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Impact of Bacillus Cereus Bacteria with GGBS on the Characteristics of Cement Concrete

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ABSTRACT - According to the study results, GGBS may be used to replace a portion of the OPC without affecting the quality of the concrete that results from it. CO_2 emissions due to global warming are attributed to OPC, a standard construction material. Due to the exponentially rising demand for OPC, this environmental concern is anticipated to worsen.

Due to the fact that GGBS decreases the need for OPC and reduces the amount of CO_2 released, it also contributes to the protection of the environment. It also improves the matrix's compressive strength, along with other strength properties, when metakaolin is used as a pozzolana in concrete with bacillus Cereus bacterial concentration. Bacteria can also increase the tensile strength of concrete by being included into the concrete matrix. The porosity of concrete is also reduced by bacteria so that water absorption of concrete is also decreased.

Key Words: OPC, GGBS, Bacillus Cereus Bacteria, Porosity

I. INTRODUCTION

Concrete is the most widely used material in the construction sector for paving roads, commercial buildings, residential structures, and bridges. Because of the lower tensile strength and endurance, the development of small cracks into large cracks in concrete buildings is increased. This is related to voids and increased permeability in cement concrete, which decreases the concrete's durability and strength [1].

Concrete has a number of disadvantages, including a poor tensile strength, a low flexural strength, and a high weight. Due of these drawbacks, civil engineers have turned to conventional reinforcing to enhance tensile and flexural strength. Waste management, on the other hand, has emerged as one of the most pressing environmental concerns in developing nations, as waste generation continues to rise in both rural and urban regions. Waste disposal also improves the aesthetics of the area and decreases the amount of crawling green, which has economic and health implications.

This research follows the addition of bacteria B. cereus which is directly added to the concrete mix and partial replacement of cement with GGBS in different percentages as 5%, 10% and 15% and 20%. The combination of bacillus cereus and GGBS in cement concrete proved to bring about a significant increase in the compressive strength and split tensile strength along with decrease in water absorption.

II. OBJECTIVES

The different objectives of the present work are as under:

- To improve the strength of concrete by using the bacillus cereus bacterial concentration along with GGBS.
- Reduce the number of voids in concrete to make it less permeable.
- Bacillus family bacteria and GGBS were used to enhance the durability of concrete.

To achieve the above objectives, the following are carried out:

- Determination of the properties of OPC, GGBS, Fine and Coarse aggregates.
- 5, 10, 15 and 20% of the OPC is replaced with GGBSalong with 10^8 cells/ml bacterial concentration in cement concrete for determination of the mechanical properties.

III. LITERATURE REVIEW

Concrete is commonly employed in the construction, with the majority of its components being used in a variety of industries. Concrete is a highly trustworthy material in terms of strength. Continuous usage of cement concrete has a negative impact on the environment, putting the ozone layer in jeopardy responsible for global warming into the environment.Cement is a binder used as a bonding agent in a variety of building applications. Cement is typically used to bind sand and gravel (aggregates) together rather than on its own. Cement is also used to harden a variety of different materials. Energy conservation and greenhouse gas (GHG) emission reduction have become increasingly important in recent years. The bulk exploitation of waste material as a resource material for the creation of value-added commodities receives a lot of attention. Cassagnabere et al. have studied that 175 kg of CO_2 is generated for every tonne of MK generated, which is substantially less than the 1 tonne of CO_2 produced for every tonne of PC produced.MK has been shown to increase the life of concrete, reducing the need for replacement and thereby conserving resources.

Mandal et al 2009 carried out various experiments on concrete by mixing it with an alkaliphitic Bacillus subtilis JC3 bacteria. Two series of concrete mix with varying grades had been prepared. First series was prepared by sand, coarse aggregate, cement and tap water. Second series i.e. bacterial series was prepared by sand, coarse aggregate, cement and bacteria suspended water. Different grades of concrete i.e. M20, M40, M60 and M80 had used in the study. Bacterial cell concentrations like 104 cells/ml, 105cells/ml, 106cells/ml and 107cells/ml were used for making bacterial series. Various strength tests like compressive strength, split tensile strength and flexural strength has been performed on concrete specimens. Water absorption test, sorptivity and porosity for concrete specimens had been experimentally performed. An increment of 17% in compressive strength for bacterial specimens at cell concentration of 105cells/ml has been noticed. Slight reduction in compressive strength has been observed, when bacterial cell concentration goes beyond 105cells/ml. Compressive strength, split tensile strength and flexural strength increased up to 25%, 20% and 25% respectively. For bacterial specimen series, strength properties are enhanced as the grade of concrete increases. Stress strain relationship criteria had been used for knowing elastic behavior of concrete. Bacterial concrete specimens having highest grade show highest peak on stress-strain curve as compared to other concrete specimens. Addition of bacteria in high grade concrete enhances its modulus of elasticity. It was clear from UPV test that pulse velocity reached more than 4.5km/s which reveals that bacteria embedded in concrete improve the pore structure and bonding in concrete specimen. Due to clogging of pores, lesser amount of water has been observed for bacterial specimen. Porosity amount and absorptive values found to be greater for concrete specimen that didn't contain any bacterial concentration. Electron microscopy of bacterial specimen showed better healing as compared to other specimens that proven the existence of Calcite mineral in bacterial specimens.

Irwan et al 2016 demonstrated the effect of Ureolytic bacteria ACRN on various properties of concrete. Strain of bacteria i.e. ACRN strain was used for incorporating in concrete mix as it contains maximum ureolytic activity as compared to other strains. Author found that bacterial strain treated samples show modified compressive quality. Individual strains blocked the pores of concrete and hence reduced its water permeability and thus presence of strain solidified the concrete matrix. XRD and SEM pictures were utilized for detecting calcium carbonate crystal in the treated concrete. This affirmed the presence of calcium crystal in concrete specimens. Greater electrical resistivity for strain specimens was found at 65 days of curing period. Hence, incorporation of urea bacterial strain in concrete gainfully modified the property of concrete mix.

Chen et al 2016 demonstrated that addition of B. Subtilis bacteria in concrete polish up the various strength properties of concrete. Six cubic samples were prepared by adding bacterial cells to concrete and tested for 7 and 28 days of curing age. 107% and 21% expansion in compressive strength at 7 and 28 days of curing stage was noticed for bacterial specimen as compared to usual concrete. Enhancement of 22.6 and 22.5% in tensile strength at two curing periods were observed for treated specimens. Flexural strength also extended up to certain figures in bacterial specimens.

Paine et al 2016 reported the properties of concrete blended with bacillus subtilis bacteria. Three different bacterial cell concentrations i.e. 103cells/ml, 106 cetensilells/ml and 109 cells/ml were merged with concrete and compared with normal concrete specimens that didn't contain any amount of bacteria. Various test experiments like compressive strength test, water absorption test, UPV test and SEM analysis had been done. Cubic specimens were also tested forload i.e. 10% of compressive strength at 28 days. Compressive strength test revealed that higher strength was achieved by cubic specimens that consists bacteria cell concentration of 106cells/ml as compared to other specimens. For bacterial specimen compressive strength enhanced i.e. Increments of

6-20% for 7 days curing, 6-17% for 28 days curing, 8-22% for 60 days curing and 7-20% for 90 days curing as compared to normal concrete had been marked. Maximum reduction in water absorption for both loaded and unloaded specimen were noticed for bacterial concrete at cell concentration of 106 cells/ml. UPV test showed that time of transmission for bacterial specimens was lesser than normal specimens. SEM analysis of bacterial concrete proved the formation of calcite crystals in their matrix. It had been detected from SEM analysis that bacteria filled the cracks and voids of the concrete matrix and also it densified the concrete. Hence, a careful use of subtilis bacteria in concrete transformed the properties of normal concrete.

Ersan et al 2017 studied the individual and combined effect of bacillus subtilis bacteria and calcium lactate on mechanical properties of concrete. Four types of concrete mix were designed according to the proportion of bacteria and calcium lactate. Mix 1 didn't contain any amount of bacteria and calcium lactate and normally prepared by adding cement, fine and coarse aggregate. Mix 2, Mix 3, Mix 4 were prepared by incorporating 0.5% calcium lactate, 0.5% of calcium lactate & bacteria and 0.5% calcium lactate & cultured bacteria of cell concentration 105cells/ml respectively. Several tests to find out workability and compressive strength of concrete had been conducted. Mix 2 that contained 0.5% of calcium lactate showed higher slump value as compared to other mixes. So, calcium lactate enhanced the workability and delayed the setting time of normal concrete. Bacterial concrete didn't show greater increasement in workability. Compressive strength of bacterial concrete found to be 16% higher than that of normal concrete. Mix 3 and Mix 4 displayed a higher value of compressive strength as compared to Mix 1 and Mix 2. Cultured bacterial concrete acquired a self healing property in selves. Therefore bacillus subtilis can be used as a self healing agent for concrete repair. Hence, It can be concluded that bacterial concrete enhanced the properties of conventional concrete.

Sarsam et al 2017 investigated the performance of bacillus lentus bacteria on concrete. Bacillus lentus were incorporated into expanded clay granules through vacuum technique. This was done to enhance survivability of bacteria in concrete at increased pH medium. Four compositions of samples were prepared. Reference sample consists of lightweight expanded clay aggregates (LWECA). SH1 mixes consist of bacteria and LWECA. SH2 mix was prepared by adding calcium lactate, yeast extract in LWECA. SH3 mix was made by incorporating bacteria and in medium in LWECA. Various tests to know the self healing properties, mechanical and physical properties of concrete were carried out. SH1, SH2, SH3 mix showed higher compressive strength as compared to the reference sample at a curing age of 28 days. Maximum of 22% enhancement in compressive strength had been noticed for SH2 mix as compared to other mixes. Compressive strength results showed that growth of bacteria flourished in calcium lactate and yeast medium. Self healing analysis revealed that bacillus lentus proved a good healing agent that causes self healing of concrete specimens. Self healing ability of a 6 years old specimen was tested out. It had been found that even six years of specimens healed the crack upto 60-90%. Monitored results showed that sealing efficiency is more for narrower cracks. Hence Bacillus lentus insured self healing of even six years specimens.

Dembovska et al 2016 studied the effect of different bacteria and curing conditions on properties of concrete. Two different bacteria with different bacterial cell concentrations incorporated in the concrete mix were S. Pasteuri and B. Subtilis. Bacterial specimen samples were cured for 28 and 91 days with two different curing conditions. Solution of Urea with calcium chloride and calcium lactate served as two different media for different specimen samples. Various tests were conducted to know water absorption, compressive strength, corrosion potential, chloride penetration and electrical resistance of concrete specimen samples. Silica fume was used by replacing 10% of mass of cement. Bacterial concrete specimens revealed lesser absorption in comparison to other concrete specimens. Concrete specimens treated with S. Pasteurii bacteria and cured in solution of calcium urea lactate disclosed an enhancement of 34% in their compressive strength. S. Pasteuri bacterial mix cured in urea calcium lactate solution unveiled lesser rate of corrosion in concrete specimen which proved that bacteria and calcium lactate save the steel bar and increased its durability. RCPT disclosed that bacterial specimens containing S pasteuri cured in urea calcium chloride solution for 28 days reduced the amount of electric current passing in them and thereby created a good resistance against penetration of chloride ions. Higher reduction in electric current and maximum resistance against chloride ion penetration were shown for bacterial concrete treated with S. Pasteuri rather than B. Subtilis. Hence S. Pasteuri treated concrete samples revealed less water absorption, greater compressive strength, improved resistance against chloride penetration and reduced electric current in conventional concrete as compared to concrete specimens that contain B. Subtilis. Therefore bacteria improve the durability of concrete.

Tayebani et al 2016 used Bacillus pseudofirmus bacteria and examined the change of compressive strength and flexural strength as well as self healing of concrete. Bacteria meets two conditions: a) concrete stand with high alkalinity for self healing b) long and durable. A new type of hydrogel crosslinked by chitosan, alginate and calcium ions was induced in this study. Varying percentage 0, 0.5, 1.0 and 1.5 of chitosan were used to determine the compressive and flexural strength. The result revealed that 5.98%, 2.3%, 10.28% and 5.98% increases of compressive strength as well as 1.97%, 3.4%, 13.79% and 1.48% increased in flexural strength respectively. Both strengths firstly increased and then decreased by increasing the content of chitosan. The optimum value of compressive strength was achieved at 1.0% of chitosan. After the 5-7 curing days white crystals are observed at the concrete surface. The bacteria Spores were stimulated based on swelling of hydrogel due to infusion of external water from the cracks, then the bacteria grew and generated carbon dioxide by metabolizing alginate in an alkaline environment. Calcium carbonate will be generated in the presence of CA2+, OH2 and CO2 show the self healing result of concrete. Positive result was observed when using calcium alginate-chitosan hydrogel bed for self healing concrete work.

Karimi et al 2020 carried out his work on bacteria for self healing of concrete. He analyzed the impact of an extremophile and non spore forming bacteria on mortar mix at room temperature (27±2°C) and low temperature (4+1°C). Different cell concentration of bacteria i.e. 103 cells/ml, 105cells/ml and 107cells/ml were mixed into mortar mix and tested for 28 days. Various tests like EDS & XRD for surface analysis, live/dead cells analysis to know the chemical composition, compressive strength and water absorption test were performed with different bacterial cell concentration at different temperatures. Maximum of 168 cubic specimens were prepared with distinct bacterial cell concentration. SEM images revealed the presence of tiny particles on the surface of bacterial cement powder mix whereas normal powder mix that didn't contain any amount of bacteria showed fine surface. Live/Dead cell analysis manifested that the amount of live cells in bacterial cement powder mix was higher than that of dead cells. Surface crack images indicate the formation of white precipitate in bacterial samples. For bacterial samples, width range significantly diminished and crack healing rate was higher at room temperature than low temperature. Cracks spread upto 1.5 mm had been properly healed by bacterial cell concentration of 107cells/ml at both temperatures. Compressive strength test result indicated lesser compressive strength at 103cell/ml bacterial concentration as compared to 105 and 107cells/ml. Reduction in bacterial cell concentration results in less precipitation of calcium carbonate. At 27±2°C, 42% increase in compressive strength was noticed with bacterial cell concentration of 105cells/ml. At 4+1°C, compressive strength increased upto 38% for bacterial cell concentration of 107cells/ml. Addition of D.radiurans in the mortar mix causes calcium carbonate to precipitate at both temperatures. At room temperature, bacterial cell concentration of 105cells/ml imparts higher precipitation whereas at low temperature, bacterial cell concentration of 107cells/ml imparts higher precipitation that depicts the same trend as that followed by compressive strength. Water absorption test showed that there was an inverse relationship between water absorption and bacterial cells concentration. Maximum of 36% reduction in water absorption had been noticed at room temperature and 26% for low temperature for bacterial cell concentration of 107cells/ml at 28 days of curing. Hence, bacteria D.radiurans successfully modified mix properties in freezing in as well as in room temperature.

Gao et al 2020 studied the effect of Sulphate resistant bacteria (SRB) in concrete mix. deterioration of concrete occurs due to corrosion of reinforcement. Chloride attack is the main cause of corrosion in reinforcement. Authors research objective to overcome deterioration of concrete. Irwan et al used Sulphate resistant bacteria (SRB) with varying percentages of 3, 5 and 7% directly in concrete mix. Compressive strength and water penetration tests were performed for 28, 56, 90, 180 and 360 curing days. Increment in compressive strength was observed by 15.7%, 10.4%, and 11.8% for 3%, 5% and 7% of SRB at 28 days respectively. Meanwhile increment in strength was recorded as 11.7%, 61% and 30% for 3, 5 and 7% of SRB 360 days of curing respectively. The maximum compressive strength was found at 63.9 MPa at 3% of SRB for 180 curing age. When compared to control specimens i.e. 0% of SRB, reduction of water depth was observed 6%, 7.8% and 10.6% for 3, 5 and 7 at 28 days of curing respectively. Meanwhile 75%, 79.4% and 80.1% reduction in water was found for 3, 5 and 7% of SRB at 360 days of curing respectively. The author concluded that at 5% of SRV achieved optimum strength and durability.

Mandal et al 2020 explored the self healing effect of bacteria, a solution of B. alkaliphlius AK13 and Boronitolerans YS11 spores was obtained using difcospoulation medium DSM , which was then spray dried to suppres further reaction. Jang et al used three types of mortar which were reference mortar (RM), nutrient mortar (NM) and bacteria co-cultured mortar (BM). The dry bacteria were added to cement mortar then examined self healing ability, bacteria survival, water absorption and compressive strength. The live survivility of bacteria was rapidly decreased on 28 days as compared to day 1, which was 0.002 - 0.006% of that day one. The author observed that absorptive rose with curing age but slope gradually decreased. RM phase value of 3.08x103 cm per second1⁄2 on day 1 and 4.5 08x103 cm per second½ on day 28 for reference mortar meanwhile absorptive value for BM sharply decreased on 7 and have value of 0.975 into 10 to the power 3 centimeter per under root as on date 28. NM has soptivity value of 1.97 x103cm/ second½. Water absorption in centimetre3 per centimetre2 for BM was much lower than both RM and NM. For BM, compressive strength and flexural strength reduced 39.3 percent and 55.7 percent as compared to reference mortar.

Irwan et al 2020 examined the effect of Thibacillusintermidus bacteria on the performance of OPC. Cement mortar specimens prepared by reading bacteria a solution either with water or both. Compressive strength, normal consistency test and water absorption sorptivity test performed to investigate the effect of bacteria on cement mortar. Concentration of bacteria was maintained at 107cells/ml. Cement mortar samples were prepared as a) controlled sample without bacteria labeled as OPC H2O (H2O) b) use the bacteria in mix water and cured under distilled water labeled as OPC TI (H2O) and c) use of bacteria solution for both labeled as OPC TI (TI). Normal consistency was observed 28% for OPC H2O (H2O) And 28.4% for OPC TI(TI), so it was found 1 mm and 3.2 mm for OPC H2O(H2O) and OPC TI(TI) respectively. For sample OPC H2O (H2O) initial setting time and final setting time were found as hundred minutes and 180 minutes, meanwhile for sample OPC TI (TI), initial setting time and final setting time found as 130 minutes and 230 minutes. Thus bacteria prolong the setting time and increase the hydration rate of cement. The compressive strength significantly decreased by 34.98% after 90 days of curing in microbial mortar. It was due to the formation of biojeniksulphuric acid from bacterial activity. Higher water absorption rate and sorptivity coefficient was observed in OPC TI(TI) and OPC H2O(TI) as compared to OPC H2O(H2O). The author concluded that TI bacteria reduced the compressive strength of mortar. TI bacteria affect the durability due to disturbance of microstructure of cement mortar, so it is not suitable for cement mortar.

Jang et al 2020 used Bacillus Pasteurii bacteria with varying concentration as 107, 108 and 109 cells/ml. Author investigated the self healing effect in concrete with bacteria. In this study pasteurii bacteria used to fill cracks in the mortar. To check the self healing, two cracks were created at a size of 0.2- 0.3 mm and 0.6- 0.7 mm. Bacteria liquid was directly mixed in cement mortar and 3% substrate was used by weight of cement. Author was recognized a linear relationship between the concentration of bacteria and amount of substrate. For small crack width size of 0.2-0.3 mm, it was observed that 108 and 109 cells/ml concentration of bacteria shows higher efficiency for self healing compared to bacteria concentration of 107cell/ml. For bacteria concentration of 107, 108 and 109 cells/ml, self healing area were recorded as 68.21%, 89.38% and 94.56%, meanwhile impermeability ratio are 53.69%, 70.13% And 86.52% for bacteria concentration of 107, 108 and 109 cells/ml, respectively. For large crack size 0.6-0.7 mm self-healing area recorded as 75.39%, 48.39% and 29.68%, while impermeability ratio were 51.73%, 39.67% and 25.36% for the bacteria concentration of 108, 109 and 107 cells/ml respectively.

Munyao et al 2020 used locally available mining isolated Bacillis sp. strain SKC bacteria to check the mechanical properties of cement mortar. Compressive strength, density and porosity analysis, water absorption and cement mortar characteristics were evaluated in this research work. Two categories of specimens were prepared a) abiotic control without bacteria b) biotic control with bacteria cells mortar. For biotic mortar compressive strength was found greater than to abiotic cement mortar. Porosity decreases by 2% in biotic motor and density increases 12% in biotic mortar. It was obvious that compressive strength was inversely proportional to porosity and directly proportional to density. An increment was recorded in permeability by 44.7% for biotic mortar.

Chaerun et al 2020 investigated the effect of specific strain of Bacillus subtills bacteria with lightweight aggregate concrete. Total 252 specimens were casted as, with and without bacteria, with and without reinforcement fiber, and with 3 different curing conditions viz. plain water, nutritient solution and urea-calcium lactate. Consideration of bacteria was kept 107cells/m. To determine the effect of bacteria with LWAC several tests were performed like water absorption test, electrical resistivity test, compressive strength test, Rapid chloride penetration test, carbonation depth test and permeability test. Reduction in water absorption was recorded about 13.1 percent for fiber reinforced bacterial mix concrete. Optimum reduction in water absorption was found 4.19 percent for bacterial mix in urea calcium-lactate at 150 days. It was also observed that bacterial mix specimens cured in urea calcium lactate lead to the highest electrical resistance value of 126.62 ohm meter at 150 days of curing. A decrement in compressive strength was observed for fully bacterial concrete mix. Highest values of compressive strength were achieved 8.9%, 19.9% and 22.22% for bacterial mix cured under nutrient, urea calcium lacted and water media at 28 days respectively. Carbonation depth decreased by 27% in bacterial mix Cured under water and water penetration decreased by 44. 3% in bacterial mix cured under urea calcium lactate.

Salmasi et al 2020 used the bacteria as bio slim over the concrete surface which was exposed to a sulphate attack environment. Bio-slime prepared by taking Rhodobactercapsulatus109cell/ml grown in super absorbent polymer (SAP) and expanded vermiculite (EV) medium with particle range sizes of SAP of 0.08 to 0.20 mm and EV size of 0.25 to 0.36 mm, respectively. Their densities were of 0.70 and 0.25 g/cc respectively. For non coating layer service life was evaluated 38.5 year and service life increased by 41.5—54.3 years for bio slime coating layers while service life increased by 50.5—83 years when 2.0 mm bio slime coating layer applied over the concrete surface, if sulphate Coefficient controlled between $0.1 \times 10{-}12$ and $0.3 \times 10{-}12$ m2/s. The author concluded that polymer bio-slime coating was highly resistant to sulphate attack and resistant to wetland. Bio–slime coating was also Highly Effective for reducing deterioration and increased surface life.Kim et al 2020evaluated the bacterial effect in terms of kinetics hydration and compressive strength on cement mortar. Several experiments performed like compressive strength, isothermal calorimetry, thermogravimetry and mercury intrusion porosimetry. Ureolytic bacteria (isolated from river) with nutrient, urea and Calcium lactate added directly in cement slurry as keeping Cement Solution ratio 0.4. Hydration kinetics evaluated by isothermal calorimetry analysis and gave a result that the hydration rate for controlled mortar specimen was 1.6 times higher than of ureolytic bacteria and urea cement mortar. The mass percentage of calcium carbonate increased in cultured bacterium cement paste as compared to controlled cement mortar. Author concluded that porosity reduced, it inferred that the voids could be filled by bio mediated calcification of ureolytic bacteria at 28 curing days. It was also concluded that when excessive dosages of ureolytic bacteria are used, it retards the hydration process cement mortar. Higher compressive strength was observed for incorporated nutritions, vegetative cells and Calcium lactate specimens that compared to incorporated vegetative cells and nutritions motor specimens. So calcium source exhibits the favourable effect for the mechanical properties of cement mortar with ureolytic bacteria.

REFERENCES

[1] N. Nain, R. Surabhi, N. V. Yathish, V. Krishnamurthy, T. Deepa, and S. Tharannum, “Enhancement in strength parameters of concrete by application of Bacillus bacteria,” Constr. Build. Mater., vol. 202, pp. 904–908, 2019.

[2] P. Kumar Tiwari, P. Sharma, N. Sharma, M. Verma, and Rohitash, “An experimental investigation on metakaoline GGBS based concrete with recycled coarse aggregate,” Mater. Today Proc., Sep. 2020.

[3] Shukla, N. Gupta, A. Gupta, R. Goel, and S. Kumar, “Natural Pozzolans a Comparative Study: A Review,” IOP Conf. Ser. Mater. Sci. Eng., vol. 804, no. 1, 2020.

[4] Gupta, N. Gupta, A. Shukla, R. Goyal, and S. Kumar, “Utilization of recycled aggregate, plastic, glass waste and coconut shells in concrete - A review,” IOP Conf. Ser. Mater. Sci. Eng., vol. 804, no. 1, 2020.

[5] Shukla, N. Gupta, A. Gupta, R. Goel, and S. Kumar, “Study on the Behaviour of Green Concrete by the use of Industrial waste Material: A Review,” IOP Conf. Ser. Mater. Sci. Eng., vol. 804, no. 1, 2020.

[6] Shukla, N. Gupta, and A. Gupta, “Development of green concrete using waste marble dust,” Mater. Today Proc., vol. 26, no. xxxx, pp. 2590–2594, 2019.

[7] S. Jena, B. Basa, K. C. Panda, and N. K. Sahoo, “Impact of Bacillus subtilis bacterium on the properties of concrete,” Mater. Today Proc., 2020.

[8] S. Mondal and A. (Dey) Ghosh, “Review on microbial induced calcite precipitation mechanisms leading to bacterial selection for microbial concrete,” Constr. Build. Mater., vol. 225, pp. 67–75, 2019.

[9] S. Joshi, S. Goyal, A. Mukherjee, and M. S. Reddy, "Protection of concrete structures under sulfate environments by using calcifying bacteria," Constr. Build. Mater., vol. 209, pp. 156–166, 2019.
[10] S. Ferreiro, D. Herfort, and J. S. Damtoft, "Effect of raw clay type, fineness, water-to-cement ratio and fly ash addition on workability and strength performance of calcined clay – Limestone Portland cements," Cem. Concr. Res., vol. 101, no. August, pp. 1–12, 2017.
[11] W. Ferdous, A. Manalo, T. Aravinthan, and G. Van Erp, "Properties of epoxy polymer concrete matrix: Effect of resin-to-filler ratio and determination of optimal mix for composite railway sleepers," Constr. Build. Mater., 2016.
[12] D. W. Fowler, "Polymers in concrete: A vision for the 2 st century," Cem. Concr. Compos., 1999.
[13] V. Achal, A. Mukerjee, and M. Sudhakara Reddy, "Biogenic treatment improves the durability and remediates the cracks of concrete structures," Constr. Build. Mater., 2013.
[14] W. Ferdous et al., "Optimal design for epoxy polymer concrete based on mechanical properties and durability aspects," Constr. Build. Mater., 2020.
[15] N. Chahal and R. Siddique, "Permeation properties of concrete made with fly ash and silica fume: Influence of ureolytic bacteria," Constr. Build. Mater., 2013.
[16] R. Siddique and N. K. Chahal, "Effect of ureolytic bacteria on concrete properties," Construction and Building Materials. 2011.
[17] S. Krishnapriya, D. L. Venkatesh Babu, and P. A. G., "Isolation and identification of bacteria to improve the strength of concrete," Microbiol. Res., 2015.
[18] P. Ghosh, S. Mandal, B. D. Chattopadhyay, and S. Pal, "Use of microorganism to improve the strength of cement mortar," Cem. Concr. Res., 2005, doi: 10.1016/j.cemconres.2005.03.005.
[19] F. Alshalif, J. M. Irwan, N. Othman, and L. H. Anneza, "Isolation of sulphate reduction bacteria (SRB) to improve compress strength and water penetration of bio-concrete," in MATEC Web of Conferences, 2016, doi: 10.1051/matecconf/20164701016.
[20] H. Chen, C. Qian, and H. Huang, "Self-healing cementitious materials based on bacteria and nutrients immobilized respectively," Constr. Build. Mater., 2016, doi: 10.1016/j.conbuildmat.2016.09.023.
[21] N. N. T. Huynh, N. M. Phuong, N. P. A. Toan, and N. K. Son, "Bacillus Subtilis HU58 Immobilized in Micropores of Diatomite for Using in Self-healing Concrete," in Procedia Engineering, 2017, doi: 10.1016/j.proeng.2017.01.385.
[22] N. Hosseini Balam, D. Mostofinejad, and M. Eftekhar, "Effects of bacterial remediation on compressive strength, water absorption, and chloride permeability of lightweight aggregate concrete," Constr. Build. Mater., vol. 145, pp. 107–116, 2017, doi: 10.1016/j.conbuildmat.2017.04.003.
[23] Y. Ç. Erşan, E. Hernandez-Sanabria, N. Boon, and N. De Belie, "Enhanced crack closure performance of microbial mortar through nitrate reduction," Cem. Concr. Compos., 2016, doi: 10.1016/j.cemconcomp.2016.04.001.
[24] J. Zhang et al., "Microbial network of the carbonate precipitation process induced by microbial consortia and the potential application to crack healing in concrete," Sci. Rep., 2017, doi: 10.1038/s41598-017-15177-z.
[25] J. Y. Wang, N. De Belie, and W. Verstraete, "Diatomaceous earth as a protective vehicle for bacteria applied for self-healing concrete," J. Ind. Microbiol. Biotechnol., 2012, doi: 10.1007/s10295-011-1037-1.
[26] H. M. Jonkers and R. Mors, "Full scale application of bacteria-based self-healing concrete for repair purposes," in Concrete Repair, Rehabilitation and Retrofitting III - Proceedings of the 3rd International Conference on Concrete Repair, Rehabilitation and Retrofitting, ICCRRR 2012, 2012.
[27] N. Parastegari, D. Mostofinejad, and D. Poursina, "Use of bacteria to improve electrical resistivity and chloride penetration of air-entrained concrete," Constr. Build. Mater., vol. 210, pp. 588–595, 2019, doi: 10.1016/j.conbuildmat.2019.03.150.
[28] S. A. Kadapure, G. Kulkarni, K. B. Prakash, and P. S. Kadapure, "Mechanical and durability performance of sustainable bacteria blended fly ash concrete: an experimental study," Int. J. Sustain. Eng., vol. 13, no. 1, pp. 45–53, 2020, doi: 10.1080/19397038.2019.1644386.
[29] L. Dembovska, D. Bajare, A. Korjakins, D. Toma, and E. Jakubovica, "Preliminary research for long lasting self-healing effect

of bacteria-based concrete with lightweight aggregates," IOP Conf. Ser. Mater. Sci. Eng., vol. 660, no. 1, 2019, doi: 10.1088/1757-899X/660/1/012034.

[30] H. W. Kua, S. Gupta, A. N. Aday, and W. V. Srubar, "Biochar-immobilized bacteria and superabsorbent polymers enable self-healing of fiber-reinforced concrete after multiple damage cycles," Cem. Concr. Compos., vol. 100, no. March, pp. 35–52, 2019, doi: 10.1016/j.cemconcomp.2019.03.017.

[31] Tayebani and D. Mostofinejad, "Penetrability, corrosion potential, and electrical resistivity of bacterial concrete," J. Mater. Civ. Eng., vol. 31, no. 3, pp. 1–11, 2019, doi: 10.1061/(ASCE)MT.1943-5533.0002618.

[32] IS 516:2014, "Method of Tests for Strength of Concrete," IS 516 - 1959 (Reaffirmed 2004), p. New Delhi,India, 2004