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The Effect of Bacteria on Steel Corrosion in Concrete: A Review

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Abstract: Concrete are one of the most commonly used building materials and are particularly vulnerable to crack formation. These cracks make reduction of concrete service life as a result causes high cost on repair. While crack formation cannot be avoided, many techniques for healing cracks have been in place. Some of the concrete crack treatment method like application of chemical and polymer have environmental risk and it is successful in short term. Therefore, treatment that is environmentally friendly is needed in current generation. A self-healing bio concrete is the environmentally friendly, long last and good in repair cracks by itself. Although the bacterial conversion in bio concrete helps increase the durability of steel reinforced concrete structure by healing cracks but the impact of bacteria to steel in concrete structure is needed to identified further. From the previous researcher's analysis, the type of bacteria, the concentration level of bacterium, time taken of steel in bio concrete to corrode and type of nutrient used in test discussed in the analysis. Based on the result, bacteria have reduced corrosion in steel in bio concrete. From the analysis, it can be concluded that the most suitable of bacteria concentration in bio concrete are 10^6 cell/ml. When the concentration of bacteria higher, the higher amount of calcium carbonate produces when there is crack occur. Therefore, this prevent the harmful substances penetrate into concrete and also prevent still to corrode as well as it took long time to steel corrode.

Keywords: Concrete, Steel, Corrosion, Bacteria

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1. Introduction

As Malaysia is one of the most industrialized countries that deals with various building projects. The development of new technologies in the field of construction generates more sustainable construction that has been generated in recent years. Concrete is one of the primary building materials that widely used in construction due to the low cost and easy availability. In compression, it also exhibits excellent strength properties. During its service life, it cracks easily in stress, shearing and flexicurity, as well as in various environmental aspects. Its durability properties are adversely affected by cracking, with the most significant effect on the de-passivation of reinforced concrete steel (RC) resulting in corrosion of steel.

Some of the present concrete treatment method like chemical and polymer usage can cause environmental risk and more over it is only effective in short term. Treatment approaches that are environmentally sustainable and long-lasting are now in high demand. Therefore, Bacterial concrete known as bio concrete is ideal solution that can solve the cracking issues in concrete on reinforced concrete structure. A microbial self-healing concrete solution (bio concrete) is environmentally friendly, active in crack repair and have potential for long lasting.

This Bio concrete utilize bacteria mineral precipitation to improve durability as well as strength of concrete. This process makes bio concrete more durable and last longer. Microorganism plays a vital role in this process to exploit deterioration in porous material, improves sand properties and sealing of concrete cracks to highly durable material. The bacteria usually used in bio concrete is *Bacillus cereus*, *Bacillus pasteurii*, *Pseudomonas aeruginosa*, *Shewanella* which is not dangerous environmentally and have the ability to precipitate calcium carbonate $CaCO_3$. Based on recent studies, it shows that the addition of mineral-capable bacteria can facilitate self-healing of the cracks in concrete and that by increasing the concentration of bacteria, the toughness or durability of the concrete can be improved [1].

1.1 Mechanism of Bacteria in Concrete

Self-healing concrete is a result that biologically creates limestone to repair cracks that occur on the surface of concrete structures. Most of bacteria normally can precipitate calcium carbonate and few selected types of bacteria genus, bacillus, are mixed with calcium-based nutrient known as calcium lactate or other types of healing agents in the ingredients of concrete mixture. These self-healing agents will be permanent in the concrete for up to 200 years. However, when a concrete structure is damaged, the rainwater or atmospheric moisture starts to seep through the cracks that appear in the concrete. The spores of the bacteria reproduce and germinate with water and nutrient [2].

Having been activated, the bacteria start to feed on the calcium lactate. As the bacteria feed's, oxygen is consumed and the soluble calcium lactate is converted to insoluble limestone. The limestone solidifies on the cracked surface and the sealing process start up. As the oxygen is consumed by bacteria in the process, no oxygen will in the structure of concrete which prevents corrosion of the embedded reinforcement meanwhile the durability of the steel increases. The microbial self-healing approach is characterized by its capacity for long-lasting, fast and active crack repair, while at the same time being environmentally friendly. Therefore, this study provides an overview of the microbial approaches to produce calcium carbonate ($CaCO_3$) and microbial approach to steel for the areas of the future research [2].

1.2 Types of Bacteria

Many types of bacteria can precipitate calcium carbonate. Table 1 shows Bacteria that commonly used for bio concrete is *Bacillus Pasteurii*, *Bacillus Subtilis*, *Bacillus Sphaericus and Bacillus flexus*. It is known that microorganisms specifically bacteria are capable of producing a broad range of minerals, such as carbonates, sulphides, silicates and phosphates. Calcium carbonate is one of the most suitable

concrete fillers due to its high compatibility with cement compositions [3]. Calcium carbonate is precipitated by a biologically induced mineralization process in the presence of a calcium source. In this process, carbonate is formed by microorganisms creates limestone ($CaCO_3$) to repair cracks that occur on the surface of concrete structures. Different types of bacteria produce different amount of calcium carbonate and it is depending its properties and characteristics itself.

Table 1: Types of bacteria and application in bio concrete

Types of bacteria	Application	Researcher
Bacillus sphaericus *Bacillus flexus* *Bacillus pasteurii*	Biomineralization of calcium carbonate by different bacterial strains and their application in concrete crack remediation	[3]
Bacillus sphaericus	Crack self-healing by modified-alginate encapsulated carbonate producing bacteria in concrete	[4]
Bacillus sphaericus *Bacillus pasteurii*	Self-healing of cracks in bacterial concrete.	[2]
Bacillus Subtilitis	Performance of standard grade bacterial (*Bacillus subtilis*) concrete.	[5]

1.3 Factors causes corrosion of steel in Concrete

Concrete is strong under compression but weak under stress and shear. Whenever concrete members are likely to be exposed to tension, the concrete must reinforce with Steel. Steel is given to resolve the tensile stress. This is called as reinforced concrete [6]. Therefore, steel can deteriorate with some of the causes. Table 2 shows the most common form of corrosion effect in reinforced concrete steel in from chloride ions, sulphate ion and from the presence of water and air.

Table 2: Factor effecting corrosion of steel in concrete

Factor	Description	Reference
The presence of Sulphate ion	The Sulphate corrosions known as sulphate induced corrosion. These sulphates can when react with water with certain temperature can cause corrosion to steel and concrete. Moreover, Sulphur increases the corrosion rate of biocorrosion which carried by bacteria. The presence of Sulphur high in water causes steel and concrete structure failure.	[7]

The presence of Chloride ion	Chloride-induced corrosion of concrete steel is the primary responsible of the reinforced concrete structures exposed to chloride in the environment especially in offshore areas. Chlorides in water reach steel through crack of the concrete react with surface steel and oxygen to form soluble salt which causes pitting corrosion. The higher the concentration of chloride content, the risk of steel to be corroded will be higher.	[8]
The presence of water and air	This is the most common type of corrosion which occurred from rusting process. Presence of the Oxygen, humidity (electrolyte) or moisture are two main parameters and without this parameter rusting is not possible. Another type of corrosionnormally caused by the presence of air which is carbonation corrosion. This corrosion happens from the carbon dioxide. Carbonation induced corrosion is the results from the entrance of atmospheric carbon dioxide (CO_2) into the concrete. The penetrated CO_2 dissolves in the pore solution to form carbonic acid, which reacts with calcium hydroxide causes corrosion.	[9]

2. Methodology

In methodology, the flow chart was used to demonstrate the process involved in proper manner. Figure 1 shows the flow of how the information gathered from case studies. From this case studies what type of selected method can be used to extract information to relate with this study. There are two types of flowchart used in this research to obtain the data of the effect of bacteria on steel corrosion in bio concrete. The data were collected from research or case study based on other researchers.

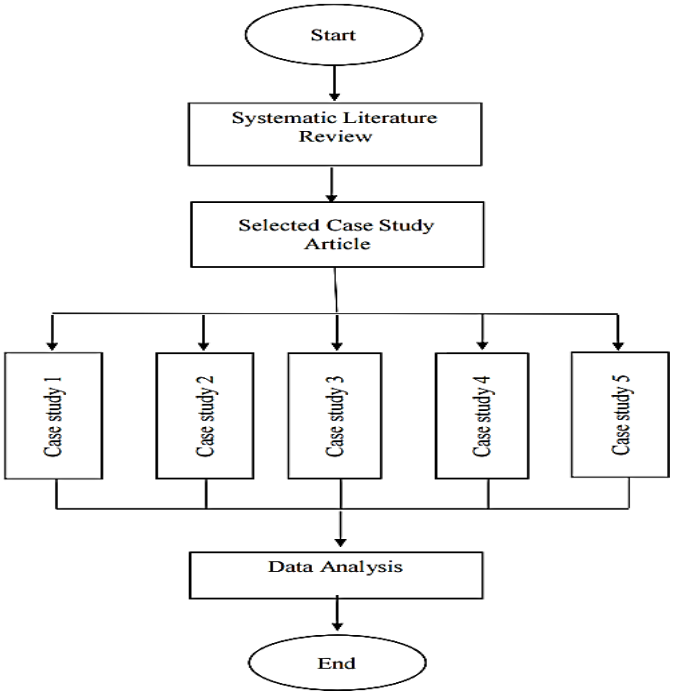

Figure 1: A workflow for methodology

2.1 Systematic Review

The first approach after the title received is the searching for case study related to the title of this research which is the effect of bacteria on steel corrosion in concrete. This case studies were extracted from the search engine. There are wide range of search engine in website like Scopus, ResearchGate, SpringerLink and etc. The search engine “Scopus”, “ResearchGate”, “SpringerLink” were used to categorize which case study related to the topic of research. The searching method is based on by keywords. This method can be known as Boolean method. These search databases were ideal method because it consists of literature’s largest abstract and citation database which is academic papers, books and conference proceedings.

A systemic and detailed search using the Boolean search method and the keywords in the database fields was done under "title/abstract/keyword." "AND," "OR" and "NOT" Boolean operators are utilized for the simplification of the search for limit the case study related to our topic research. The Boolean operators which used in the early stage with combination of the keywords are used in this research which is “concrete” AND “Steel” OR “corrosion” AND “bacteria” which shown in Figure 2. From this detail approach, the important number of case studies were identified.

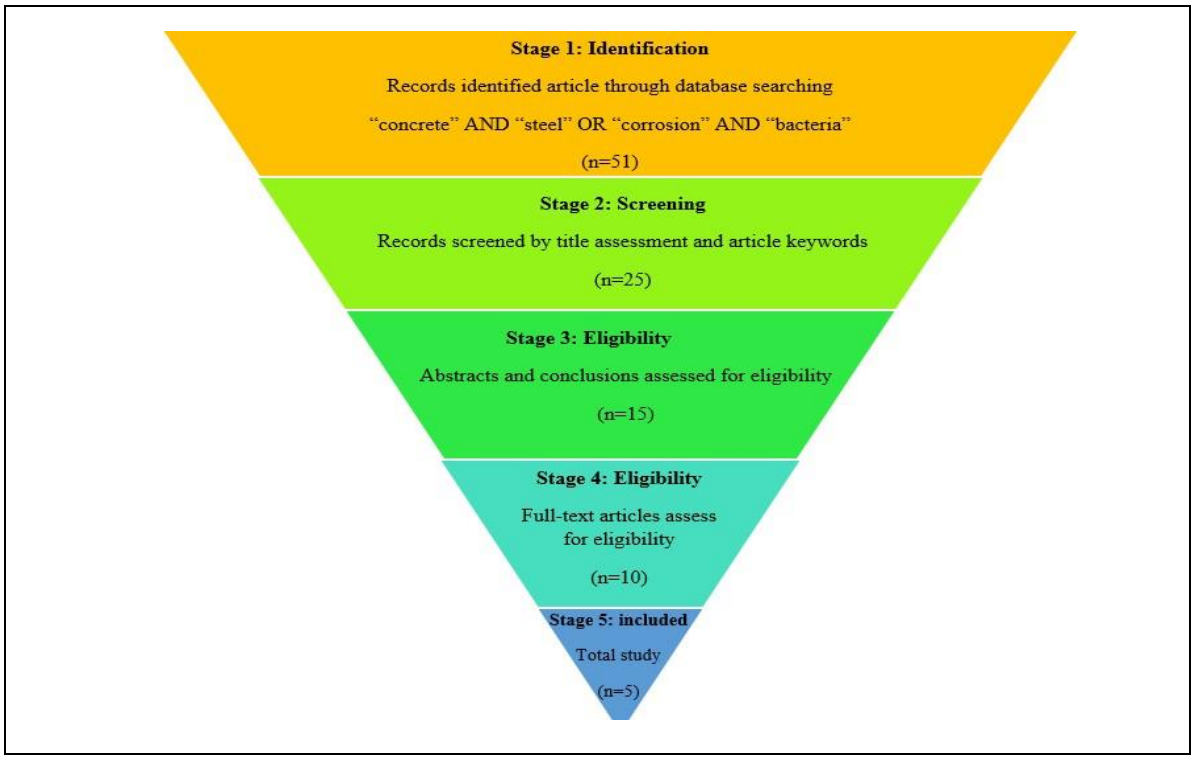

Figure 2: Step of review protocol

2.2 Accelerated Corrosion Test

Steel corrosion in concrete is a gradual or slow process. Even in the presence of strong corrosive exposure circumstances, the commencement and progression of reinforcement corrosion takes a long time due to the protective character of concrete. In the limited time available for research trials, it is difficult to acquire a considerable degree of reinforcement corrosion. An accelerated corrosion test is a method usually used for testing of corrosion test which results were obtained in a shorter period of time. This test fastens corrosion process to identify corrosion value in short period of time. The Figure 3 shows the setup of accelerated corrosion test.

Figure 3: Accelerated corrosion test setup [10]

3. Results and Discussion

The data collected from the previous researcher to make the comparison of corrosion result. Table 3 shows the comparison between the effect of bacteria to steel corrosion in concrete discussed by made by researcher Achal *et al.,* (2012) and Khaled *et al.*, (2021). The findings show the corrosion rate with different properties. The concentration of all samples is same therefore the comparison will easier to analyzed. The Existence of different bacteria with different nutrient usage shows the different value in corrosion. From the comparison it shows that which sample is give the lowest corrosion rate from this samples.

Table 3: Corrosion rate with different properties

Sample	Bacteria	Concentration (cell/ml water)	Nutrient	Corrosion Rate (mm/ year)	References
CS	Control sample	-	-	890.00	
NB	*Bacillus Sphaericius*	5×10^6	Nutrient Broth	237.00	[11]
CSL	*Bacillus Sphaericius*	5×10^6	Corn Steep Liquor	310.00	
CS	Control sample	-	-	1228.00	
BS-A3	*Bacillus Pasteurii*	5×10^6	Calcium lactate	193.70	[12]
BS-B3	*Bacillus Sphaericius*	5×10^6	Calcium lactate	265.70	

3.1 Comparison on the effect of bacteria on steel corrosion

Figure 4 clearly shows that all bacterial samples have good results because the corrosion rate compared to control sample is very low. The test on corrosion rate BS-A3 have good resistant to corrosion than BS-B3 as the corrosion rate value is 193.7mm/year lower than 265.7mm/year. Therefore, BS-A3 is the better than BS-B3. The Nutrient Broth (NB) have corrosion rate 237 mm/year lower to compared Corn steep liquor (CSL) 310 mm /year. Definitely the Nutrient Broth (NB) is better than Corn steep liquor (CSL). When have different nutrient, it doesn't affect any changes to the concrete and steel. The nutrient is for improving the growth of microorganism. This shows that Nutrient (NB) has good in improving growth of bacteria.

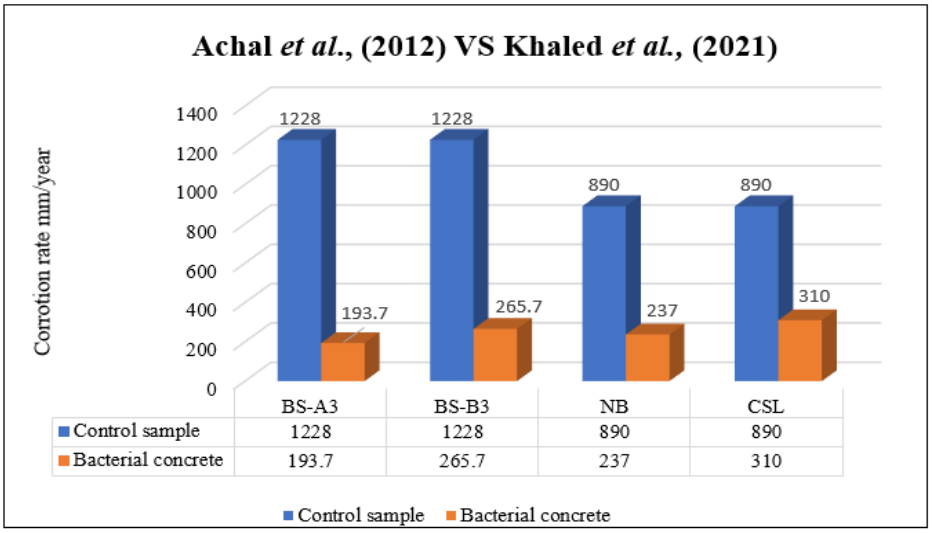

Figure 4: Comparison of steel corrosion in bio concrete

When have the comparison with these two researchers from graph, for BS- A3 is the best choice than Nutrient Broth because among all samples BS-A3 have the lowest corrosion rate. The usage bacteria like *Bacillus Sphaericus* and *Bacillus Pasteurii* bacterium with higher concentration like 5×10^6 helps produce high percentage calcium carbonate which become protective layer to the steel in bio concrete. Based on the Figure 4, *Bacillus Pasteurii* have better percentage than *Bacillus Sphaericus* which is 25 % more corrosive protection. The bacteria used in BS-B3 is *Bacillus Sphaericus*. There is different in corrosion result due to different bacteria. Different bacteria have different physical properties. This shows that the urease produce by the *Bacillus Pasteurii* is more compared to *Bacillus Sphaericus*. Therefore, *Bacillus Pasteurii* have the ability to produce high percentage of calcium carbonate than *Bacillus Sphaericus*.

4. Conclusion

Based on previous researchers study it can be concluded that bacteria in concrete lowers the steel corrosion in concrete because calcium carbonate produced by bacteria prevent any harmful chemical penetrate into the concrete. Most importantly the type of bacteria, the concentration of bacteria, the type of nutrient as well as concrete thickness plays important role significantly reduce of steel corrosion in bio concrete. The maximum concentration usage of bacterium in test samples by previous researcher proves that around 80 % of corrosion reduction happen in bio concrete. When it compared to normal ordinary concrete, this bio concrete provides huge reduction of steel corrosion in concrete. This bio concrete will be last longer and bacteria usage in concrete improves in term of durability, strength, permeability, water absorption and as well as corrosion also. By using this type of bacterial concrete in construction industry, it creates more sustainable and effective which can reduce the cost of maintenance of the building by self-healing.

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