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USE OF BACTERIA IN THE RECOVERY OF THE CONCRETE'S CRACK

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ABSTRACT

According to the size of the bacteria they are very small but the use of bacteria in different field of the world is unbelievable. The application of microbes is not for specific things. Its use is beyond what we can imagine. Currently our research is pointing out the use of bacteria in the healing of the crack of the concrete. Concrete is one of the most common materials using in the construction. Concrete is susceptible to external factors and in future we may have to face many calamities too. So there will be chances of formation of cracks and also the strength of the concrete may be lessening. The cracks formed in concrete are inescapable and they are the major reason for the weaknesses of the concrete. So the objective of the present research is to heal the concrete by the addition of the calcium carbonate precipitating bacteria that is Bacillus subtilis. This bacteria is mixed along with the concrete. Tests on the bacterial concrete by comparing with the standard concrete cube. The compression strength of both the cubes will be calculated and the calcium carbonate precipitation will also examine. By testing the compressive strength we can understand whether the bacteria have the ability to precipitate calcium carbonate, only if the calcium carbonate is precipitated the concrete will be stronger. Then only we can state that calcium carbonate is healing the crack. When the concrete is harden, cracks are healed by bacterial reaction as water ingresses through the cracks. It is a novice technique with an old perspective that the microbial mineral sedimentation persistently takes place naturally in the environment.

Keywords: Bacteria, Calcium carbonate precipitation, Bacillus subtilis.

INTRODUCTION

Bio-concrete is dead concrete infused with bacteria used to increase the strength of concrete. Concrete is a composite material composed of fine and coarse aggregate bonded together with fluid cement that hardens over time. Cracking of concrete is a common phenomenon. Without immediate and proper treatment, cracks in concrete structures tend to expand further and eventually require costly repairs. Even though it is possible to reduce the extent of cracking by available modern technology, remediation of cracks in concrete has been the subject of research for many years. There are a large number of products available commercially for repairing cracks in concrete: structures epoxy, resins, epoxy mortar and other synthetic mixtures. Cracks and fissures are a common problem in building structures, pavements, and historic monuments [1-3].

Bacteria are a type of biological cell. They constitute a large domain of prokaryotic microorganisms. Typically a few micrometers in length, bacteria have number of shapes, ranging from spheres to rods and spirals. Bacteria were among the first life forms to appear on earth, and are present in most of its habitats. Bacteria were first observed by Antoine van Leeuwenhoek in 1676, using a single- lens microscope of his own design. He called them "animalcules" and published his observations in a series of letters to the Royal Society. The name bacterium was introduced much later, by Christian Gottfried Ehrenberg in 1838 [4].

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Louis Pasteur demonstrated in 1859 that the fermentation process is caused by the growth of microorganisms. Along with his contemporary, Robert Koch, Pasteur was an early advocate of the germ theory of disease. Bacterial growth follows three phases. When a population of bacteria first enters a high-nutrient environment that allows growth, the cells need to adapt to their new environment. The first phase of growth is the lag phase, a period of slow growth when the cells are adapting to the high-nutrient environment and preparing for fast growth. The lag phase has high biosynthesis rates, as proteins necessary for rapid growth are produced. The second phase of growth is the logarithmic phase (log phase), also known as the exponential phase. The log phase is marked by rapid exponential growth. The rate at which cells grow during this phase is known as the growth rate, and the time taken for the cells to double is known as the generation time. During log phase, nutrients are metabolized at maximum speed until one of the nutrients is depleted and starts limiting growth. The final phase of growth is the stationary phase and is caused by depleted nutrients. The cells reduce their metabolic activity and consume non-essential cellular proteins [5,6].

The study of bacteria is known as bacteriology, a branch of microbiology. The vast majority of the bacteria in the body are rendered harmless by the protective effects of the immune system, and a few are beneficial. However, a few species of bacteria are pathogenic and cause infectious diseases, including cholera, syphilis, anthrax, leprosy, and bubonic plague. The most common fatal bacterial diseases are respiratory infections, with tuberculosis alone killing about 2 million people a year, mostly in sub-Saharan Africa. In industry, bacteria are important in sewage treatment and the breakdown of oil spills, the production of cheese and yogurt through fermentation, the recovery of gold, palladium, copper and other metals in the mining sector, as well as in biotechnology, and the manufacture of antibiotics and other chemicals [7,8].

Concrete is a composite construction material made primarily with aggregate, cement, and water. There are many formulations of concrete, which provide varied properties, and concrete is the most-used man-made product in the world. In this experiment subtilis species is used. *Bacillus subtilis*, known as hay bacillus or grass bacillus, is a gram positive, catalase-positive, bacterium, found in soil and the gastrointestinal tract of ruminants and humans. Microbiologist Hendrick Jonkers has put the idea of bio-concrete. Bio- concrete is a new material that incorporates limestone-producing bacteria, allowing the concrete to repair its own cracks, without the need for human intervention. Bio-concrete has been used in concrete industry and change the way construction companies used and apply concrete. Bio-concrete is a sustainable solution that could prolong the life span of structures [9, 10].

Strength of a concrete is very much important while constructing buildings. Now -a- days many countries facing natural calamities like flood, earthquakes etc. that leads to destruction of many buildings and sometimes develop cracks. Those cracks may be life threatening in future.

So increasing strength of a concrete and also healing of the cracks is very necessary. We only know about the healing of living things but healing of concrete crack is something beyond our imagination and this is only possible by the bio- concrete .So our study is leading to an idea of increasing the strength and healing of a cracked concrete. We have introduced a novel technique in fixing cracks with eco- friendly biological processes that is a continuous self-remediating process. *Bacillus subtilis* that is abundant in soil has been used to induce $CaCO_3$ precipitation. It is therefore vital to understand the fundamentals of microbial participation in crack remediation [11].

The commonly used bacteria in bacterial concrete are *Bacillus pasteurii*, *Bacillus sphaericus* and *Bacillus subtilis*. When cement and water are mixed together, that mix has a pH value of up to 13, usually a hostile environment for life. Most organisms die in an environment with a pH value of 10 or above. Thus researches concentrated on microbes that thrive in alkaline environments which can be found in natural environments, such as alkali lakes in Russia, carbonate rich soils in desert areas of Spain and soda lakes in Egypt. Bacteria geniuses Bacillus were found to thrive in this high-alkaline environment. The only groups of bacteria that are able to survive after pulverizing a casted concrete block were the ones that produced spores comparable to plant seeds. Such spores have extremely thick cell walls that enable them to remain intact for up to 200 years while waiting for a better environment to germinate. They would become activated when the concrete starts to crack, food is available, and water seeps into the structure. This process lowers the pH of the highly alkaline concrete to values in the range (pH10 to 11.5) where the bacterial spores become activated. Finding a suitable food source for the bacteria that could survive in the concrete took a long time and many different nutrients were tried until it was discovered that calcium lactate was a carbon source that provides biomass. If it starts to dissolve during the mixing process, calcium lactate does not interfere with the setting time of the concrete. In this experiment we are using *Bacillus subtilis* [12].

Originally named Vibrio subtilis in 1835, this organism was renamed *Bacillus subtilis* in 1872. Other names for this bacterium also include *Bacillus uniflagellatus*, *Bacillus globigii*, and *Bacillus natto*. *Bacillus subtilis* bacteria were one of the first bacteria to be studied. These bacteria are a good modelfor cellular development and differentiation. *Bacillus subtilis* cells are rod- shaped, Gram-positive bacteria that are naturally found in soil and vegetation. The optimal temperature is 25-35 degrees Celsius. Stress and starvation are common in this environment. Therefore, *Bacillus subtilis* has evolved a set of strategies that allow survival under these harsh conditions. One strategy, for example, is the formation of stress-resistant endospores. Another strategy is the uptake of external DNA, which allows the bacteria to adapt by recombination. However, these strategies are time-consuming. *Bacillus subtilis* can also gain protection more quickly against many stress situations such as acidic, alkaline, osmotic, or oxidative conditions, and heat or ethanol.

Bacillus subtilis are rod-shaped bacteria that are Gram-positive .The cell wall is a rigid structure outside the cell. It is composed of peptidoglycan, which is a polymer of sugars and amino acids. The peptidoglycan that is found in bacteria is known as murein. Other constituents that extend from the murein are teichoic acids, lipoteichoic acids, and proteins. The cell wall forms the barrier between the environment and the bacterial cell. It is also responsible for maintaining the shape of the cell and withstanding the cell's high internalpressure.

Bacillus subtilis is a model organism for studying endospore formation in bacteria. Endospores in *Bacillus subtilis* bacteria are mostly formed in the tips of protuberances extending downward from liquid surface pellicles .Many strains produce spores with brown pigments. Depletion of carbon, nitrogen, or phosphorous causes the process of sporulation to begin, however, the process needs to start before the entire exhaustion of nutrients. Otherwise, the spore formation cannot be completed due to the fact that the nutrients are too low for the energy-requiring sporulation process. This allows the cells to avoid being stuck in a vulnerable position [13, 14].

The formation of the endospore occurs in several stages. Sporulation occurs in the following fashion. First the nucleoid lengthens, becoming an axial filament. Then, the cell forms a polar septum, one-fourth of the cell length from one end, and begins to divide. The smaller product of this division is called the forespore and the larger product is called the mother cell.

The mother cell is responsible for nourishing the newly formed spore. When the septum forms, 30% of the chromosome is already on the forespore side. The remaining 70% of the chromosome enters the forespore in a fashion similar to DNA transfer during conjugation; it is pumped by a protein. The mother cell then engulfs the forespore by acting like a phagocyte. This causes the forespore to have two cytoplasmic membranes with a thick murein layer, namely the cortex, between them. A protein spore coat and an exosporium, a membranous layer, form outside of the forespore membranes. At this time, the forespore undergoes internal changes. Lastly, the forespore leaves the mother cell upon lysis of the mother cell .A mature endospore has no metabolic activity; it is inert. The interior of the endospore, the core, is very dry and resistant to moisture.

The self-healing concrete is a result of limestone and a calcium based nutrient with the help of bacteria to heal the crack appeared on the concrete. This bacteria *Bacillus subtilis* can be in dormant stage for around 200 years. When the concrete is coming in contact with water the spores of the bacteria germinate. The bacteria are capsulated. When it comes in contact with the water it will become decapsulated and active. When the water comes in contact with the unhydrated calcium in the concrete, calcium hydroxide is produced by the help of bacteria, which act as a catalyst. This calcium hydroxide reacts with the atmospheric carbon dioxide and forms limestone and water. The extra molecule of water keeps the reaction going on. This is how the concrete is becoming stronger and we can say this is another way also, when the bacteria starts feeding on the calcium lactate consuming oxygen. [6] The soluble calcium lactate is converted to insoluble limestone. The insoluble limestone starts to harden. So that we can include another advantage also, the bio-concrete will have the ability to fill the cracks too. When the cracks appear water reaches into the crack and same mechanism willoccurs in between the cracks [15-17].

The main aim of this research is to find out the compression strength of the standard concrete and the bacterial concrete, to compare in order to know the calcium precipitate formation that will heals the crack. The objective is to addition of the bacteria that is *Bacillus subtilis* into the concrete mix and to Casting of standard concrete cube and bacterial concrete cube. The objective is to Test the compression strength of both concrete cubes and to check the formation of calcium carbonate precipitation on the cracks and also to prove that the bacterial concrete have a self-healing property which will help the concrete to become more stronger.

MATERIALS USED

Bacillus subtilis, Powder of alumina, silica, lime, iron oxide, and magnesium oxide burned together in a kiln and finely pulverized and used as an ingredient of concrete. Ordinary Portland cement of grade 53 available in local market is used in the investigation.

Coarse aggregates

They are construction components made of rock quarried from ground deposits. Examples of these types of coarse aggregates are river grave, crushed stones from rock quarries, and previously used concrete Crushed angular aggregates of nominal size 20mm from local source [18].

Fine aggregates

They generally consist of natural sand or crushed stone with most particles passing through a 3/8 –inch sieve. Here we used M sand. [3, 5, 7, 9, 10, 14].

METHODOLOGY

Casting of concrete cube required a proper mould. So fixing the mould is the first step of the casting. This type of 4 mould is required to perform the experiment because we have to cast two standard concrete cube and two test concrete cubes. After the preparation of the cubes don't forget to grease the mould for the easy separation of the concrete cube from the mould. Next is the mixing of the bacteria, cement, coarse aggregate, fine an aggregate, and water in accurate ratio. First of all the weighing of the materials that is to be mixed. The weighing is done according to the ratio 1: 1.5: 3.

Cement : 10kg.
Coarse aggregate : 30kg
Fine aggregates : 15kg
Water : 2 liters (totally)
Bacteria : 20ml (10ml of each bio-concrete cube).

This the weighing done for the whole four cubes. The weighed materials are transferred to the mixing pan. Two pans are taken for the mixing of the standard and the test cube separately. The mixing is started by adding the water very slowly. For standard cubes we add the water alone but for the test cubes we are mixing bacteria along with water then poring to the mixing pan. The bacteria are mixed along with the water so that the even mixing of the bacteria to the concrete will take place.

After the even mixing next step is to fill the mould withtheconcretemixfor that spread grease all over inside the mould it will help the easy removal of the cube from the mould. Fill the mould then place it over the vibrator forthe complete compacting of concrete. Pour each layer and place it over vibrator. [19-24]

After filling the moulds keep all four aside by marking as test on the mould which having bacterial concrete and mark as standard over the mould which having the concrete alone for twenty four hours. Next step is to unscrew the mould and placing the cubes inside the bucket having water and the cube should be completely immersed in the water. Each cube have to be placed separately should be marked as test and standard and the strength of each cube is tested respectively. Here we are planning to test the strength of the cubes on the 7th day and on the 14th day after immersing the cubes in thewater.
This is the compression testing machine loaded with cube.

After the compression testing the cube have to put back into the water to know the healing of the crack obtained during the compression. This is the condition of cube after the compression. We can see the crack formed in the cube. [25-27].

Now we are coming to the compression strength testing of the cube that is casted with and without bacteria. Here we are planning to testthe strength using the manually hand operated concrete strength testing machine. Its capacity lying between 2 5 0 -2000 kN. The prepared cubes are placed between the space of the machine and it is tightened. Compression of cube is the next step. During the compression the cube is compressed and crack will form on the cube only after that the machine will stop. The reading is taken and the calculation is done. After the reading is taken we have to put back the cube into the water to check the healing. The reading obtained from the machine is in kilo Newton (kN). The value obtained is then have to be changed to strength used to compressed and the strength obtained is compared to know whether there is any difference in the strength between the standard cube and test cube. There is an equation for finding the compression strength [28-35].

$$Compression\ strength = \frac{Load}{Area}$$

Area = $(15)^2 = 225\ cm^2$.
Load = According the values obtained from the strength testing machine.
Eg: - Compressive Strength = $330\times10^3/225\times10^2 = 14.66\ N/mm^2$.

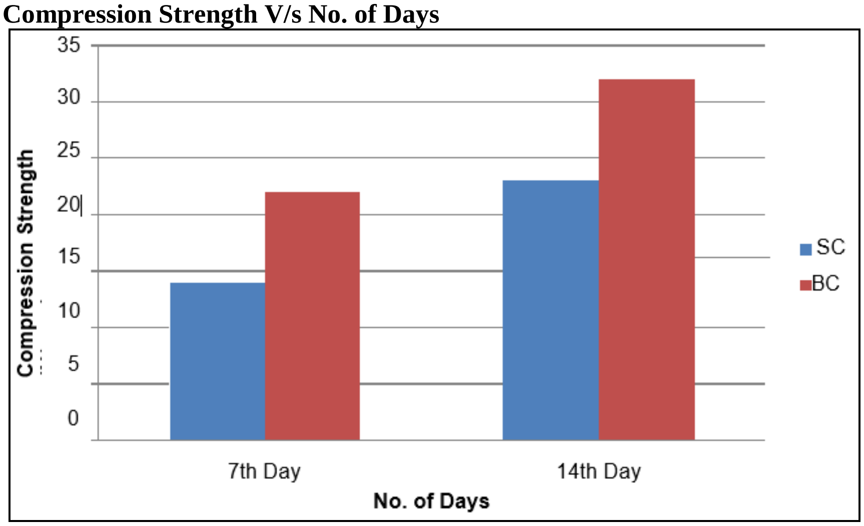
We observed the healing of the cube. The white patches started to form on the cracks of the cube from the 5th day after immersing back into the water.

Tabel 1. **Compressive Strength of cube**

Sl. No	mension (mm)	Date of Casting	Date Of Testing	Age of Curing	Load (kN)	Compressive Strength (N/mm^2)
1	150×150×150	21/2/2020	28/2/2020	7	330	14.66
2	150×150×150	21/2/2020	28/2/2020	7	490	21.77
3	150×150×150	21/2/2020	6/3/2020	14	520	23.11
4	150×150×150	21/2/2020	6/3/2020	14	730	32.44

Fig 1. Casting of concrete cube

Fig 2. Concrete Block Compression Strength V/s No. of Days



RESULT AND DISCUSSION

The white patches we saw in between the crack are calcium carbonate. The more production of the calcium carbonate will heal the crack that is formed during the compression strength testing. As per the result obtained from the above calculation we can draw a chart.

From the chart it is very evident that bio-concrete cube is stronger than that of the standard concrete cube. So the addition of the bacteria just improved the strength of concrete. The compressive strength of Bacterial concrete is found to be increased as compared to that of the standard concrete.

After 7 days of casting we tested the strength. The load that required breaking the standard concrete cube is 330kN and the compressive strength we got is 14.66.

But at the same time the load required for the breaking of the bio-concrete cube is 490kN and the compressive strength is 21.77

On the 14thday the load required for the breaking of standard concrete cube is 520kN and the compressive strength is 23.11. As we expected the load required for the breaking of the bio-concrete cube is 730kN and of a compressive strength 32.44. The difference between the compressive strength of standard concrete cube and the bio-concrete cube is 7.11 after 7 days of curing and the difference between the compressive strength after 14 days is 9.33. So not only the compressive strength the difference but the compressive strength is also been increasing day by day.

So from the above results we can say that the increased strength of the cube to which the bacteria is incorporated is because of the calcium carbonate formation. This calcium carbonate causes the healing of crack not only but also these calcium carbonate is what we saw in between the cracks.

CONCLUSION

To sum up, using the bacteria in the concrete mixing enhanced the compressive strength of the concrete approximately more than 18.11% than the standard concrete cube. We got this result by adding Bacteria *Bacillus subtilis* of concentration 105 cell/ml. As per the experiment we done, it is proven that the bio-concrete is stronger than the standard concrete. Above we discussed about the mechanism that is happening due to the interaction of the bacteria starts feeding on the calcium lactate consuming oxygen and the formation of insoluble limestone. The insoluble limestone starts to harden. This is how the bio-concrete is becoming more and more stronger when it comes in contact with water or any other foreign particles and if it is having the property of producing calcium carbonate definitely it have the ability to heal the crack on the concrete. Here during the experiment the cube is immersed in the water thus the water helped to strengthen it more. Likewise when the crack is formed the water helped the bacteria to get activated and start the conversion of the calcium hydroxide to calcium carbonate. It is evident from the white color patch like formation in between the cracks. So that our bio-concrete is a self-healing, eco-friendly, increasing in durability, very effective in increasing the strength, resistance to acid attack and any temperature, corrosion of the iron bars inside the concrete can be prevented. Also in future during the calamities like flood, earth quakes the concrete needed to be stronger. Buildings that haven't enough strength and cracks are threatening to the people.

REFERENCES

1. De Muynck, W, De Belie N and Verstraete W. Microbial carbonate precipitation in construction material: A review. EcolEng.2010, 36,118-136.
2. Van Tittelboom, K, De Belie N, De Muynck W, Verstraete W. Use of bacteria to repair cracks in concrete. Cement Concrete Res. 2010, 40, 157-166.
3. De Muynck W, Debrouwer D, De Belie N, Verstraete W. Bacterial carbonate precipitation improves the durability of cementitious materials. CementConcrete Res 2008, 38, 1005-1014.
4. De Muynck W, Cox K, De Belie N and Verstraete W. Bacterial carbonate precipitation as an alternative surface treatment for concrete. Constr Build Mater, 2008, 22, 875-885.
5. Ghosh P, Mandal S, Chattopadhyay BD and Pal S. Use of micro- organisms to improve strength of cement mortar. Cement Concrete Res.2005, 35, 1980- 1983.
6. Li VR and Yang E. Self-healing in concrete materials. In Self healing materials - An alternative approach to 20 centuries. Materials science, 2007, 161–194.
7. Neville AM. Properties of concrete (4^{th}edn). Pearson Higher Education, Prentice Hall, New Jersey, 1996.
8. Jonkers, Thijssen, Muyzerand S. Application of bacteria as self-healing agent for the development of sustainable concrete. Ecological Engineering, 2010, 36(2), 230–235.
9. Li VC and Herbert E. Robust self-healing concrete for sustainable infrastructure. Journal of Advanced Concrete Technology, 2012, 10(6), 207–218.
10. Wu M, Johannesson and Geiker M. A review: self-healing in cementitious materials and engineered cementitious composite as a self-healing material. Construction and Building Materials, 2012, 28, 571–583.
11. Sahmaran M, Keskin, Ozerkan and Yaman. Self-healing of mechanically-loaded self-consolidating concretes with high volumes of fly ash. Cement and Concrete Composites, 2008, 30,872–879.
12. De Muynck, De Belie and Verstraete. Microbial carbonate precipitation in construction materials: a review. Ecological Engineering, 2010, 36, 118–136.
13. Wong. Microbial cementation of ureolytic bacteria from the genus Bacillus: a review of the bacterial application on cement-based materials for cleaner production. Journal of Cleaner Production, 2015, 93, 5–17.
14. Huang, G. Ye, Qian CX, Schlangen E. Self-healing in cementitious materials: materials, methods and service conditions. Materials and Design, 2016, 92, 499–511.
15. Wang JY, ErsanYC, Boon N and N. De Belie. Application of microorganisms in concrete: a promising sustainable strategy to improve concrete durability. Applied Microbiology and Biotechnology, 2016, 100, 2993– 3007.
16. Xu Jand Yao W. Multiscale mechanical quantification of self-healing concrete incorporating non-ureolytic bacteria-based healing agent, Cement and Concrete Research, 2014, 64, 1–10.
17. Achal V and Mukherjee A. A review of microbial precipitation for sustainable construction. Construction and Building Materials, 2015, 93, 1224–1235.
18. Siddique R and Chahal NK. Effect of ureolytic bacteria on concrete properties. Construction and Building Materials, 2011, 25, 3791–3801.
19. Seifan M, Samani AK and Berenjian.Bioconcrete: next generation of self-healing concrete. Applied Microbiology and Biotechnology, 2016, 100, 2591–2602.
20. Xu J, Yao and Jiang. Non-ureolytic bacterial carbonate precipitation as a surface treatment strategy on cementitious materials. Journal of Materials in Civil Engineering, 2014, 26 (5), 983–991.
21. Wiktor and Jonkers HM. Quantification of crack-healing in novel bacteria- based self-healing concrete. Cement and Concrete Composites, 2011, 33, 763–770.
22. Xu, Du, Jiang, She A. Effects of calcium source on biochemical properties of microbial CaCO3 precipitation. Frontiers in

Microbiology, 2015, 6, 1–7.
23. Wang JY, Soens H, Verstraete W and De Belie. Self-healing concrete by use of microencapsulated bacterial spores. Cement and Concrete Research, 2014, 56, 139–152.
24. Wang JY, De Belie N, Verstraete W. Diatomaceous earth as a protective vehicle for bacteria applied for self-healing concrete. Journal of Industrial Microbiology & Biotechnology, 2012, 39, 567–577.
25. De Koster, Mors, Nugteren, Jonkers, Meesters, Van Ommen.Geopolymer coating of bacteria- containing granules for use in self-healing concrete. Procedia Engineering, 2015, 102, 475– 484.
26. Zhang J, Liu Y, Feng T. Immobilizing bacteria in expanded perlite for the crack self-healing in concrete. Construction and Building Materials, 2017, 148,610–617.
27. Zhang JL, Mai BX, Cai TW. Optimization of a binary concrete crack self-healing system containing bacteria and oxygen. Materials, 2017, 10, 116, 2017.
28. Bundur ZB, Kirisits MJ, Ferron RD. Use of pre-wetted lightweight fine expanded shale aggregates as internal nutrient reservoirs for microorganisms in bio- mineralized mortar, Cement and Concrete Composites, 2017, 84, 167–174.
29. Chen HC, Qian CX, Huang HL. Self-healing cementitious materials based on bacteria and nutrients immobilized respectively. Construction and Building Materials, 2016, 126, 297–303.
30. Pacheco-Torgal F and Labrincha JA. Biotech cementitious materials: Some aspects of an innovative approach for concrete with enhanced durability. Construction and Building Materials, 2013, 40, 1136–1141.
31. Ersan YC, Hernandez-Sanabria, Boon N. Enhanced crack closure performance of microbial mortar through nitrate reduction. Cement and Concrete Composites, 2016, 70, 159– 170.
32. Luo M, Qian CX, Li RY. Factor’s affecting crack repairing capacity of bacteria-based self-healing concrete. Construction and Building Materials, 2015, 87, 1–7.
33. Ling Hand Qian C. Effects of self-healing cracks in bacterial concrete on the transmission of chloride during electro migration. Construction and Building Materials, 2017, 144, 406–411.
34. Douglas LA and Bremner JM. Extraction and colorimetric determination of urea in soils. Soil Science Society of America Journal, 1970, 34, 859–862.
35. Wang C, Wu and Zhang FS. Development of porous ceramist from construction and demolition waste.Environmental Technology, 2013, 34, 2241–2249.