Study of Volcanic-Ash-Impregnated-Bacteria Filler to the Compressive Strength of Concrete

Hendry Anjar Purwanto[1,*], *Ananto* Nugroho[2,*] , and *Ririt* Aprilin S[3,*]

[1,3]Department of Civil Engineering, State University of Jakarta, 13220 Rawamangun, Indonesia
[2]Biomaterial Research and Development Center, Indonesian Institute of Sciences (LIPI), 16911 Cibinong, Indonesia

Abstract. Technology of concrete has been advanced recently to improve the properties of concrete. Utilization of ash as the substitute of cement or filler of concrete also indicates good result in compressive strength concrete in certain amount. Harnessing the bacteria for self-healing concrete has also been successfully performed in order to maintain the destruction of the concrete by itself. Past research indicated that bacteria can be beneficiary to improve the compressive strength, absorption, permeability, and so on. In this paper, *Bacillus Altitudinis* was extracted from the karst (source from the limestone mountain) and bred through liquid media to be impregnated inside the volcanic ash. The impregnated bacteria in volcanic ash were used as the filler to the concrete mixture with the proportion of filler varied from 1%, 1.5% and 2% to the weight of cement. Mechanical properties of the concrete specimen showed that the compressive strength reached its best when the filler proportion was 1.5%. The absorption referred analogously to the increment of compressive strength due to the success of filling the void inside the concrete. Based on compression test to all the concrete specimens, there was enhancement about 18% and the average absorption can be abated around 23%. Future research due to some drawbacks turning up is the need of developing another media for bacteria to live and making sure the exact amount of bacteria impregnated to the media so that the desired advance of concrete compressive strength can be acquired.

Keywords: *Bacillus altitudinis*, volcanic ash, impregnation, compressive strength, concrete

* Corresponding author: hendryanjar@gmail.com (Hendry AP) ; ananto@biomaterial.lipi.go.id (Ananto N) ; ririt-aprilin@unj.ac.id (Ririt AS)

1 Introduction

The approach of biotechnology for increasing the cement-based materials mechanical properties is called bio-mineralization. This process involves living cells which produce mineral from the microbial metabolism under favourable settings of interaction with selective cations [1]. Lately, the use of bacteria as the agent for applying bio-mineralization to the concrete mixture to form the self-healing concrete has been widely investigated. Types of bacteria from the genus of *Bacillus* are one of the most widely used to be lived inside the concrete until the deterioration of the concrete occurred so that the bacteria will work to heal once crack happens.

Methodologies for importing bacteria to the concrete are mentioned some, for instance immobilization through impregnation and encapsulation. Different results of each to the efficiency of bacteria to perform better in mechanical properties or healing process. Immobilization process would significantly increase the compressive strength when the ureolitic activity involved. Impregnation process creates better self-healing particularly for larger cracks if the chemical agent is inserted. Second, encapsulation would be more effective to be applied for healing larger cracks [2].

The major purpose of this research is gaining the information about the effect of the impregnation of bacteria to the volcanic ash to the compressive strength of concrete. Therefore, physical properties and chemical properties test conducted in this paper will be detail discussed in order to expand the analysis.

1.1 Research limitation

Research target for this paper is investigating the mechanical properties of concrete at the maximum age of 28-days. The proportion of concrete mixture is set as 1:2:3 for cement, fine aggregate, and coarse aggregate. Water cement ratio is also fixed to 0.5 with the targeted slump of 100±20 *mm*. Volcanic ash which is originally got from *Kelud* mountain is selected as filler for the concrete and the media for the bacteria to be impregnated. *Bacillus altitudinis* is utilized in this research as got from isolation process of limestone from mountain in Central Java.

The examination of concrete properties was limited to physical properties, mechanical properties, and chemical properties. Density and absorption are the representation for physical properties of concrete, compressive strength is chosen for mechanical properties data, and acid titration to be performed in checking the acid tenacity for the chemical properties. Photo scanning electron microscope (SEM) is performed only for identifying the void size of the volcanic ash to be eligible for *Bacillus altitudinis* to live on. Other limitations are quantification of bacteria and SEM experimentation after the acid titration process is not performed.

2 Material and method

The composition of concrete mixture was taken from the nearest deposit of the research field, whilst the cement used was Portland Cement Type I. The use of volcanic ash as the filler of concrete mixture was selected due to its similarity to cement properties especially the grain size. Filler works best in filling the void inside the concrete so that the failure of concrete can be significantly decreased. As the bacteria is another component tht we want to investigate, then impregnation method is chosen as the method for importing bacteria to the concrete by lodging it to the volcanic ash. The proportion of volcanic-ash-impregnated-bacteria to cement will be discussed in the following.

2.1 Concrete compounds

The preliminary test result for fine aggregate and coarse aggregate is provided in table 1, besides the grain size distribution after conducting sieve analysis and mud content test is also proven that the aggregate is eligible to be used for concrete mixture. Qualification of Portland cement is taken from the specified product without any test performed.

Table 1. Experimental result for fine and coarse aggregate

Specimen	Components	Value
Fine Aggregate	Bulk density	1.65
	SSD density	2.65
	Apparent density	1.49
	Absorption	0.6%
Coarse Aggregate	Bulk density	2.54
	SSD density	2.54
	Apparent density	2.63
	Absorption	1.35%

2.2 Filler

Physical characteristic of the volcanic ash especially the grain size is almost the same as cement. Some of the ash also has similarity in chemical properties so that cement can be replaced partially. By performing scanning electron microscope (SEM) experiment, the chemical components of the volcanic ash is served in table 2 below, at the same time the void size can be identified in order to determine the adequacy space for the bacteria to live through impregnation process.

In this research, the proportion of volcanic ash to cement is varied from 0% to 2% with the interval of 0.5%. Before, the impregnation of bacteria to the volcanic ash will be performed. Basically, the utilization of the volcanic ash as filler will improve the compressive strength due to its micro grain size to fulfil the pore between concrete matrix which cannot be accommodated by the fine aggregate and cement.

Table 2. Chemical compounds of *Kelud* volcanic ash

Oxides	Contents (%)
Calcium oxide (CaO)	62.30
Silicon dioxide (SiO_2)	25.40
Aluminium oxide (Al_2O_3)	7.60
Iron (III) oxide (Fe_2O_3)	4.20
Potassium Oxide (K_2O)	0.19
Sodium Oxide (Na_2O)	0.10
Titanium dioxide (TiO_2)	0.21

The dimension of the void is detected in the interval of 50 – 100 μm so that the spore of around 1.2μm *Bacillus altitudinis* is matched to be lodged.

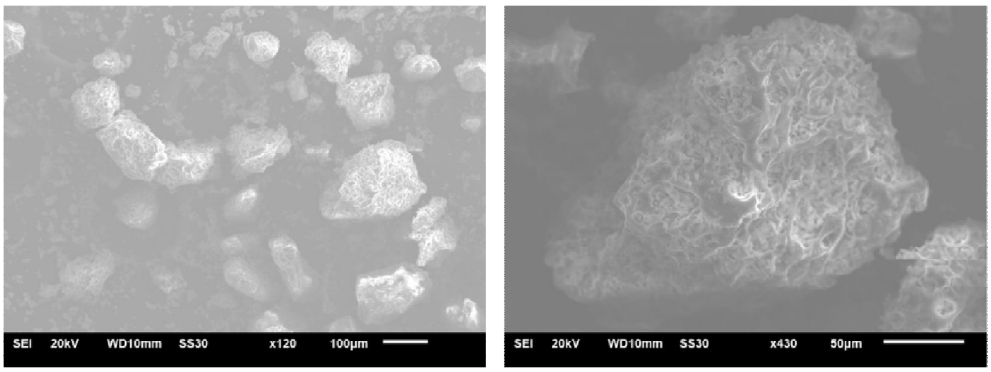

Fig. 1. SEM investigation for *Kelud* volcanic ash

2.3 Bacteria

Type of strain of *Bacillus altitudinis* is 41KF2b^T (= MTCC 7306^T = JCM 13350^T) with a gram positive categorized bacteria. The colonies of *Bacillus altitudinis* on nutrient agar are white, convex with a regular margin and 2-3 *mm* in diameter. Growth occurs between 8 and 45°C at pH 5-8. It tolerates up to 2% NaCl and degrades tyrosine, but tests negative for casein hydrolysis, urease, and phenylalanine deaminase activities, reduction of nitrate to nitrite, utilization of citrate and the Voges-Proskauer test [3].

Culture of bacteria *Bacillus altitudinis* is performed by adding 5 gr/l peptone, 5 gr/l NaCl, and 3 gr/l yeast extract. The bacteria is grown in liquid media using sterilized tube then agitated at 125 rpm for 24 hours [4]. Later, the growths bacteria will be impregnated to the volcanic ash through freeze-dry process.

3 Analysis and discussion

3.1 Physical properties

Water can be seen as the main cause of degradation of building materials, especially concrete [5]. The durability of concrete may utilize the absorption result from total absorption, porosity, surface absorption, and capillary absorption [6]. During the life service of concrete, high porosity compromises the physical-mechanical properties of concrete and its permeability [7].

Absorption and density of concrete will be analyzed to get the physical properties of the volcanic-ash-impregnated-bacteria filler concrete. As shown in Figure 2, the absorption of concrete degrades as the proportion of volcanic ash increases. The maximum of absorption is reached for the 1.5% addition of volcanic ash. The number of pores will be completely blocked by volcanic ash so that the water entrance to the concrete diminishes. When reaching 2% of variation, the absorption rises about 12%.

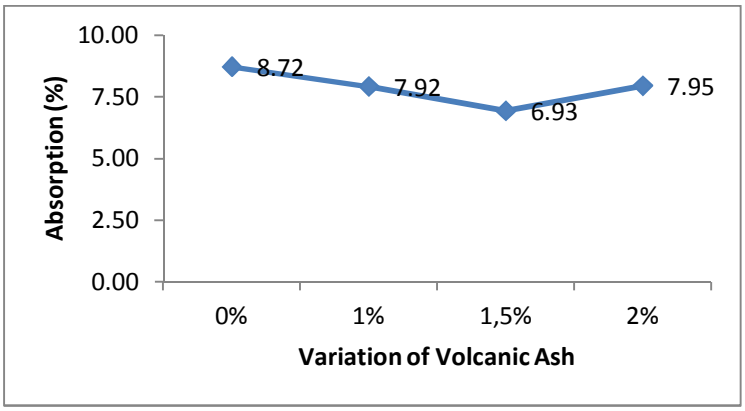

Fig. 2. Absorption of Concrete

Density value can be seen in table 3, where the density of concrete rises along the augment of volcanic-ash-impregnated-bacteria. The increment of 2% from the control concrete specimen is not really significant, but it affects the absorption significantly as the number of volcanic ash added.

Table 3. Density of Concrete

Variation	0%	1%	1.5%	2%
Density	2.56	2.63	2.63	2.61

3.2 Mechanical properties

The slump value of the concrete mixture reaches the target interval so that the workability is good enough during moulding of concrete specimen. The specimens are cylindrical based on ASTM requirements. Compressive strength as the main concern to see the effect of the volcanic-ash-impregnated-bacteria after 28-days is shown in figure 3. Enhancement of the volcanic ash variation indicates the increment of compressive strength; the maximum refers to 1.5% variation. Lesser void in concrete is not only increasing the absorption and density but also compressive strength. Bacteria inside the concrete create the crystal which affect to the compressive strength of concrete [8], [9]. The maximum increment achieves 18% at the 1.5% variation compare to control concrete specimen.

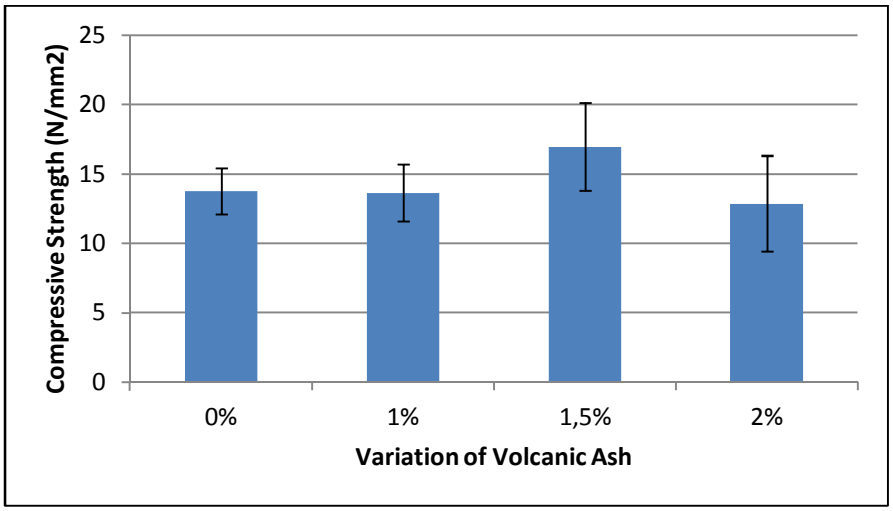

Fig. 3. Compressive strength of volcanic-ash-impregnated-bacteria concrete

The variation of volcanic-ash-impregnated-bacteria inside the concrete results the degradation in density and compressive strength concrete as well as the absorption escalates. Ideally, absorption of bacteria and precipitation of calcite crystals resulted in weight increase of concrete specimen [10], [9]. But in the case of 2% variation concrete specimen, the pore is too dense so that the bacteria have no supply of oxygen to perform ureolytic activity and carbonate biomineralization.

3.3 Chemical properties

Tenacity due to acid performed by using phenolphthalein 1gr/l which is soluble using alcohol content 90% about 50 ml and added by water 100 ml. The result refers to figure 4 that the purple colour in the surface of concrete so that the specimen is acid proof, in other words the condition of concrete specimen is alkali. It also strengthened by the result of the compressive strength of concrete specimen which is constant compare to the usual curing condition.

Fig. 4. Acid titration experiment

4 Conclusion and suggestion

Based on the discussion above, we can conclude and summarize as follows:

a. Utilization of *Bacillus altitudinis* to the concrete specimen has brought enhancement of physical, mechanical, and chemical properties even though the number of addition is very small to the weight of cement.

b. Physical properties of volcanic-ash-impregnated-bacteria filler of concrete specimen indicate analogue result with its mechanical properties. The enhancement of density and compressive is achieved due to calcite crystal formed from the bacteria through ureolytic activity and carbonate bio-mineralization.

c. The maximum satisfying result refers to the volcanic-ash-impregnated-bacteria variation of 1.5% with the 18% compressive strength increment, whilst after 1.5% variation shows degradation.

d. Better detail experiment must be conducted such as quantification of bacteria, SEM investigation after the compression test, and condition of bacteria either live or die. Another type of immobilization process of bacteria to the concrete can also be performed in order to see the effectiveness between them to the physical, mechanical, and chemical properties. Besides, it is also worth to observe the concrete specimen into self-healing activity after it is deteriorated due to compression test.

References

[1] L. S. Wong, "Microbial cementation of ureolytic bacteria from the genus Bacillus: a review of the bacterial application on cement-based for cleaner production," *Journal of Cleaner Production,* pp. 5-17, (2015).

[2] N. Z. Muhammad, A. Shafaghat, A. Keyvanfar, M. Z. A. Majid, S. Ghoshal, S. E. M. Yasouj, A. A. Ganiyu, M. S. Kouchaksaraei, H. Kamyab, M. M. Taheri, M. R. Shirdar

and R. McCaffer, "Tests and methods of evauating the self-healing efficiency of concrete: A review," *Construction and Building Materials,* pp. 1123-1132, (2016).

[3] S. Shivaji, P. Chaturvedi, K. Suresh, G. Reddy, C. Dutt, M. Mainwright, J. Narlikar and P. Bhargava, "Bacillus aerius sp. nov., Bacillus aerophilus sp. nov., Bacillus stratosphericus sp. nov. and Bacillus altitudinis sp. nov., isolated from cryogenic tubes used for collecting air samples from high altitudes," *Systematic and Evolutionary Microbiology,* **vol. 56**, pp. 1465-1473, (2006).

[4] A. Nugroho, I. Satyarno and Subyakto, "Bacteria as self-healing agent in mortar cracks," *J. Eng. Technol. Sci.,* **vol. 47**, no. 3, pp. 279-295, (2015).

[5] A. Fernandez and A. Palomo, "Propiedades y applicaciones de los cementos alcalinos," *Revista Ingenieria de Construction,* **vol. 24**, pp. 15-213, (2009).

[6] N. T. Castellanos, J. T. Agredo and R. M. de Gutierrez, "Evaluation of permeation properties of concrete added with a petrochemical industry waste," in *Calcined Clays for Sustainable Concrete*, Switzerland, (2015).

[7] R. Detwiler and P. Mehta, "Chemical and physical effects of silica fume on the mechanical behavior of concrete," *ACI Mater J.,* **vol. 86**, pp. 609-614, (1989).

[8] S. Krishnapriya, B. D. Venkatesh. and P. A. G., "Isolation and identification of bacteria to improve the strength of concrete," *Microbiological Research,* **vol. 174**, pp. 48-55, (2015).

[9] N. Chahal, R. Siddique and A. Rajor, "Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of fly ash concrete," *Construction and Building Materials,* **vol. 28**, pp. 351-356, (2012).

[10] R. Siddique and N. K. Chahal, "Effect of ureolytic bacteria on concrete properties," *Construction and Building Materials,* **vol. 25**, pp. 3791-3801, (2011).