International Journal of Scientific Research in Civil Engineering
© 2021 | IJSRCE | Volume 5 | Issue 1 | ISSN : 2456-6667

Experimental Investigation of a Self-Healing Concrete Considering Bacillus Megaterium Bacteri and Fibers : A Review

Randhir Kumar Singh[1], Ajeet Saxena[2]

[1]P.G. Scholar, Department of Civil Engineering, Radharaman Engineering College, Bhopal, Madhya Pradesh, India

[2]Assistant Professor, Department of Civil Engineering, Radharaman Engineering College, Bhopal, Madhya Pradesh, India

Article Info
Volume 5, Issue 1
Page Number: 49-57
Publication Issue :
January-February-2021
Article History
Accepted : 06 Jan 2021
Published : 16 Jan 2021

ABSTRACT

It is strong enough to resist compressive load but prone to cracking due to weak in tension which ultimately reduce the life of structure. Hence, any effort to improve the life span of structure will indirectly improve the sustainability of the environment. Cracks in concrete lead to ingress of chemicals in to concrete structure resulting in lower strength and durability

In this paper we are presenting review of literatures related to utilization of bacterial effect on concrete.

Keywords : Bacteria, Concrete, Fibers, Strength, Self Healing, Material, Admixtures.

I. INTRODUCTION

The word concrete comes from the Latin expression "concretus" which means compounded. It was used by the ancient Romans in construction of walls and roofs, and it is a heterogeneous composite material with the following constituents: cement, coarse aggregate, fine aggregate, and water. There are two types of concrete used in the world: ordinary plain concrete which is made by mixing cement, fine aggregate and coarse aggregate with water; when steel reinforcement is added to plain concrete, it is called reinforced concrete. Concrete is the most commonly used building material in the world. It is durable, available everywhere and strong and is the cheapest man-made construction material to produce and recycle. Unfortunately, concrete is susceptible to many different types of damage which result in cracks. These cracks can be broadly classified as (i) structural cracks which come from design defects, construction and supervision problems; and (ii) non-structural cracks caused by ambient conditions e.g. (temperature, humidity) and/or quality of materials. Ambient conditions cause damage to concrete by freeze/thaw cycles, chemical attacks, corrosion, extreme loads and other environmental factors. Consequently, maintenance of concrete structures is recurrent and costly. Many countries in the world have spent billions of dollars every year on maintaining infrastructure such as buildings and bridges.

The research work concerning the various application and methods used for testing of the concrete with a property of self-healing due to chemical or biological effect are discussed. This research is supported by the related reading material previous research about the different bacteria or chemical which had been done as the references to describe more and explain the characteristics and application of such concrete.

II. LITERATURE SURVEY

Lagazo, Magil A et. al. (2019) the research paper introduced the use of microorganisms-Bacillus Subtlis as its very profitable for building up an intense system and set forth a concentrated exertion retouching concrete as a technique for brake control to overhaul organization life in a strong structure. The framework Microbiologically Induced Calcite Precipitation (MICP) was grasped. It was the usage of Bacillus Subtilis close by its supplements which are the Sodium Bicarbonate (NaHCo3), Ammonium Carbonate (NH4Cl), Calcium Chloride Dehydrate (CaCl2), and supplement stock. The blending extent utilized was 1:2 ½: 5:0.45 alongside 30 ml fluid type of Bacillus Subtilis with the cell convergence of 105 cells/ml. The strength of solid blend was assessed by directing a test on 150mm x 150mm x 150mm 3D shape for compressive strength test, 6in x 12in the round and hollow form for split elasticity test, 21in x 6in x 6in rectangular pillars for flexural strength text and 3in x 6in for water assimilation test, 3 examples each test. All example used for recovering is 4in x 2in x 2in which was purposely broken. The examination exhibits that there was a critical augmentation in the nature of concrete added with microbes or bacterial cement diverged from ordinary concrete and thusly calcium carbonate precipitation is clear after 3 a month in limited scope parts.

The outcomes reasoned that the development of minute life forms that the expansion of bacterial arrangement Bacillus Subtilis in cement introduced upgrades in various properties of concrete the extent that a compressive quality test, split rigidity test, water ingestion test, and flexural quality test. As the microorganisms can convey in the examination community, it very well may be wound up being particularly secured and does‟t give a treat to human wellbeing. The assessment accomplished use of minute creatures in concrete upgraded its solidarity and solidness henceforth utilizing this kind of microscopic organisms for the self-mending instrument in cement can deliver financially economical solid or tough structures.

Abubakar Magaji et. al. (2019) the exploration paper researched on self-mending of breaks in concrete based substances and black-top cement. The break arrangement was a fundamental well known to marvel in a solid structure that empowers the water and different kind of synthetic substances into the solid into the breaks and diminishes their solidness, strength and which assaults the fortification in the event that it interacts with water, CO2 in addition to different synthetic substances. Self-mending cement could resolve the snag of solid structures deteriorating impressively before the finish of their life expectancy. Presenting the microbes inside the solid performs it incredibly valuable it improves the characteristic of the solid, which is higher than the customary cement. Microorganisms fix the breaks in cement by giving the calcium carbonate gem that hinders the breaks and fixes them. Numerous scientists have taken care of their work on oneself mending kind of cement and they had gotten the ensuing outcome that microbes build up the property of customary cement, for example, increase in 13.75 percent strength brought up in 3 days, 14.28 percent in multi-week just as 18.35% in week one. In any case, on the off chance that solid could distinguish breaking and mend itself, at that point there would not exclusively be significant cost reserve funds yet additionally save an ecological increase furthermore in light of the fact that solid creation represents a significant amount of the world's CO2 discharges.

Kusuma K et. al. (2018) the examination paper introduced the impact on compressive strength, water assimilation and water porousness of concrete solid 3D squares because of the blending of microbes, the stopping of a fake break-in concrete solid utilizing Bacillus megaterium. It was discovered that the utilization of Bacillus Megaterium improves the compressive strength and firmness of cement. It likewise introduced that there was a decrease in water retention and water porousness when contrasted with customary cement. The microbes which would have been presented in cement ought to have the property of antacid opposition and it likewise should frame endospore, so it withstands the anxieties delivered in cement while blending, shipping and setting.

The outcomes introduced urease positive microbes (the microscopic organisms which can accelerate calcium carbonate, for example, Bacillus subtilis, bacillus pasterui, Bacillus megaterium and to introduce the mending method of breaks in cement by them. The examination surveyed the various kinds of microscopic organisms that can be utilized for curing breaks in cement. There was the upgrade of compressive strength of cement. The utilization of such microbes positively affects water assimilation, playfully and water porousness in cement. The conclusion expressed that utilizing self-mending cement can be a capable other option and excellent solid sealant which was eco-accommodating, practical and furthermore brings about an improvement in the sturdiness of building materials.

Amirreza Talaiekhozan et. al. (2014) the research paper reviewed natural, chemical and biological processes of self-healing concrete technologies. The review presented a new insight into the research for the treatment of unexpected cracking of concrete. The results proposed a taxonomy to cover possible methods for the design, namely natural, chemical and biological methods. Chemical methods were the conventional methods that have been used as a sole method to design self-healing concrete. This paper concluded intensively about the great potential of biological method, using the bacteria capable of precipitating calcite, as providing the way forward for developing biological self-healing concrete. The precipitation of calcite will form calcium carbonate that would help in healing concrete cracks. The taxonomy contributed significantly for researchers in the field of biological to embark on the research work of self-healing concrete.

Salmabanu Luhar and Suthar Gourav (2015) the research paper stated that Introduction of the bacteria into the concrete made it very beneficial as it improved the property of the concrete which was more than the conventional concrete. Bacteria repair the cracks in concrete by producing the calcium carbonate crystal which block the cracks and repair it. Various research stated that bacteria improves the property of conventional concrete such as increase in 13.75% strength increased in 3 days, 14.28% in 7 days and 18.35% in 28 days. The development of calcium carbonate crystal decreases the water permeability by decreasing the width of cracks from 0.5 mm to 0.35 mm. Compressive strength was increases by 30.76% in 3 days, 46.15% in 7 days and 32.21% in 28 days and in mathematical modal it was found that the bacterial concrete shows the better value of stress and strain as compared to controlled concrete for the high strength grade of concrete. The regular inspection for the concrete will be less need due to use of self-healing material used in the concrete. In quantified the cracks healing capacity of the concrete containing LWA (light weight aggregate) Encapsulation self – healing agent. The observation stated that the width of the cracks was less than 0.46 mm for bacteria- based specimens. From the capillary water suction test it was found that the bacterial concrete showcased the lower values of relative capillary index as compare to the uerolytic mixed culture and from the gas permeability tests it was found that the permeability decreases in bacterial concrete as compare to the conventional concrete.

Suman R. Tabiyar et. al. (2018) the research paper evaluated the influence of Bacillus Pasturii bacteria on the compressive strength, resistance against acid attack and chloride penetration of concrete made with and without FLY ASH & GGBS. Cement was

replaced with three percentages 30, 40 and 50 with GGBS by weight, and FLY ASH 20 percentages, with a cells concentration of 10 cells/ml of bacteria were used in making the concrete mixes. The tests were performed at the age of 7, 28 and 91 day.
Results concluded that the compressive strength of the bacterial concrete increased when the addition of the bacillus pasteurii, fly ash, and GGBS. There was decrease in permeability, water absorption. Self-healing technology by using bacteria has proved to be better than many old technologies because this technology has ecofriendly in nature. At 20% replacement of fly ash with cement maximum compressive strength were obtained, while on further increment in reduce. Addition of flyash and GGBS with bacterial concrete provided almost same compressive strength of conventional concrete. Bacillus pasteruii can be produced from laboratory which proved to be a safe and cost effective.

Ashish Babarao Gawande et. al. (2016) The research paper presented concrete containing bacteria in the form of capsules which remain dormant till 100 years unless it receives water which is its nutrient to become active and multiplicate. Self healing concrete was a new technology developed in Delft University, Netherlands. Capsules receive water only when exposed to the environment which is possible when cracks appear in the structures. The bacteria heal the cracks or gap within three to four weeks by producing limestone as its byproduct. The cost of construction for constructing cement road has increased by about 2 crores with the implementation of self-healing agents in the cement. However, on the long run, this method was actually economic. This could be understood by analyzing the additional cost required for the repair and maintenance of roads made using conventional methods.

The results concluded that by adding of self-healing agents, the service life of various structures could be improved exponentially and hence incur savings in the cost of maintenance. Method of preparation of conventional bricks involve the process of baking the bricks in large kilns. This process was not environmental friendly as it involves release of poisonous gases into atmosphere, contributing towards green house effect. Bricks can be prepared using self healing concrete which are environmental friendly as they are not produced in kilns and are more durable than conventional bricks.

B.Arthi and.K.K.Dhaarani (2016) the aim of the study was to incorporate an autonomous self-healing mechanism in concrete based on the application of bio-mineralization of bacteria and to recover the strength after the formation of cracks in concrete. Attempts were made to prevent further concrete deterioration, such as corrosion, using Bacillus Subtilis and Bacillus Licheniformis. Tests were performed at the ages of 7, 14 and 28 days. The applicability of specifically calcite mineral precipitating bacteria to fill the cracks in concrete and the bacteria chosen must have the self-healing capacity and the bacteria used must be nonpathogenic and sustainable. It was found that the cracks in the concrete have been healed and the formation of calcite precipitation was observed using Scanning Electron Microscopy (SEM). Usage of bacteria like Bacillus Subtilis, Bacillus Licheniformis improves the strength and durability of concrete through selfhealing effect.

Results stated that the compressive strength of concrete cubes using Bacillus Subtilis and Bacillus Licheniformis has been increased upto 8% and 15% respectively. The compressive strength of Bacillus Licheniformis was 46.66% of Bacillus Subtilis. The split tensile strength of concrete cubes using Bacillus Subtilis and Bacillus Licheniformis has been increased upto 6.66% and 12.69% respectively. The split tensile strength of Bacillus Licheniformis was 47.52% of Bacillus Subtilis. The flexural strength of concrete cubes using Bacillus Subtilis and Bacillus

Licheniformis was increased upto 6.87% and 9.25% respectively. The flexural strength of Bacillus Licheniformis was 25.73% of Bacillus Subtilis. The water absorption value of concrete using Bacillus Subtilis and Bacillus Licheniformis has been decreased upto 46.93% and 52.04% respectively. The water absorption of Bacillus Licheniformis was 9.82% of Bacillus Subtilis. Results concluded that Bacillus Subtilis and Bacillus Licheniformis can be easily cultured and safely used in improving the strength characteristics of concrete.

Jing Xu et. al. (2018) the research paper used porous ceramsite particles microbial carrier. Heat treatment and NaOH soaking was first employed to improve the loading content of the ceramsite. The viability of bacterial spores was assessed by urea decomposition measurements. Then, the self-healing efficiency of concrete cracks by spores was evaluated by a series of tests including compressive strength regain, water uptake, and visual inspection of cracks. Results indicated that heat treatment can improve the loading content of ceramsite while not leading to a reduction of concrete strength by the ceramsite addition. The optimal heating temperature was 750°C. Ceramsite particles act as a shelter and protect spores from high-pH environment in concrete. When nutrients and spores are incorporated in ceramsite particles at the same time, nutrients are well accessible to the cells. The regain ratio of the compressive strength increases over 20%, and the water absorption ratio decreases about 30% compared with the control. The healing ratio of cracks reaches 86%, and the maximum crack width healed was near 0.3 mm.

H. M. Jonkers (2011) the research paper investigated the crack healing capacity of a specific bio-chemical additive, consisting of a mixture of viable but dormant bacteria and organic compounds packed in porous expanded clay particles. Microscopic techniques in combination with permeability tests revealed that complete healing of cracks occurred in bacterial concrete and only partly in control concrete. The mechanism of crack healing in bacterial concrete presumably occurs through metabolic conversion of calcium lactate to calcium carbonate what results in crack-sealing. This biochemically mediated process resulted in efficient sealing of sub-millimeter sized (0.15 mm width) cracks. It was expected that further development of this new type of self-healing concrete will result in a more durable and moreover sustainable concrete which will be particularly suited for applications in wet environments where reinforcement corrosion tends to impede durability of traditional concrete constructions.

Conclusion proposed two component bio-chemical healing agent, composed of bacterial spores and a suitable organic bio-cement precursor compound, using porous expanded clay particles as a reservoir was a promising bio-based and thus sustainable alternative to strictly chemical or cement-based healing agents, particularly in situations where concrete parts of a construction was not accessible for manual inspection or repair. However, before practical application becomes feasible, further optimization of the proposed system is needed. E.g., the amount of healing agent needed should be minimized in order to become economically competitive with currently existing repair techniques and furthermore to reduce consequences such as loss in compressive strength.

Nishant Dahake et. al. (2019) the research paper stated the properties of self healing nature of concrete and they had found that bacteria improves the property of conventional Encapsulation self – healing agent.

The results observation stated that the width of the cracks was less than 0.46 mm for bacteria- based specimens. From the capillary water suction test it was found that the bacterial concrete presented the lower values of relative capillary index as compare to the uerolytic mixed culture and from the gas permeability tests it was found that the permeability decreases in bacterial concrete as compare to the conventional concrete. Concrete such as increase in 13.75% strength increased in 3 days, 14.28% in 7 days and 18.35% in 28 days. The development of calcium carbonate crystal Decreases the water permeability by decreasing the width of cracks from 0.5 mm to 0.35 mm. Compressive strength was increases by 30.76% in 3 days, 46.15% in 7 days and 32.21% in 28 days and in mathematical modal it was found that the bacterial concrete presented the better value of stress and strain as compared to controlled concrete for the high strength grade of concrete. The regular inspection for the concrete will be less need due to use of self-healing material used in the concrete. The quantified the cracks healing capacity of the concrete containing LWA (light weight aggregate).

Nele De Belie et. al. (2019) the research paper investigated the durability of self-healing concrete. Application of self-healing concrete reduces the need for expensive maintenance and repair actions. Durability was assessed indirectly through parameters such as water absorption or permeability of cracked and healed concrete. The durability of self-healing concrete with macroencapsulated polyurethane on the one hand, and with granulated denitrifying bacteria on the other hand was presented.

The conclusion stated that self-healing implies that a crack formed in a concrete structure activates a healing mechanism, leading to crack filling, regain of liquid tightness and/or mechanical properties. However, complete healing takes time, ranging from several hours (for encapsulated polymers) to several weeks (for encapsulated mineral or crystalline additions and bacteria). In this time span, corrosion of reinforcement steel can be initiated. The simple corrosion test stated that that in the case of bacteria-based healing; only the denitrifying cultures were able to protect the reinforcement as efficiently as if the specimens contained a chemical nitrite based inhibitor. This can be ascribed to the release of nitrite as an intermediate metabolic product by the bacterial granules with a denitrifying core. In cracked mortar, rebar corrosion initiated after 16 days exposure to 0.5 M Cl– solution (drop of open circuit potential below -250 mV). In the case of bacteria based self-healing using a ureolytic culture, corrosion continued as well, even though complete crack healing was seen after 4 weeks.

Gursimran Kaur Uppal et. al. (2019) the objective of the research paper was to heal the crack by bacterial precipitation and investigate the effect of bacterial species in achieving strength in contrast to conventional concrete so as to improve durability and compressive strength of concrete. Use of silica gel as moisture absorbing agent to rapid the self healing activity.

Results stated that cracks up to 1 mm were healed with help of bacteria present in it due to bacterial precipitation. When bacteria was present in the form of solution, crack was observed to get healed within 28 days and when bacteria are present in the form of beads, crack was observed to get healed completely by 18th day. With the addition of silicone gel in concrete it was found that the cracks were healed in less duration. Calcium carbonate layer was formed on the concrete surface. The compressive strength of concrete cubes in which the bacteria was introduced in the solution form was increased by 19.6 %. The compressive strength of concrete cubes in which the bacteria was introduced in beads form was increased by 20.1 %.

Shubham Ajay Puranik et. al. (2019) the primary objective of the research paper was to promote sustainable development and to identify sustainable materials for treating cracks formed in concrete. The research was dedicated to check the suitability of mixing these self-healing calcite depositing bacteria with concrete in order to increase the compressive strength of concrete, reduce its permeability and seepage of water by bio-mineralization process. Substantial increase in strength is observed in concrete specimens when casted with bacterial solution. The research has devised methods or ways to test the effect of use of bacteria in concrete. Tests on concrete slab with various combinations of bacterial solution as well as varied percentage of bacterial solution was conducted. Use of bacterial solution for surface application on slab to test the sealing capacity was done. Results have been compared with conventional concrete. Biological modifications of construction materials are the need of the hour for strength improvement and long term sustainability.

Compressive strength of concrete presented significant increase with the addition of bacteria. 30 ml of Bacillus Sphaericus in concrete mix M20 showed the maximum improvement in compressive strength as compared with the conventional concrete's strength. Upon application of the selected bacteria, it was witnessed that it can also be used as waterproofing material. Bacillus Sphaericus showed better results as a waterproofing material and seepage control as it works better than Bacillus Subtilis.

Bacterial concrete was fairly new concept and is implementable on site. It was easy to prepare and requires basic knowledge of bacteria and cultures. It was a very innovative idea to make use of these natural phenomena of bacteria to improve concrete's performance. The solution was not only reliable but also increases durability of the structure making it maintenance free. Comparatively, this technique was cheaper than the methods that are resorted to in case of crack formation and deterioration of the structure. It thus requires due attention in order to make a more sustainable infrastructure to move towards a more eco friendly construction practices.

Tim Van Mullem et. al. (2020) the research paper carried our tests on laboratory control specimens made from the same concrete batch, as well as the findings of an inspection of the roof slab under operating conditions. Lab tests showed that cracks at the bottom of specimens and subjected to wet/dry cycles had the best visual crack closure. Additionally, the sealing efficiency of cracked specimens submersed for 27 weeks in water, measured by means of a water permeability setup, was at least equal to 90%, with an efficiency of at least 98.5% for the largest part of the specimens. An inspection of the roof slab showed no signs of cracking, yet favorable conditions for healing were observed. So, despite the high healing potential that was recorded during lab experiments, an assessment under real-life conditions was not yet possible.

The test results presented that the need for liquid water to start $CaCO_3$ production of the bacteria. The best visual crack closure for specimens subjected to wet-dry conditions, compared to humid conditions (>95% RH) or permanent saturation. A negligible improvement in capillary water absorption after healing for cracks larger than 300 μm which can be attributed to an incomplete crack closure at the surface. A manual addition of healing agent into an industrial concrete mixer was not an ideal solution, as the mixing time has to be extended which might result in an increased air content. Additionally, structural designs are done taking into account a wide variety of realistic load cases, yet it is possible that the most severe load combination does not occur in reality (or takes a long time to occur). In any case, this application of self-healing concrete has been an important step in gaining confidence of designers, contractors, as well as engineers at concrete mixing plants to consider self-healing concrete as an option for challenging applications.

Lianwang Yuan et. al. (2019) in the research paper, through the ultrasonic test and optical micrograph observation, the self-healing properties of concrete prepared by cement with different particle size distributions were presented. Besides, the effect of carbonation and continued hydration on self-healing of concrete was analyzed. Results presented that for the Portland cement containing more particles with the size 30~60 μm, the concrete could achieve a better self-healing ability of concrete at 28 days. For the two methods to characterize the self-healing properties of concrete, the ultrasonic test was more accurate in characterizing the self-healing of internal crack than optical micrograph observation. The autogenous self-healing of concrete was jointly affected by the continued hydration and carbonation. At 7 days and 30 days, the autogenous self-healing of concrete is mainly controlled by the continued hydration and carbonation, respectively.

The results concluded that for the Portland cement containing more particles with the size of 30~60 μm, the surface crack closure was more complete and the recoveries of ultrasonic signal was better. Therefore, the concrete could achieve a better self-healing ability of concrete at 28 days. For the methods to characterize the self-healing ability of concrete, the ultrasonic tests was more accurate in characterizing the self-healing of internal crack than optical micrograph observation, especially the ultrasonic waveform and frequency tests. The autogenous self-healing of concrete was jointly affected by the continued hydration and carbonation. The autogenous self-healing of concrete was mainly controlled by the continued hydration at the early period of self-healing, while the carbonation played an important role at the late stage of self-healing. Calcite was mainly form of self-healing products and plays a role in the whole self-healing process, while the continued hydration products interlace into a loose network structure in the early stages of self-healing. The cement particle size could affect the continued hydration by affecting un-hydrated cement content and the carbonation by affecting the Ca(OH)2 content. Therefore, a proper distribution of cement particle size, which bought a suitable amount of Ca(OH)2 and un-hydrated cement, could improve the self-healing ability of concrete.

Baban Kumar (2015) the objective of the research paper was to report the effects of bacteria-based additives on the properties of concrete such as compressive strength, split tensile strength and flexural strength and a clear comparison can be made for strengths of different specimens of bio concrete using different bacteria and conventional concrete. Moreover, the water permeability and chloride penetration resistance properties of concrete specimens were investigated. Self-healing was also confirmed by SEM photographs and XRD analysis.

The conclusion stated that Self-healing of concrete yielded by using natural method and is environmentally friendly. It was done for improving the lifespan of concrete structure which indirectly improvise the sustainability of environment. Effectiveness of crack repairing and regaining of lost strength is also depend on microorganism embedded in concrete matrix. Mechanical properties also improve by incorporating bacteria as long term compressive and tensile strength increases depending on bacteria embedded. Durability properties of concrete improve by incorporating bacteria as concrete perform better against water permeability, chloride ingression and water absorption. SEM and XRD analysis confirms the precipitation of calcium carbonate which densifies the concrete matrix and ultimately improve the strength of concrete.

III. CONCLUSION

Here authors analyzed concrete considering bacterial effect to enhance concrete properties. Chemical reactions were performed to determine the effect of bacteria over concrete in self healing and repairing of failures. But none of the author determine strengthening properties of concrete considering bacterial effect and admixtures to provide strengthening.

IV. REFERENCES

[1]. AMMAR YASER ALI - AHMED MOHAMMED MAHDI: Analysis for behaviour and ultimate strength of concrete corbels with hybrid reinforcement. International journal of civil engineering and technology, 6(10), 2015, pp. 25-35.

[2]. SHENDE, A. M. - PANDE, A. M. – GULFAM PATHAN, M.: Experimental study on steel fiber reinforced concrete for M-40 grade. Vol. 4, Iss. 2, February, 2013.

[3]. WANG, J. - VAN TITTELBOOM, K. - DE BELIE, N. – VERSTRAETE, W.: Use of silica gel or polyurethane mmobilized bacteria for self-healing concrete. Construction and building materials, 26(1), 2012, pp. 532-540.

[4]. LI, V. C. – HERBERT, E.: Robust self-healing concrete for sustainable infrastructure. Journal of Advanced Concrete Technology. 10(6), 2012, pp. 07-218.

[5]. JONKERS, H. M. – THIJSSEN, A. – MUYZER, G. – COPUROGLU, O. – SCHLANGEN, E.: Application of bacteria as a self-healing agent for the development of sustainable concrete. Ecological engineering, 36(2), 2010, pp. 230-235.

[6]. REDDY, S. – SATYA, K. A. – RAO, M. V. – AZMATUNNISA, M.: A biological approach to enhance strength and durability in concrete structures. International Journal of Advances in Engineering & Technology, 2012, pp. 2231-1963.

[7]. SCHLANGEN, H.E.J.G. – JONKERS, H. M. – QIAN, S. – GARCIA, A.: Recent advances on selfhealing of concrete. In FraMCos-7: Proceedings of the 7th International Conference on Fracture Mechanics of Concrete and Concrete Structures, Jeju Island, Korea, 2010.

[8]. IS: 4031-1996. Methods of physical tests for hydraulic cement, Bureau of Indian Standards, New Delhi, India.

[9]. SANTHOSH, K. R. – RAMAKRISHNAN, V. – DUKE, E. F. – BANG, S. S.: SEM Investigation of Microbial Calcite Precipitation in Cement. In Proceedings of the International Conference on Cement Microscopy, Vol. 22, 2000, pp. 293-305, International cement microscopy association, 2000.

[10]. JONKERS, H. M.: Bacteria-based self-healing concrete. Heron, 56(1/2), 2011.

[11]. IS: 4031-1996, Methods of physical tests for hydraulic cement, Bureau of Indian Standards, New Delhi, India.

[12]. IS: 12269-1987, Specification for 53 grade ordinary Portland cement. Bureau of Indian Standards, New Delhi, India.

[13]. IS: 516-1959, Indian standard code of practice methods of test for the strength of concrete, Bureau of Indian Standards, New Delhi, India.

[14]. IS: 5816-1999, Splitting tensile strength of concrete - method of test. Bureau of Indian Standards, New Delhi, India.

[15]. IS: 10262-2009, Concrete mix proportioning-Guidelines. Bureau of Indian Standards, New Delhi, India.

[16]. IS: 456- 2000, Plain and reinforced concrete code of practice (fourth revision). Bureau of Indian Standards, New Delhi, India.

[17]. ACI Committee 318, Building Code Requirements for Reinforced Concrete and Commentary, ACI, MI. NZS - 3101-2006. Concrete structures standard. New Zealand, 2002.

[18]. EC- 02Designers, Handbook to Euro-code 2 Part1.1 Design of Concrete Structures. Thomas Telford

Cite this article as :

Randhir Kumar Singh, Ajeet Saxena, "Formulation of Modified Dense Graded Bituminous Macadam with Low Density and High-Density Polythene Waste with Zycotherm Admixture : A Review", International Journal of Scientific Research in Civil Engineering (IJSRCE), ISSN : 2456-6667, Volume 5 Issue 1, pp. 49-57, January-February 2021.

URL : http://ijsrce.com/IJSRCE21515