure of water absorption.

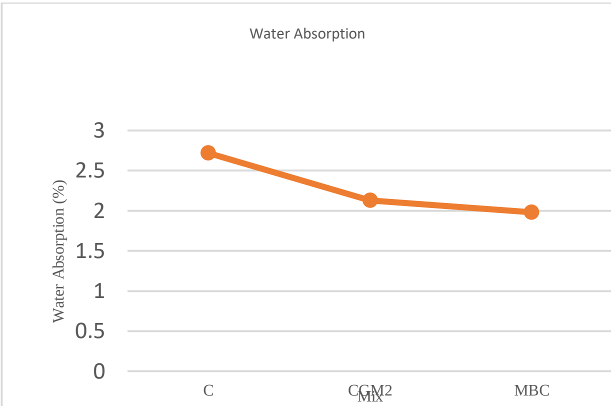

Figure 5 Water Absorption Test Results

3.1.5. Chlorine Penetration Depth Test

In the present study, water absorption test was conducted on three mixes such as conventional, blended mix and Microbial blended mix and the test

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https://doi.org/10.47392/IRJAEH.2024.0238

results are shown in fig 5. Percentage of Water Absorption = [(Wet weight – Dry weight)/Dry weight] x 100 One of the methods for determining the level of chlorine penetration in concrete sample is calorimetric chlorination technique. For all mixes, a minimum of two specimens measuring 150x150x150 mm are taken into consideration. The specimens are removed from the water after 28 days of water curing, dried at ambient temperature, and then submerged in water containing approximately 3.5% sodium chloride (NaCl). Specimens are removed from the NaCl solution after 28 days. The specimens are then divided into two equal halves after drying at room temperature. The specimens are immediately sprayed with a 0.1M solution of Silver Nitrate ($AgNO_3$) (broken part). Sodium chloride and silver nitrate react chemically, causing a white precipitate to form on the samples. This precipitate's depth is measured and noted. In the current investigation, three mixes, conventional, blended, and microbial mix were subjected to a water absorption test. The test findings are shown in table 7.

Table 7 Chlorine Penetration Depth

Mix	Depth of Penetration (mm)
C	18
CGM2	11
MBC	8

Table 7 illustrates, a lower 8 mm penetration depth was observed in the microbially blended concrete mix that contains GGBS (15%), metakaolin (10%), and bacteria.

3.1.6. Self-Healing Mechanism

Surface cracks on concrete as a result of shrinkage, insufficient water for hydration, application of loads, etc. More than 0.2 mm wide fissures as shown in fig 6. prevent concrete from self-healing and allow access to chemicals and other corrosive substances. If water enters the concrete in Bio-concrete through cracks, bacteria get activated from their dormant condition to perform metabolic processes that produce calcite as shown in fig 7, which serves as a healing agent. It returns to the dormant stage once the bacteria have filled the cracks. Once more, in the future, if fractures enlarge and foreign objects frequently penetrate, bacteria get active and mend the cracks. MBC (microbial blended concrete) mix, and regular mix cubes are taken into consideration in the current investigation. To calculate the healing %, the specimens are pre-cracked and maintained in water for three days at a consistent temperature and environment. According to the findings, the MBC mix specimens healed at a rate of 95% after 3 days of conventional curing and 30% for the traditional mix specimens. Bacteria have the ability to totally heal fractures that a standard or conventional mix is unable to perform if the number of days increases.

Figure 6 Pre-Cracked Specimens

Figure 7 Calcite Formation on Cracks

Conclusion

The current study's findings lead to the following interpretations:

1. Using blended concrete with Bacillus subtilis bacteria can improve the properties of concrete while also aiding in the healing of fractures.

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2. The strength properties of concrete improved by using GGBS and Metakaolin as partial replacement of cement and there is a further improvement in characteristics of concrete including healing property because of addition of bacillus subtilis at constant concentration of about 105 cells/ml. According to the findings of a compressive strength test, when bacteria introduced in blended concrete the compressive strength increased by 11% & 15.3 % at 28 days compared to blended mix (GGBS (15%) & Metakaolin (10%)) and mix with GGBS (15%) alone respectively. At 56 days it shown about, 6.48 % and 10.30 % respectively and from the results of split tensile and flexural strength tests, the same MBC mix outperformed compared to all other mixes by about 3.98 MPa and 6.96 MPa at 28 days, respectively.
3. When bacillus subtilis bacteria is introduced into blended concrete, there is reduced water absorption and a lower chlorine penetration depth of roughly 1.8% and 8 mm, respectively.
4. When compared to standard mixes, MBC mix shows the most extensive fracture healing. This is due to the fact that, in the proper environmental conditions, microorganisms aid in the synthesis of calcite in concrete, which aids in the even healing of fractures. The strength of the concrete may be reduced if the quantity of bacteria is too high, so this is a further aspect to consider when introducing bacteria to concrete.

Acknowledgement

The present study was conducted at Bangalore University, UVCE, Bangalore, Karnataka-560056.

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