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Effect E. coli Bacteria Concentration as Self Healing on Compressive Strength and Hydrophobic Properties on Micro Cracks of Concrete

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Abstract: Buildings are facilities created by humans to support various human activities. Potential damage to old buildings, such as the appearance of cracks in building concrete. Self-healing is carried out by bacteria to repair micro cracks that occur in concrete by deposition of CaCO3. Bacteria-based preservatives consist of bacterial spores and organic compounds that are incorporated into the concrete structure. This research aims to determine the effect of variations in the concentration of E. coli bacteria on compressive strength and contact angle. Based on the results of the research data, two research results can be stated. First, the concentration of bacteria affects the compressive strength of the concrete and the maximum compressive strength occurs on day 14. Second, the concentration of bacteria affects the contact angle of the concrete so that it can be said that the concrete is hydrophobic. As for the XRD characterization, intensity data (I), diffraction angle (θ) were analyzed using High Score Plus. FTIR characterization was carried out in the range 4000 cm^{-1}-500 cm^{-1}. SEM characterization to see the morphology of the concrete with a magnification of 2500 times. SEM can also show E. coli bacteria in concrete.

Keywords: Concentration; Concrete; E. coli Bacteria; Hidrophobic; Self Healing

Introduction

Buildings are facilities created by humans to support various activities and activities of humans themselves (Keerthana et al., 2016). In general, concrete is the main material in building construction because it is known for its durability. However, its brittle nature makes concrete susceptible to cracking (Iheanyichukwu et al., 2018). Therefore, over time the durability and strength of concrete can decrease in quality. This is caused by mechanical, physical, chemical processes, or those originating from human activities. These processes can accelerate the appearance of cracks in concrete (Ariyanto, 2020; Algaifi et al., 2020). Cracks can also occur when the concrete surface frequently interacts directly with water, because water is an element that is very easily absorbed by the pores of the concrete. Excessive water absorbed into the pores of the concrete can cause brittleness of the concrete structure, thereby affecting the durability and compressive strength of the concrete (Althoey et al., 2022). So, it can be said that excessive water absorption is the main problem that affects the decline in quality of concrete.

Decreased concrete quality can be overcome by making the concrete hydrophobic. Hydrophobicity can be interpreted as being afraid of water or being water-resistant (Salam et al., 2021). The hydrophobicity of a surface can be determined by estimating the contact angle between water and the sample surface (Ratnawulan et al., 2022; Wang et al., 2012; Huang et al., 2022). To make concrete hydrophobic, you can include bacteria in the manufacturing process. Some bacteria are known to be able to carry out self-healing because their metabolism can produce lime which can then fill the

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pores in concrete (Bandlamudi et al., 2022; Muller et al., 2021; Orozco et al., 2022). Self-healing in concrete is the ability of concrete to repair itself when it experiences cracks. This self-healing ability can be useful in dealing with micro-cracks. This process can occur when adding bacteria to the concrete composition (Bandlamudi et al., 2022; Qu et al, 2021). The bacteria used in this process are special bacteria that are added along with calcium-based nutrients to the concrete material during the mixing process (Riad et al., 2022).

In this research, the special bacteria used were Escheriachia coli bacteria or better known as E. coli bacteria. The use of this bacteria is because E. coli has a metabolism that can produce lime or calcium carbonate (CaCO3) (Swami et al., 2022). Apart from its metabolic capabilities, E. coli also has the ability to survive difficult and extreme environmental conditions. The ability of E. coli to survive during cooling and freezing has been proven to make E. coli tolerant of dry conditions. E. coli has a generation time of approximately 30 to 87 minutes depending on temperature. The optimum time for the growth of E. coli is 37 0C with a generation time of 30 minutes (Rahayu et al., 2018), so it is very helpful in the research process. E. coli is an obligate aerobic bacterium and has round tip spores (Swami et al., 2022). The main benefit of embedding E. coli bacteria in concrete is to accelerate CaCO3 (Islam, et al., 2022). Therefore, the selection of E. coli bacteria that will be included in the cement paste mixture is in accordance with the standards and classification, such as the Bacillus bacteria used in previous research (Hussein et al., 2019; Rong et al., 2019; Riad et al., 2022).

The choice of bacteria used in this research was Escheriachia coli (E. coli). E. coli bacteria were chosen because they have the same properties and characteristics as Bacillus bacteria. Where in the metabolism of E. coli bacteria it produces lime or calcium carbonate ($CaCO_3$) (Swami et al., 2022). The main benefit of embedding E. coli bacteria in concrete is to accelerate $CaCO_3$ (Islam et al., 2022). In previous research, E. coli was used in concrete mixtures (Bhan Singh Sikarwar % Tauheed, 2019). Variations in the concentration of Bacillus subtilis bacteria have value 10^3, 10^6, 10^9 cells/ml (Hussein et al., 2019). Bacillus pasteuri bacteria are introduced into concrete with a marked impermeability ratio (Rong et al., 2020).

Method

This research is experimental research. This research went through several stages, namely: Literature study stage, material preparation, making SNI concrete and concrete with varying bacterial concentration mixtures with values of 10^3 cells/ml, 10^6 cells/ml, 10^9 cells/ml, sample characterization and data analysis. The temperature used remains 60^0C. The flow diagram can be designed in Figure 1.

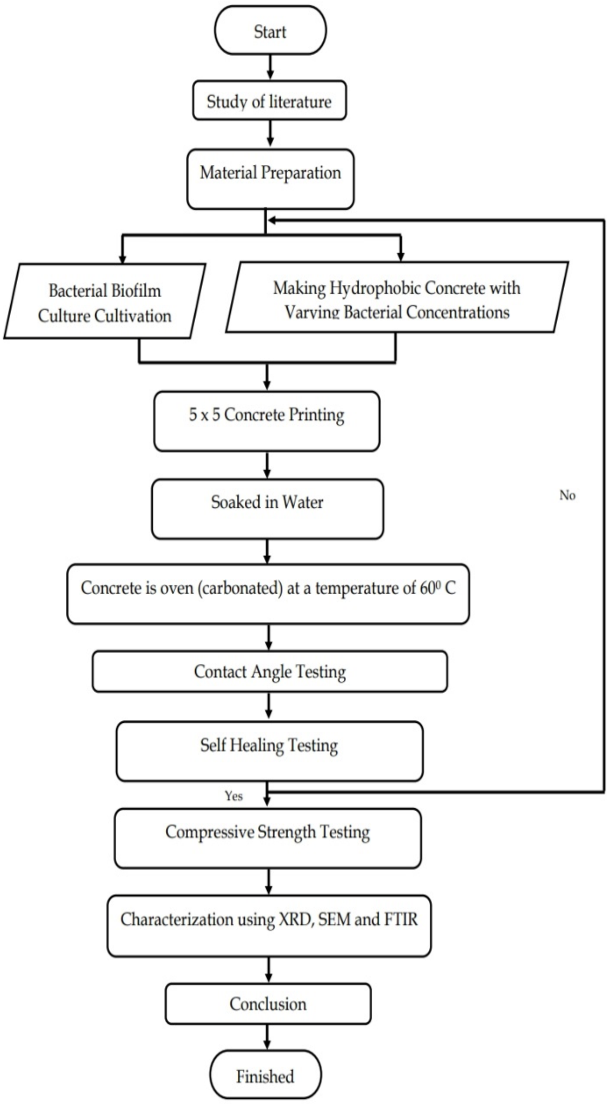


Figure 1. Flow diagram

Based on the flow diagram above, to be able to understand the research briefly, it can be shown in the research flow in Figure 2.

Figure 2. Research flow

Result and Discussion

Effect of Bacterial Concentration on Compressive Strength of Hydrophobic Concrete

Research data on the effect of bacterial concentration on the compressive strength of hydrophobic concrete can be described in table 1.

Tabel 1. Compressive strength of Hydrophobic concrete

Sample	Mass (kg)	Cross-sectional area (cm^2)	Compressive load (kgf)	Compressive strength (kg/cm)
INS	0.28	25	2930	117.4
103	0.32	25	6990	279.7
106	0.29	25	6080	243.3
109	0.31	25	4890	195.5

Based on Table 1, there are four samples used in this research, namely: SNI concrete samples and samples with E. coli bacteria concentrations having values of 10^3 cells/ml, 10^6 cells/ml and 10^9 cells/ml. Where SNI concrete has a compressive strength of 117.4 kg/cm, a bacterial concentration of 10^3 cells/ml has a compressive strength of 279.7 kg/cm, a bacterial concentration of 10^6 cells/ml has a compressive strength of 243.3 kg/cm and a concentration of 10^9 cells/ml has a compressive strength of 195.5 kg/cm.

Effect of Bacterial Concentration on Contact Angles on Hydrophobic Concrete Surfaces

Contact angle measurements from tests on concrete samples treated with varying concentrations of E. coli bacteria of 10^3, 10^6, 10^9 cells/ml in the concrete paste mixture. The concrete made has dimensions of 5 cm x 5 cm. The concrete is also in the oven for the drying process at a temperature of 60 ^{0}C. Apart from the three variations in bacterial concentration, SNI standard concrete was also made as a reference. This concrete sample test was carried out on the 14th day. Contact angle measurements on SNI concrete samples on day 14 can be seen in Figure 3.

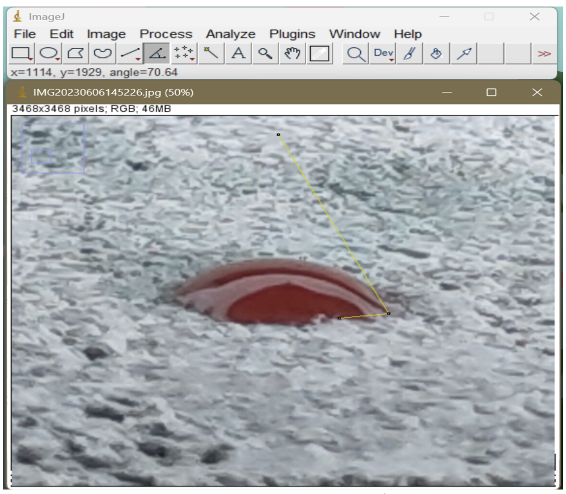


Figure 3. SNI concrete contact angle measurement

Based on Figure 3, water droplets are applied to the concrete to determine the contact angle. Then photographed using a DSLR camera, the resulting photo will be processed using the image J application. The SNI concrete contact angle is worth 70.64^0. Contact angle measurements on concrete samples with a concentration of 10^3 cells/ml on day 14 can be seen in Figure 4.

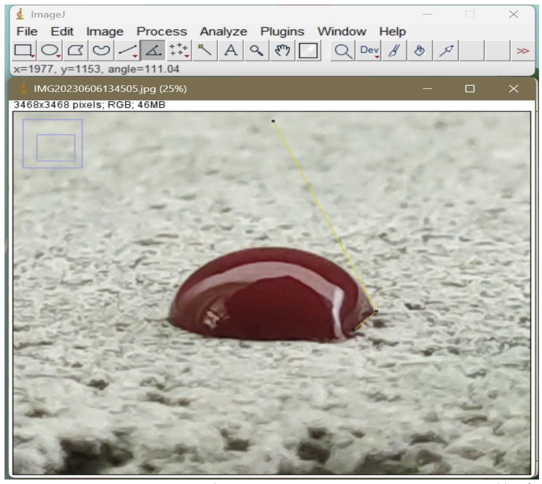


Figure 4. Contact angle measurement was 10^3 cells/ml

Based on Figure 4, water droplets are applied to the concrete to determine the contact angle. Then photographed using a DSLR camera, the resulting photo will be processed using the image J application. The concrete contact angle is 10^3 cells/ml, which is worth 111.04^0.

Contact angle measurements on concrete samples with a concentration of 10^6 cells/ml on day 14 can be seen in Figure 5.

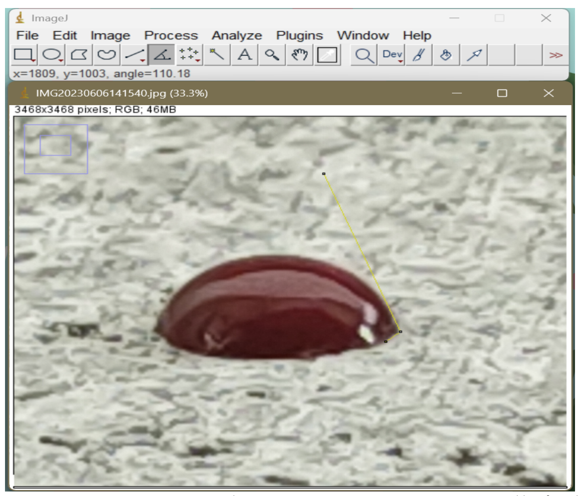


Figure 5. Contact angle measurement was 10^6 cells/ml

Based on Figure 5, water droplets are applied to the concrete to determine the contact angle. Then photographed using a DSLR camera, the resulting photo will be processed using the image J application. The concrete contact angle is 10^6 cells/ml, which is worth 110.18^0. Contact angle measurements on concrete samples with a concentration of 10^9 cells/ml on day 14 can be seen in Figure 6.

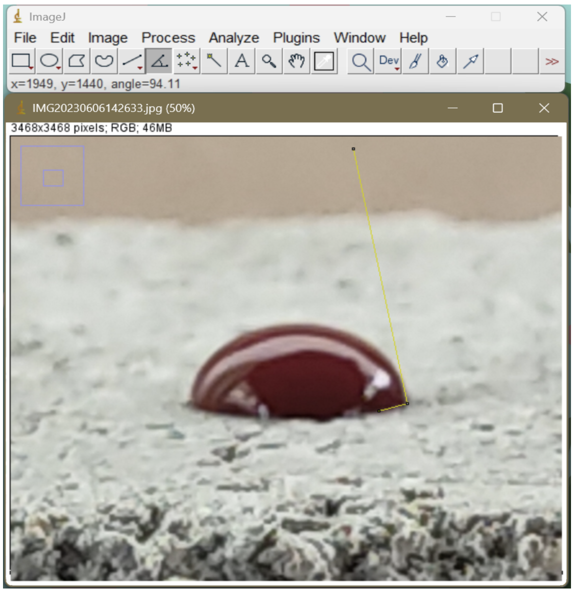


Figure 6. Contact angle measurement was 10^9 cells/ml

Based on Figure 6, water droplets are applied to the concrete to determine the contact angle. Then photographed using a DSLR camera, the resulting photo will be processed using the image J application. The concrete contact angle is 10^9 cells/ml, which is worth 94.11^0.

XRD characterization

Concrete data examined using XRD and analysis with the PANalytical X'Pert Highscore Plus application can be seen in the following explanation:

SNI Concrete

The x-ray diffraction pattern on reference concrete or SNI concrete can be seen in Figure 7.

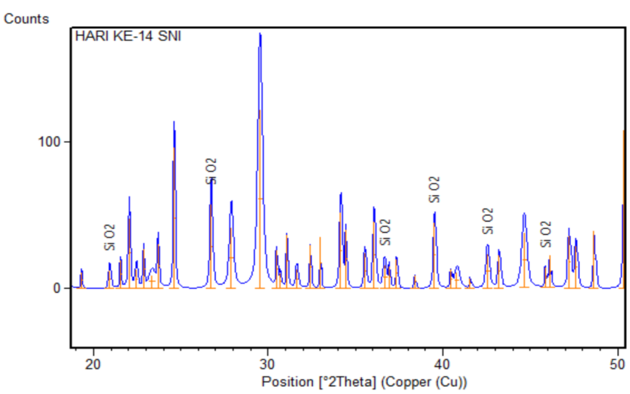


Figure 7. X-ray diffraction pattern on SNI concrete

Based on Figure 7, the diffraction pattern consists of several peaks. The mineral in SNI concrete is SiO2 or also known as silica. The peak intensity is plotted in the y-axis and the measured diffraction angle is plotted in the x-axis which is diffracted from planes in the specimen or material tested using XRD.

Bacteria concentration 10^3 cells/ml

The x-ray diffraction pattern of hydrophobic concrete at a concentration of 10^3 cells/ml can be seen in Figure 8.

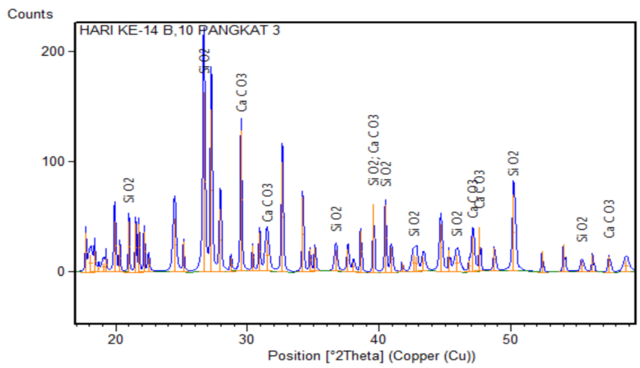


Figure 8. X-ray diffraction patterns in concrete concentration 10^3 cells/ml

Based on Figure 8, the diffraction pattern consists of several peaks. The peak intensity is plotted on the y-axis and the measured diffraction angle is plotted on the x-axis. Each peak or reflection in the diffraction pattern occurs due to x rays being diffracted from planes in the specimen or material being tested using XRD.

Bacteria concentration 10^6 cells/ml

The x-ray diffraction pattern of hydrophobic concrete at a concentration of 10^6 cells/ml can be seen in Figure 9.

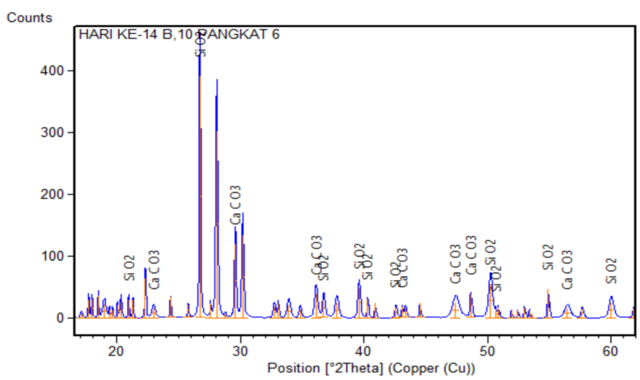


Figure 9. X-ray diffraction patterns in concrete concentration 10^6 cells/ml

Based on Figure 9, the diffraction pattern consists of several peaks. The peak intensity is plotted on the y-axis and the measured diffraction angle is plotted on the x-axis. Each peak or reflection in the diffraction pattern occurs due to x rays being diffracted from planes in the specimen or material being tested using XRD.

Bacterial Concentration 10^9 sel/ml

The x-ray diffraction pattern of hydrophobic concrete at a concentration of 109 cells/ml can be seen in Figure 10.

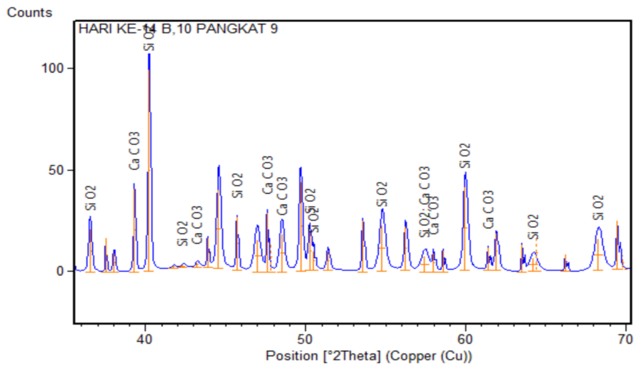
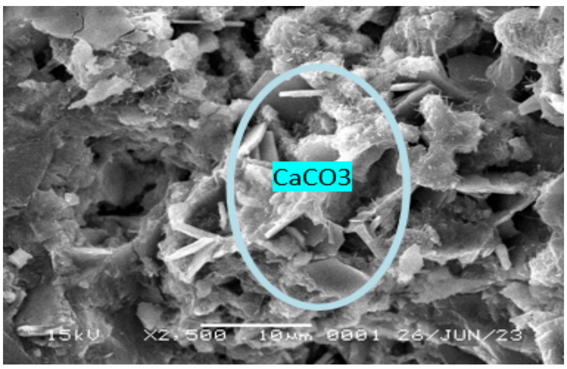


Figure 10. X-ray diffraction pattern on concrete with a concentration of 10^9 cells/ml

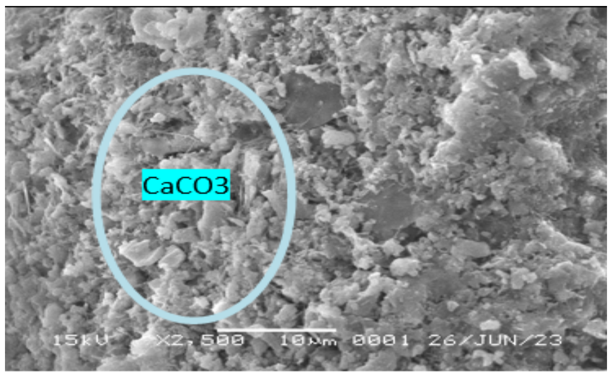
Based on Figure 10, the diffraction pattern consists of several peaks. The peak intensity is plotted on the y-axis and the measured diffraction angle is plotted on the x-axis. Each peak or reflection in the diffraction pattern occurs due to x rays being diffracted from planes in the specimen or material being tested using XRD.

SEM characterization

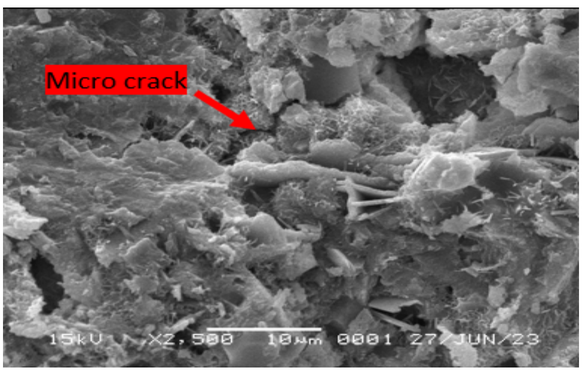
Characterization using SEM was carried out to determine the particle size and surface morphology of hydrophobic concrete samples. All concrete samples were prepared before SEM measurements to meet size requirements as well as to reduce vacuuming duration. The concrete samples used had varying concentrations of E. coli bacteria of 103, 106, and 109 cells/ml. The concrete used has gone through an oven process at a temperature of 60 0C. The results of concrete testing with SEM on day 14 are in Figure 11.



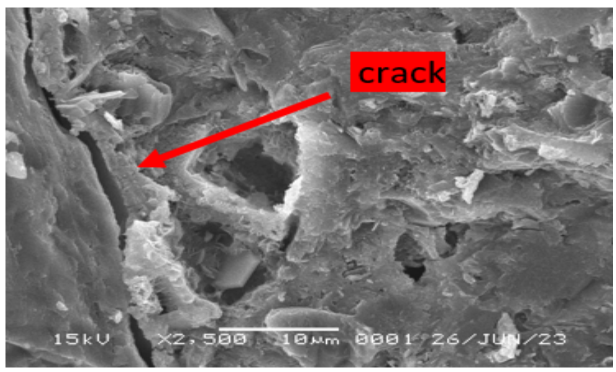
Day 14 Concentration 10^3



Day 14 Concentration 10^6



Day 14 Concentration 10^9



Day 14 SNI concrete (without bacteria)

Figure 11. SEM results on self-healing concrete

Based on Figure 11, the SNI concrete sample has many crack cavities compared to the concrete sample that has been given a mixture of bacteria. In addition, the bacterial concrete samples with concentrations of 10^3, 10^6, and 10^9 cells/ml were denser in microstructure compared to the SNI concrete samples, which means that it increased the strength of the concrete. From SEM analysis, calcium carbonate ($CaCO_3$) as calcite crystals can be clearly distinguished in the pores of bacterial concrete deposited by bacterial cells and is not present in SNI concrete samples.

FTIR Characterization

FTIR spectroscopy results are based on the functional group characteristics of the concrete sample. Measurements were carried out in the wave number range of 4000 cm^{-1} - 500 cm^{-1}. The results of characterization using FTIR with a concentration of 10^3 cells/ml can be seen in Figure 12.

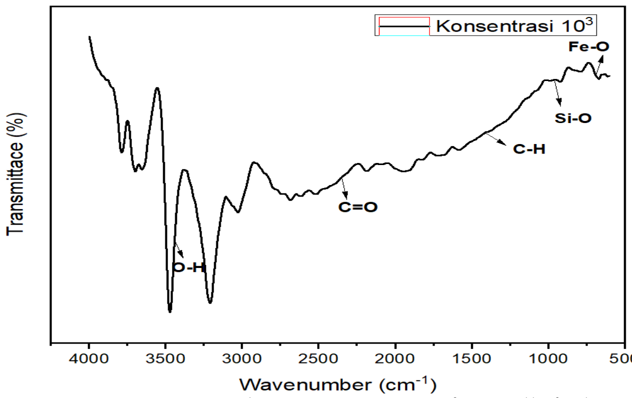


Figure 12. FTIR with a concentration of 10^3 cells/ml

Based on Figure 12, the reading transmission technique of the sample is subjected to direct light, this causes all the functional groups contained in the sample to experience vibrations. So that it gives rise to a peak).

The second concrete sample had a concentration of E. coli bacteria with a concentration of 10^6 cells/ml. Measurements were carried out in the wave number range of 4000 cm^{-1} – 500 cm^{-1}. The results of characterization using FTIR with a concentration of 10^6 cells/ml can be seen in Figure 13.

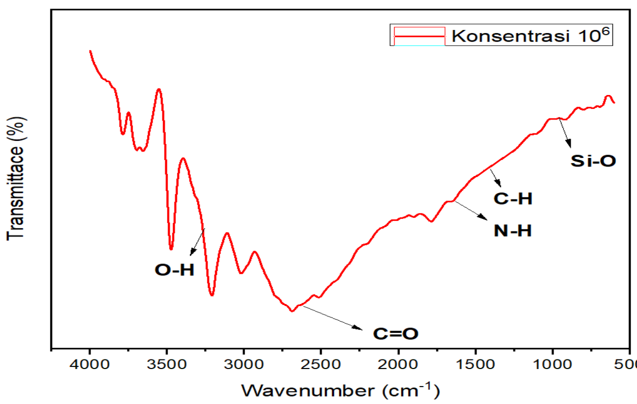


Figure 13. FTIR with a concentration of 10^6 cells/ml

Based on Figure 13, the reading transmission technique of the sample is subjected to direct light, this causes all the function groups contained in the sample to experience vibrations. So that it gives rise to a peak).

The third concrete sample had a concentration of E. coli bacteria with a concentration of 10^9 cells/ml. Measurements were carried out in the wave number range of 4000 cm^{-1} - 500 cm^{-1}. The results of characterization using FTIR with a concentration of 10^9 cells/ml can be seen in Figure 14.

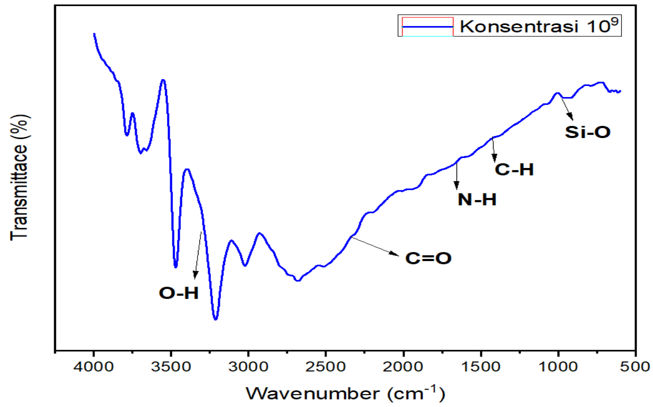


Figure 14. FTIR with a concentration of 10^9 cells/ml

Based on Figure 14, the reading transmission technique of the sample is subjected to direct light, this causes all the function groups contained in the sample to experience vibrations. So that it gives rise to a peak.

The fourth concrete sample is an SNI concrete sample that does not have E. coli bacteria added. Measurements were carried out in the wave number range of 4000 cm^{-1} - 500 cm^{-1}. The results of characterization using FTIR of SNI concrete samples can be seen in Figure 15.

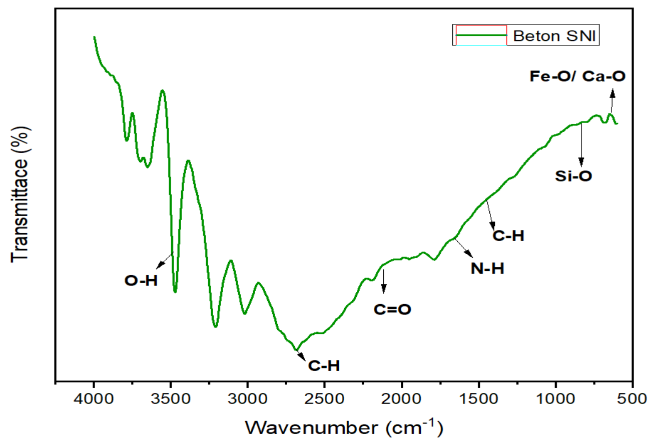


Figure 15. FTIR of SNI concrete samples

Based on Figure 15, the reading transmission technique of the sample is subjected to direct light, this causes all the function groups contained in the sample to experience vibrations. So that it gives rise to a peak).

Data Analysis of Compressive Strength Test Characteristics

The results of the compressive strength test data obtained can be expressed in graphical form. A graph of the relationship between compressive strength and the concentration of E. coli bacteria on day 14 can be seen in Figure 16.

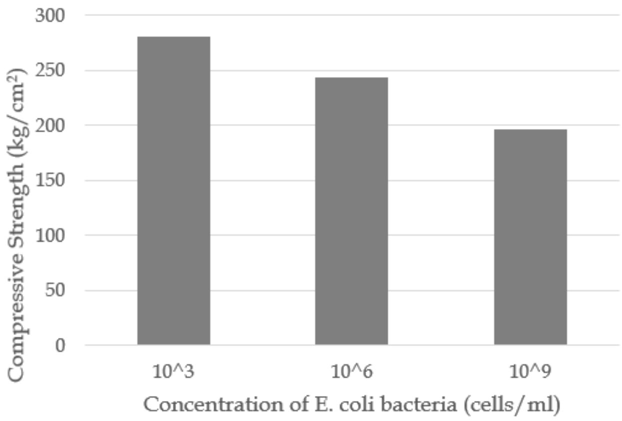


Figure 16. Graph of the relationship between compressive strength and E. coli concentration

Based on Figure 16, it can be explained that the second test was carried out on the 14th day after the concrete was finished. There were three variations in the concentration of E. coli bacteria used, namely 10^3, 10^6, 10^9 cells/ml. In the first variation, with a concentration of E. coli bacteria of 10^3 cells/ml, it has a compressive strength value of 279.7 kg/cm^2. The second variation, namely with a concentration of E. coli bacteria of 10^6 cells/ml, has a compressive strength value of 243.3 kg/cm^2. Meanwhile, the third variation, namely with a concentration of E. coli bacteria of 10^9 cells/ml, has a compressive strength value of 195.5 kg/cm^2.

From the graph results of the effect of the concentration of E. coli bacteria on the compressive strength of concrete, it can be concluded that the greater the concentration of bacteria given to the processed concrete paste mixture, the higher the compressive strength value of the resulting concrete. In other words, a concentrated mixture of bacterial solutions can strengthen the strength of concrete.

Data Analysis of Contact Angle Characterization

Contact angle measurements are carried out directly, then the imaging is captured by a DSLR camera. The captured image results will be processed using the Image J application software. Contact angle testing on concrete samples is carried out on day 14. This contact angle measurement aims to determine whether the concrete is hydrophobic from the addition of the concentration of E. coli bacteria to the processed cement. A graph of the relationship between contact angle and the concentration of E. coli bacteria on day 14 can be seen in Figure 17.

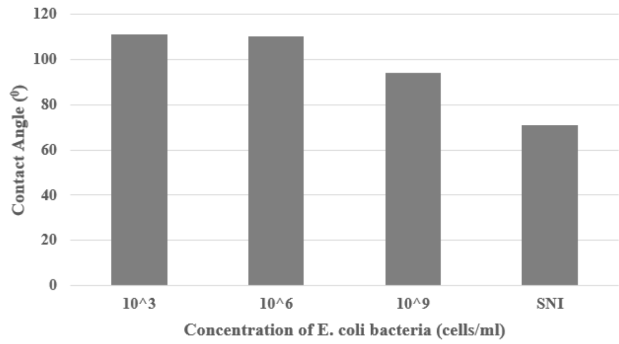


Figure 17. Graph of the relationship between contact angle and E. coli concentration

Based on Figure 17, contact angle measurements carried out on the first concrete sample with a concentration of E. coli bacteria of 10^3 cells/ml had contact angle data of 111.04^0. Contact angle measurements carried out on the second concrete sample with an E. coli bacteria concentration of 10^6 cells/ml had contact angle data of 110.18^0. Contact angle measurements carried out on the third concrete sample with an E. coli bacteria concentration of 10^9 cells/ml had contact angle data of 94.11^0. Meanwhile, contact angle measurements carried out on reference concrete or SNI concrete which did not add bacterial concentration to the processed cement paste mixture had contact angle data of 70.64^0.

Conclusion

The conclusion of the research is that variations in the concentration of E. coli bacteria given to concrete samples have an influence on the compressive strength of the concrete. Varying bacterial concentrations further strengthen and strengthen the concrete. Of the three variations in E. coli bacterial concentration, 10^3 cells/ml, 10^6 cells/ml and 10^9 cells/ml were observed to have the highest compressive strength at a concentration of 10^3 cells/ml with a compressive strength of 279.7 kg/cm^2. Variations in the concentration of E. coli bacteria given to concrete samples also have an influence on the contact angle. Where testing the contact angle on concrete with variations in the concentration of E. coli bacteria shows that the contact angle obtained can represent that the concrete sample is hydrophobic. The bacterial concentrations used were 10^3 cells/ml, 10^6 cells/ml and 10^9 cells/ml.

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Author Contributions
The idea of conceptualizing YO and RR. Developing research design by YO and RR. Writing of original draft preparation by YO and approved by RR. Compiling articles by YO. RR validation methodology. Investigation by YO. Analyzing data by YO. Resources by YO and RR. Review and editing by YO and RR. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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