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Synthesis and Characterization of Hydrophobic and Self Healing Concrete Materials Based on Microorganisms

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Abstract: The high water absorption of concrete causes the concrete to easily experience cracking and damage. One way to increase the durability of concrete is by adding microbes which can fill the micro cavities in the concrete with the resulting Calcium Carbonate ($CaCO_3$) deposits. However, the weakness of using microorganisms is that they are unable to withstand high hydration heat. Therefore, by varying the temperature in this research, it is possible to determine the effect of the metabolism of the bacteria produced. This research was carried out to avoid damage by creating a hydrophobic and self-healing layer which helps increase the durability and strength of the concrete. The concrete sample made resembles a cube measuring 5 cm x 5 cm x 5 cm. The manufacturing materials are Portland cement, Otawa sand, distilled water and a mixture of *E. coli* bacteria. Heating was carried out using an oven at temperatures of 30, 60, 90, and 120 °C. Characterization testing was carried out using a Cpmreson machine, XRD and contact angle testing.

Keywords: Concrete; *E. coli* bacteria; Hydrophobic; Self healing; Temperature

Introduction

As building construction develops very rapidly, the public's need for infrastructure such as bunkers, nuclear reactors and high-rise buildings made of concrete is increasing. Most of the problems with durability in concrete materials are when the concrete surface is in direct contact with water so that it easily absorbs into the pores to the deepest parts (Ryparova & Tesarek, 2020). High water absorption in concrete can be overcome by creating a hydrophobic layer to increase the durability and strength of the concrete (Zheng, 2018). According to Bashir et al. (2016), Ratnayake et al. (2018), Njau et al. (2022), Schreiberova et al. (2021), Priyom et al. (2021), Tomczak et al. (2021), and Danish et al. (2020) self-healing techniques are used to repair concrete independently by combining materials and microorganisms that are able to deposit $CaCO_3$ on concrete.

Based on previous research on self-healing concrete which uses *Bacillus sp*. and *Sporosarcina sp*. bacteria which can produce the enzyme urease as a catalyst to form $CaCO_3$ which can close cracks in concrete. However, the use of other bacteria such as *E. coli* has not been widely used as an agent in curing concrete. Apart from the important role of bacteria as healing agents, the method used in previous research still requires further development because several unfavorable effects are still found, such as the vulnerability of bacteria when exposed to direct sunlight and the use of bacteria if it exceeds a certain limit is not good for human health as well as the atmosphere.

Based on research by Xu et al. (2014), Micallef et al. (2016), Kalhori et al. (2017), Yip et al. (2022), Ganesh et al. (2020), Reddy (2016), and Qu et al. (2021) how to make a simple hydrophobic mortar using *Bacillus subtilis* cultured in liquid. This test sets a temperature of 20 °C for 80 hours. The results obtained are a new hydrophobic mortar capable of providing water resistance with a contact angle of 92.6˚. This research has achieved the desired results in the form of a good hydrophobic mortar, however the contact angle obtained is still very low and it has not been carried out

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as a bacteria-based self-healing mortar which can provide resistance and strength to the mortar.

According to Huo et al. (2020), Syaputri et al. (2021), and Salam et al. (2021) hydrophobic layers made on cement mortar using polymer materials show optimal results as proven by the comparison of compressive strength to standard mortar. Apart from that, the contact angle obtained is still very low and it has not been used as a bacteria-based self-healing mortar which can provide durability and strength to concrete. Therefore, the author raises the aim of this research which is to apply variations in heating temperature to the development of microorganism-based hydrophobic and self-healing concrete that is of higher quality, environmentally friendly so that it is easy to use.

Method

Material

This research used materials in the form of Portland cement and Otawa sand, which were purchased at a Padang Indonesia building shop, then distilled distilled water directly in the UNP Indonesia chemistry laboratory and *E. coli* bacteria, which were cultured naturally in the UNP Indonesia biology laboratory.

Method

This research method is experimental research that begins with the process of cultivating *E. coli* bacteria. Bacterial cultivation can be done using solid nutrient plate media (NA) (Senthil et al., 2019; Islam et al., 2022). Next, take 10 ml of pure bacterial seeds in the vial using a micro pipette and drip it into the well of the nutrient plate and incubate the plate at room temperature 37˚C for 3 days (Akki et al., 2019). While waiting for the bacteria to grow, the next step is to make concrete based on SNI 2049:2015 using 500 grams of Portland cement, 1,375 grams of silica sand and 250 ml of distilled water. The next stage is making hydrophobic and self-healing concrete by mixing 106 cells/ml of cultured bacteria into the concrete cement mixture (Dhamale & Devgire, 2019). Characterization can be done by testing the compressive strength of concrete using a compressor machine, contact angle testing using Image-J software and X-ray characterization using XRD.

Result and Discussion

Compressive Strength Test

Compressive strength testing on concrete materials is carried out to determine the maximum load weight carried by the concrete. The compressive strength test was carried out using a compressor machine on concrete that was 14 days old and cured. The results of the concrete compressive strength test at 14 days can be seen in Figure 1.

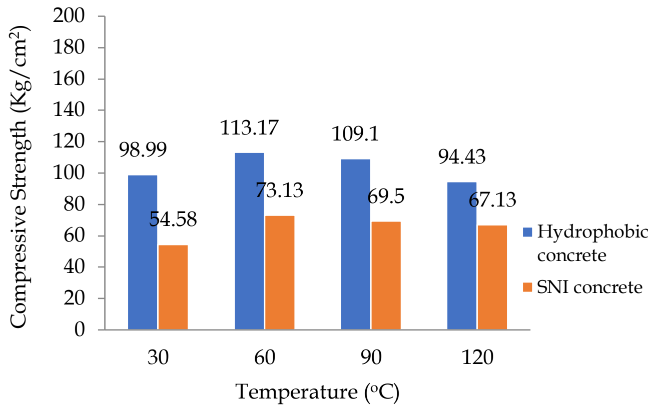

Figure 1. Graph of the relationship between compressive strength and temperature

Figure 1 shows the results of the compressive strength of concrete tested after 14 days of manufacture. This compressive strength test was carried out on each sample with different heating temperatures of 30, 60, 90, and 120 °C on hydrophobic concrete and heating temperatures of 30, 60, 90, and 120 °C on SNI concrete as a comparison. The test results showed that the compressive strength of hydrophobic concrete which was added with microorganisms during mixing had a higher compressive strength than the compressive strength of SNI concrete. This proves that microorganisms are able to provide good resistance and strength to concrete.

XRD

XRD analysis is a diffractogram produced in the form of intensity peaks along the 2θ value with varying shapes. Data analysis of characterization results using XRD on hydrophobic concrete at a temperature of 60°C can be seen in the diffraction pattern in Figure 2. Figure 2 shows the results of characterization using XRD on hydrophobic concrete after self-healing testing for 14 days. The results of this characterization obtained data on 2θ and its intensity. Based on XRD analysis data on hydrophobic concrete (with added bacteria) SiO_2 and $CaCO_3$ phases appear. $CaCO_3$ is produced from the metabolism of bacteria deposited on concrete. Meanwhile, in SNI concrete (without added bacteria) only the SiO_2 phase appears. The X-ray Diffraction Pattern is a plot of the diffraction angle 2θ against the intensity of the SiO_2 and $CaCO_3$ X-ray diffraction patterns tested on concrete after 14 days of age. In the XRD results, the $CaCO_3$ produced is the metabolism of microorganisms which can increase the hydrophobicity of concrete.

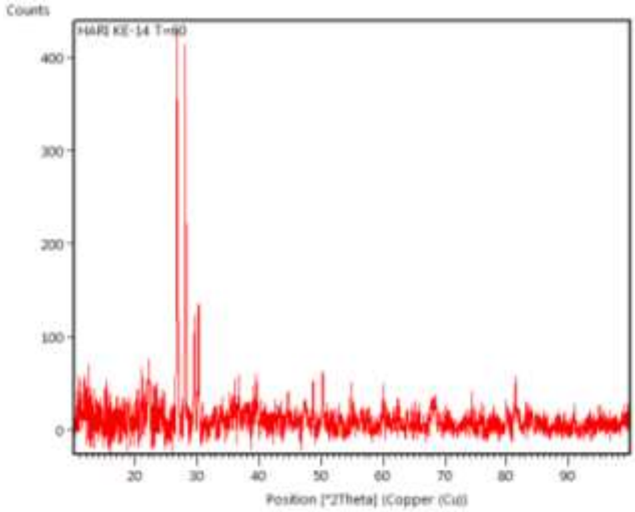

Figure 2. X-Ray Diffraction (XRD) pattern in concrete

Contact Angle

Measurement of the contact angle of the concrete surface at each temperature was carried out to determine the level of hydrophobicity of the concrete material (Davies et al., 2018; Al-Tabbaa et al., 2019; Liu et al., 2021; Yang et al., 2022). This contact angle measurement is carried out by photographing water droplets on the concrete surface using a camera and measuring it using Image-J software. Concrete material can be said to be hydrophobic if water dripping on the surface rolls well as evidenced by a contact angle ≥ 90° (She et al., 2018; Shen et al., 2018; Rasitha et al., 2019). The resulting contact angle is in Figure 3.

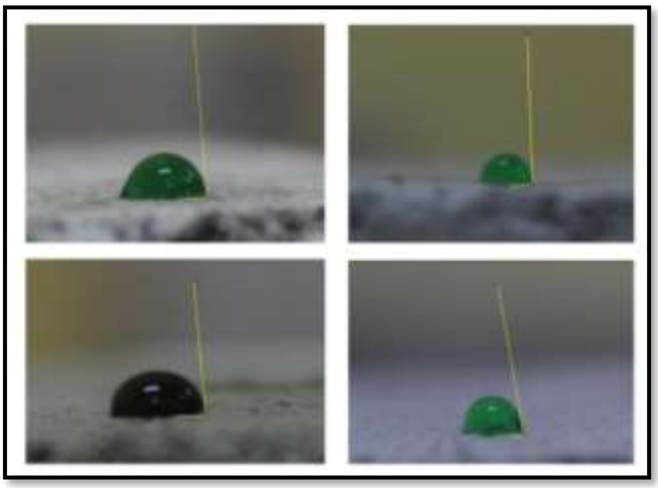

Figure 3. Contact angle on Hydrophobic Concrete with varying heating temperatures a) 30 °C, b) 60 °C, c) 90 °C, d) 120 °C

Figure 3 shows the shape of the contact angle produced in hydrophobic concrete. Where at a temperature of 30 °C the resulting contact angle reaches hydrophobic requirements, namely 86.21°. At a temperature of 60 °C the resulting contact angle was higher, namely 89.91°. However, at a temperature of 90 °C, the resulting contact angle decreases, namely 87.95°. At a temperature of 120 °C the resulting contact angle decreases, namely 82.53°. This is because increasing the temperature causes a reduction in the metabolism of microorganisms in the concrete. In SNI concrete the resulting contact angle is shown in Figure 4.

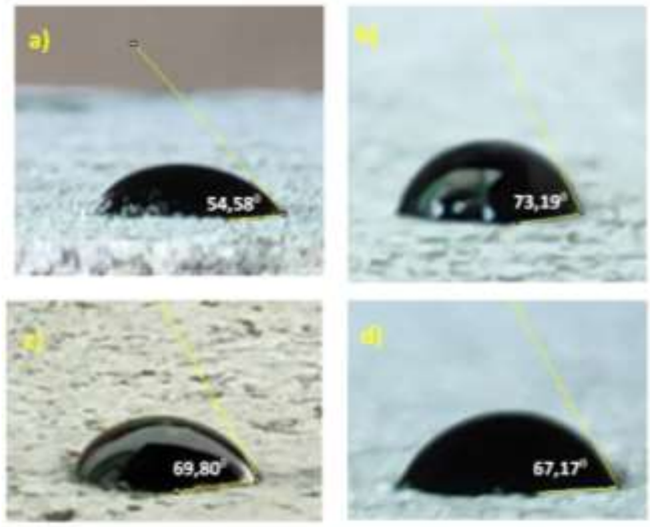

Figure 4. Contact angle on SNI Concrete with varying heating temperatures a) 30 °C, b) 60 °C, c) 90 °C, d) 120 °C

Figure 4 shows the shape of the contact angle produced in SNI concrete. On the SNI concrete surface, dripping water absorbs the concrete pores quickly. This is because SNI concrete does not contain additional microorganisms as hydrophobic agents. Therefore, the resulting contact angle is less than 90o which is called hydrophilic.

Conclusion

The use of temperature variations in this research can influence the metabolism produced by bacteria in the form of $CaCO_3$ which will close cracks in the concrete so that it is self-healing. Temperature also greatly influences the compressive strength, contact angle and surface morphology of hydrophobic concrete. The optimum compressive strength produced in hydrophobic concrete is 219 kg/cm^2 at a temperature of 90 °C, while the compressive strength in SNI concrete at a temperature of 90 °C is 121.4 kg/cm^2. In the contact angle test, the optimum results were found at a temperature of 60 ˚C of 113.38°. Temperature also affects the morphology and particle size of hydrophobic and self-healing concrete. Providing a temperature of 30-60 °C is the optimum temperature for bacteria to carry out activities and produce $CaCO_3$ metabolism. So that at this temperature micro cracks that occur on the concrete surface can be covered properly. It is hoped that future research will use other types of bacteria at high temperatures so that they can increase the compressive strength, contact angle and good self-healing values of concrete.

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Author Contributions
Yulia Maulida and Ratnawulan conceptualized research idea, methodology and data analysis. Riri Jonuarti and Harman Amir give critical feedback and substantial review.

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Conflicts of Interest
The authors declare no conflicts of interest.

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