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Alginate encapsulation technology of bacteria for promising self-healing concrete

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Abstract. Concrete is a material that is often used in construction in Indonesia. Concrete has the disadvantage that it tends to form cracks. The cracks that form start from small cracks and then enlarge, causing a decrease in quality. Self-healing concrete is a type of concrete that could repair itself with the help of healing agents in the form of bacteria. There are several methods of mixing bacteria into concrete, one of which is by mixing bacteria directly or using a shell which is often called encapsulation. The purpose of this study was to analyze the behavior of the addition of Bacillus Megaterium bacterial encapsulation in terms of compressive strength of concrete with encapsulation proportions of 0%, 2% and 4% by volume weight and using alginate-based shells. The samples used were 15 x 30 cm cylindrical specimens. These specimens were then tested after 7 days and 28 days. Based on test result, it was found that the highest compressive strength was obtained when 2% alginate capsules were added on day 7 and day 28, namely 25.6 MPa and 32.2 MPa. Concrete begun to heal after 2 weeks of curing based on visual observation.

1 Introduction

Concrete is a mixture of Portland or hydraulic cement, coarse aggregate, fine aggregate and water with or without additional ingredients to form a dense mass. Concrete is most widely used in building construction [1]. One of the weaknesses of concrete is its tendency to form cracks. The causes of cracks in concrete are continuous overload, weathering, and external loads [2]. Therefore, these cracks must be addressed immediately before they become greater damage and reduce the quality of the concrete itself [3].

Sealing cracks in concrete presents various techniques, one of which involves the injection of epoxy material into the cracks. However, this approach is often deemed less cost-effective and safe due to the presence of hazardous toxins within epoxy materials [4]. In the realm of concrete technology advancements, researchers have explored an alternative method for crack sealing: the development of self-healing concrete. Self-healing concrete represents a unique category of concrete capable of autonomously mending itself following damage [5]. The process of creating self-healing concrete entails incorporating healing agents into the

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concrete mixture. Subsequently, these healing agents react with both air and water, resulting in the formation of calcium carbonate or calcite, which effectively covers and repairs cracks in the concrete structure [6]. One of the healing agents that is often used to make self-healing concrete is bacteria.

The most common approach to mixing concrete with a healing agent is to either directly mix the concrete and healing agent or encapsulate the healing agent with a specific material to maximize its functionality. This method of encapsulating the healing agent within a material is referred to as encapsulation [7]. There are many biopolymers that are often used for encapsulation, but the most frequently used is sodium alginate [8]. In light of the aforementioned issues, this research is conducted to assess the effectiveness of utilizing alginate as an encapsulation material and *Bacillus Megaterium* bacteria as healing agent in self-healing concrete.

2 Material and methods

2.1 Research location

This research conducted in the Civil Engineering Materials Laboratory for concrete preparation and in the Bioprocess Laboratory of the Chemical Engineering Department at Bandung State Polytechnic for bacterial culture and the production of encapsulation materials.

2.1.1 Concrete

Concrete is a composite material made up of several materials that use the main ingredients of cement, fine aggregate, coarse aggregate, water and additional materials if needed with a certain composition. Concrete is a composite material, therefore the quality of concrete is highly dependent on the quality of each of its constituent materials. Concrete is a construction material that is widely used in building structures. It can be said that all structural buildings are built using concrete as the main construction material, for example building structures, water building structures, transportation building structures and many other structural buildings. One of the advantages of concrete is that it can withstand compressive loads, weather changes, high temperatures, can be formed and is easy to maintain. [9].

2.1.2 Bacillus megaterium

Bacillus Megaterium is a gram-positive rod-shaped organism that lacks filaments, has the ability to form endospores, is aerobic, nitrite-negative, and tests negative for the VP (Voges-Proskauer) test. Bacteria in this group have endospores located within the cell. Furthermore, *Bacillus Megaterium* have characteristics such as oval or cylindrical spores, are facultatively anaerobic, possess the ability to hydrolyze sugars and casein, and have thin spore walls [10]. *Bacillus megaterium* belongs to the largest group of Eubacteria found in soil environments. The morphology of *Bacillus Megaterium* includes a tail with a length of approximately 201±3.9 nm and a width of about 9.7±0.6 nm. The ability to form spores allows *Bacillus*

Megaterium to survive in extreme environmental conditions, such as deserts. This bacterium can grow in a temperature range between 25 and 37°C. [11].

2.1.3 Alginate

Alginate is a type of polysaccharide capable of forming a gel after extraction from brown seaweed. Characteristics of alginate include a variable color ranging from white to yellowish, occurring in the form of powder or fibers, having a nearly undetectable aroma and a neutral taste, forming thick colloidal solutions in water, insolubility in alcohol or hydroalcoholic solutions with alcohol concentrations exceeding 30%, and insolubility in chloroform, ether, or acidic solutions with a pH below 3 [12]. Polysaccharides found in seaweed, such as alginate, jelly, carrageenan, and fucellaran, possess the ability to form gels under certain conditions. When alginate interacts with divalent and trivalent cations, it results in gel formation within a temperature range from room temperature to 100°C. The formed gel does not change into a liquid state when heated [13].

2.2 Methods

This research is an experimental study that begins with the Bacillus Megaterium bacterial cultivation stage using liquid media and agar media. The liquid media used is Nutrient Agar (MERCK) and the liquid media is Nutrient Broth (MERCK). The preparation of the liquid bacterial media begins with the stage of weighing 8 gram Nutrient Broth, then suspending it into 500 mL of distilled water and stirring until homogeneous. The liquid media was then sterilized in an autoclave at 121°C for 15 minutes at a pressure of 15 lbs. After cooling and sterilize, bacteria were added to the liquid media using an ose needle and incubated on a shaker for 2-3 days at 33-34°C until the liquid media became cloudy due to bacterial growth.

Fig. 1. Liquid media (Nutrient Broth).

To prepare the bacterial capsules, 5.1 g of alginate was weighed and suspended in 140 ml of distilled water. The solution was then pasteurization at 80°C for 15 minutes. Pasteurization is carried out to kill pathogenic microorganisms and inhibit the growth of microorganisms. After cooling, the alginate solution was mixed with bacteria at a ratio of 1:5 and dripped into

0.2 M CaCl2 to form spheres. The size of the capsule depends on the pressure exerted on the syringe. After the capsule hardens, it is rinsed and dried.

Fig. 2. Bacillus megaterium in alginate capsule.

Before the capsules are mixed into the concrete, the capsule material is tested using a Universal Testing Machine (UTM) to determine the mechanical properties of the capsule material to be used.

Fig. 3. Universal Testing Machine (UTM).

Making concrete mix design refers to the SNI 7656: 2012 [14]. The specimens used were cylinders with a diameter of 15 cm and a height of 30 cm. The number of samples made are presented in **Table 1**

Table 1. The variations of sample

Variations	**Days**	
	7	**28**
Virgin Concrete	3	3
Alginate 2%	3	3
Alginate 4%	3	3
Total	9	9

The selection of the use of 2% and 4% capsule variations is based on research conducted by Mauludin [15]. In the study, the optimum capsule usage results were the percentage of between 2% and 4%. However, the study was a numerical study. based on the percentage that has been obtained from the research conducted by Mauludin [15], this study was conducted to determine the percentage during experimental testing.

To make a concrete mixture, first prepare the tools and materials that will be used. Next, add the coarse aggregate, fine aggregate and cement first into the mixer then stir until evenly distributed. Next, add water gradually until it reaches the planned the planned cement water factor. Stir for approximately 10-15 minutes, then stop the mixer and add the capsule containing the bacteria. stir again for about 2 minutes. It is advisable not to stir for too long after adding the capsule to prevent the capsule from breaking prematurely. Once the mixture is sufficient, pour it into a cylindrical mold.

(a) (b)

Fig. 4. (a) Test specimen mold 15 x 30 cm (b) The specimen.

3 Results

From the results of compressive strength testing and visual observations carried out for approximately 2 months, it was found that the highest compressive strength occurred at 2% alginate variations on days 7 and 28. Visual observations also showed the desired results, namely crack closure after testing within a time interval. less than 1 month.

The results of the compressive strength test are presented in Fig. 5 below. The unit of measurement used is Megapascal (MPa) for compressive strength

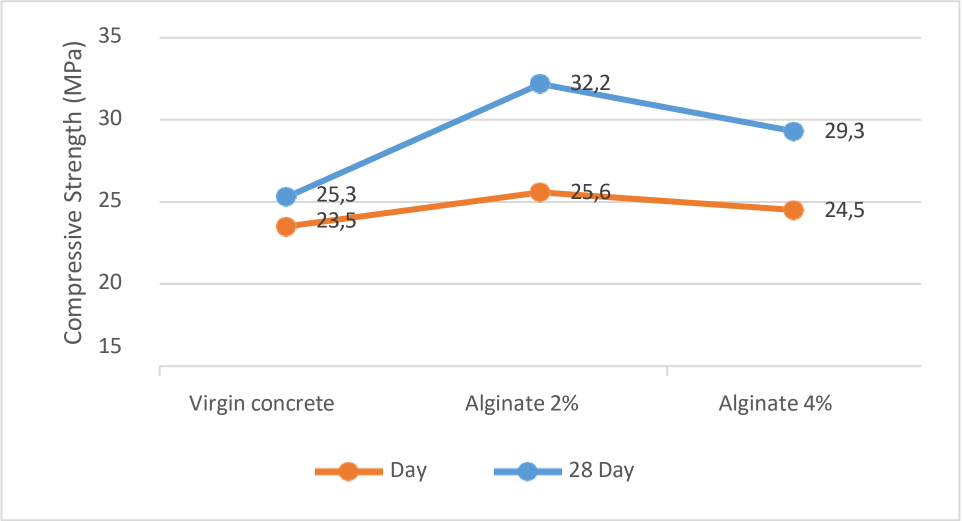

Fig. 5. Comparison of the compressive strength of virgin concrete and alginate capsulation concrete.

Figure 5 shows that the compressive strength of normal concrete on days 7 and 28 is 23.5 MPa and 25.3 MPa, the concrete variation using 2% alginate is 25.6 MPa and 32.2 MPa, and the concrete variation using 4% alginate is 24.5 MPa and 29.3 MPa. From the test results, it was found that there was an increase in concrete compressive strength of 9% for the 2% alginate variation at the 7-day test, while for the 4% alginate variation there was an increase of 4%. On the 28th day of testing, there was an increase in concrete quality of 27% for the 2% alginate variation, while the 4% variation increased by 16%. These results show that the higher the percentage of the number of capsules used, the compressive strength of concrete decreases due to the reduced volume of concrete due to the large number of capsules contained in the concrete.

Visual observations begin after the concrete has been tested for compressive strength. Concrete that has been compressed is soaked in a water bath. One of the concrete compression test samples using the addition of capsules was taken to be observed for 2 months (in this study samples of the 2% capsule variation were used (Fig. 6)). Visual observations show that capsules that break due to cracks will release a healing agent in the form of Bacillus Megaterium bacteria which will fill the cracks and then react with air to form calcium carbonate. This calcium carbonate will cover the cracks in the concrete. Calcium carbonate began to appear in the 2nd week after the compression test.

Fig. 6. Specimen contain 2% capsule after compressive test and curing.

4 Conclusion

The objective of this research is to observe the behavior of Bacillus Megaterium bacteria encapsulated using alginate biopolymer and its effect on the compressive strength of normal concrete. Alginate biopolymer is a material that is easily available and widely available on the market. The price is affordable so alginate has advantages from an economic perspective. Based on the test results, concrete added with bacterial capsules has increased in compressive strength at a variation of 2%, but when it is added to 4% the compressive strength of the concrete decreases. This is because adding too many capsules will cause a reduction in the volume of the concrete which will also result in reducing the density of the concrete so that the compressive strength of the concrete decreases. From the test results, it was also found that the highest compressive strength was obtained when 2% alginate capsules were added on day 7 and day 28, namely 25.6 MPa and 32.2 MPa. The increase that occurred was 27.27% of normal concrete. Meanwhile, when 4% alginate capsules were added to concrete, the concrete increased by 4.25% on day 7 and 15.81% on day 28. When the percentage of capsules was increased, the compressive strength of the concrete would decrease.

Visual testing carried out for approximately 2 months with samples of 2% alginate capsules showed that the cracks began to be covered by calcium carbonate in the 2nd week. By comparing the addition of 2% and 4% capsules, the optimum proportion of increase in compressive strength was the addition of capsules as much as 2%. However, this must be studied further by adding a larger percentage to see the behavior of the capsule in relation to the concrete.

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