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The Usage of Crystalline Additive on Concrete Performance

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Abstract Indonesia as a maritime country has a number of structures in coastal areas that are made from concrete. Sulfate attack is one of the common deteriorations that could occur due to the exposure of saltwater to the concrete. Unfortunately, the Type II and Type V cements, which are the special cements that are resistant to sulfate, are rarely used due to their high prices. The objectives of this research are to compare the performance of concrete mixture that was prepared by using the standard cement mixed with crystalline material and the concrete mixture that was prepared by using two different brands of Type V cement. There were five concrete mixture variations tested for their compressive strength and permeability. To assess the permeability of the concrete, the specimens were placed under pressured water for 72 hours and the water penetration depth was measured. From the research results, it was found that the usage of crystalline additive (CA) made the compressive strength increased at a faster rate and the concrete mixture that contained Type I cement and 0.7% of crystalline material had the highest compressive strength value. In terms of the permeability of the concrete, it can be seen that the specimens that were mixed with CA were more effective in stopping the water to penetrate the specimens than the specimens prepared with either of Type V cement.

Keywords Concrete, Crystalline Additive, Sulfate Attack, Permeability

1. Introduction

Sulfate attack is one of the deteriorations that could occur in concrete structure that is in contact with water that contains sulfate, such as seawater, groundwater, and swamp water [1]. Sulfate attack could occur due to the reaction between sulfate ions with calcium hydroxide and calcium aluminate hydrate to form gypsum and ettringite [2]. It was further explained that the formation of ettringite could lead to an increase in concrete expansion, and hence, cracking in concrete could be developed, while the formation of gypsum could lead to softening and loss of mass and strength of the concrete. The sulfate attack was more affected by the cement paste, rather than the aggregates, although when the aggregates used contained sulfate minerals, an internal sulfate attack could occur [3].

This issue is critical to Indonesia as a maritime country, where there is a significant number of coastal and offshore infrastructure projects, such as jetty. Most jetties that have been built in Indonesian coastal areas are made from concrete and the concrete mixture is not usually made of Type II Cement or Type V Cement, which are the types of cement that are specially designed to have medium and high resistance to sulfate, respectively [4]. This is due to the fact that Type II Cement is harder to obtain and more expensive than the Type I Cement or the normal Portland cement.

This research project compared the performance of concrete mixtures that were prepared by using Type I cement, with crystalline additive (CA) added, with the ones that were prepared by using Type V cement. There were five concrete mixtures tested for its compressive strength and its permeability.

2. Experimental Design

2.1. Materials

2.1.1. Cement

There were two different types of Portland cement used in this research study, namely Type I and Type V. The Type I cement was sourced from a local supplier (Supplier A) and the Type V cement was sourced from two different local suppliers (Supplier A and Supplier B). All cements used were commercially available and were conformed to ASTM 150.

2.1.2. Aggregates

The fine and coarse aggregates used to be mixed with Type I cement had SSD specific gravity values of 2.6 and 2.58, respectively. Different fine and coarse aggregates were used for the concrete mixture using Type V cement. The SSD specific gravity values were slightly higher than the ones used for concrete mixture using Type I cement, which were 2.66 for the fine aggregates and 2.72 for the coarse aggregates.

2.1.3. Fly Ash

Class F fly ash was added onto the mixture with Type I cement, which was conformed to ASTM C618 and the SSD specific gravity was 2.2. Fly Ash was added to the concrete mixture due to some of its benefits, including improving workability, increasing ultimate strength, and reduced permeability [5].

2.1.4. Admixture

In this research, the CA used was named Xypex Admix C-1000 NF, which is an additive that can help cracks in concrete structure to heal by itself (self-healing concrete). It is available in three types, depending on its setting time. This admixture is a type of crystalline admixture that consists of Portland Cement, silica sand (reactive silica), and other reactive components that could help, not only increasing the compressive strength of concrete structure, but also reducing the permeability of concrete structure, and hence, making the concrete to be more resistant to water. The reactive components, which are kept confidential by the producer [6], react with $Ca(OH)_2$ to produce a non-soluble crystalline that could fill the void in the concrete and permanently seals the concrete and prevent water or other liquids to penetrate the concrete mixture in any direction [7]. This reaction, however, can only happen with the presence of moisture in concrete. A number of research projects have confirmed that this admixture is efficient in improving the waterproofing ability of the concrete [6, 8].

In this study, Xypex Admix C-1000 NF was used, which is formulated for normal and mildly delayed set [9]. The recommended dosage is between 0.8% and 1.2% by weight of cementitious material, but for this study, the Xypex Admix C-1000 NF was added at 0.5% and 0.7% of the cement weight.

2.2. Research Matrix

There were five different concrete mixtures tested in this study, which can be seen in Table 1. The weight for each component was calculated to create $1m^3$ of concrete mixture and it was designed to reach 35 MPa.

For the concrete mixtures Mix 1, Mix 2, and Mix 3, the same amount of Type I Cement, fly ash, coarse aggregate, fine aggregate, and water was used. Mix 1 was the control sample. For the concrete mixtures Mix 2 and Mix 3, Xypex Admix C-1000 NF was added into the concrete mixture with a dosage of 0.5% and 0.7% of the cement weight, respectively. It is important to note that the admixture was added at a dosage lower than the recommended dosage, which is between 1% and 1.5% of the cement weight.

Table 1. Concrete Mixture Composition

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
Type I Cement A (kg)	356	356	356		
Type V Cement A (kg)				401	
Type V Cement B (kg)					526.29
Fly Ash (kg)	63	63	63		
Coarse Aggregate (kg)	688	688	688	679	931.55
Fine Aggregate (kg)	971	971	971	1022	762.17
Water (L)	231	231	231		

The compositions for the concrete mixture using Type I Cement and Type V Cement were different. It can be seen that, when using Type V Cement, more cement was required in the concrete mixture and no fly ash was added. Mix 4 and Mix 5 used different brands of Type V Cement and the amount of cement required was different. There were more of fine aggregates compared to the coarse aggregates in Mix 4, while on Mix 5, the opposite was observed. Additionally, both Mix 4 and Mix 5 required slightly less water compared to the concrete mixtures that used Type I Cement.

The concrete mixture was prepared in a concrete batching plant according to concrete mix designs that had been made according to the research matrix (Table 1). Slump tests were performed for each mixture and the target slump value was 12 ± 2 cm. The concrete mixture was then placed onto cylindrical molds, which would produce specimens with diameter of 15 cm and height of 30 cm.

2.3. Laboratory Test

There were two laboratory tests conducted to analyze the prepared specimens, namely the compressive strength and the permeability tests. The compressive strength tests were conducted twice for each type of sample variation according to ASTM C-39 [10] and the concrete specimens were tested when they were 7, 14, and 28 days old.

The permeability of the concrete was analyzed by finding the depth of penetration of water under pressure, which was conducted according to BS EN 12390-8:2019 [11]. This test was done three times for each type of mixture. The concrete specimens were, firstly, measured and weighed and then, the specimens were placed under pressured water for 72 hours, as seen in Figure 1. After the specimens had been removed from the device, the specimen was cut in half (perpendicular to the direction of water being applied). The part of the concrete where the water penetrated was marked, as seen in Figure 2 and the depth of water penetration was measured by using a caliper (Figure 3) and recorded. In this research study, the ratio of the depth of water penetrated onto the concrete specimen to the specimen height was calculated and the result was presented as the percentage of water penetration (% Penetration).

Figure 1. Concrete specimens were placed on the apparatus

Figure 2. The water penetration front of the tested specimens

Figure 3. Measurement of water penetration depth by using a caliper

3. Results and Discussion

3.1. Compressive Strength Test Results

Figure 4 shows the average values of compressive strength test results for all sample variations when they were 7, 14, and 28 days old. The y-axis shows the compressive strength values in MPa and the x-axis shows the age of the specimens. It can be seen that the compressive strength values for all sample variations at 28 days old were higher than 35 MPa, which means the designed concrete strength was achieved.

Comparing the samples that were constructed by using Type I Cement, it can be seen that the compressive strength values of the samples added with CA were higher than the samples that were not added with the CA (Mix 1), regardless of the age of the samples. The addition of 0.5% and 0.7% of the CA was able to increase the compressive strength values by 5.7% and 10.7% higher than the control sample when they were all at 28 days old.

The compressive strength values for samples that were constructed by using Type V Cement were compared and it can be seen that the samples that were prepared by using Type V Cement from supplier B (Mix 5) had a higher compressive strength value, which was 38.2 MPa, than the other one (Mix 4), which was 35.5 MPa. Interestingly, the compressive strength values of Mix 1 and Mix 4 were similar at 7, 14, and 28 days old, which means that both had a similar increasing rate. In this case, it can be said that the usage of Type V Cement from supplier A did not have much added value compared to the usage of Type I Cement from the same supplier and the Type V cement from supplier B performed better than the Type V cement from supplier A.

The increasing rate of compressive strength values for Mix 3 was relatively stable from 7 days old to 28 days old, while the compressive strength values for other samples increased at a faster rate from 7 days to 14 days and increased at a slower rate from 14 days to 28 days. Therefore, at 28 days, Mix 3 had the highest compressive strength value compared to the others. It can also be seen that the compressive strength values for Mix 2 increased from 7 days old to 14 days old with the fastest rate compared to the others and the compressive strength values of Mix 2 increased at a similar rate with Mix 3 from 14 days to 28 days.

To sum up, it can be stated that adding CA at 0.5% and 0.7% could improve the increasing rate of the compressive strength. Amongst the five concrete mix variations, at 28 days, Mix 3 had the highest compressive strength, Mix 5 came second, and Mix 2 came third. It seems that adding CA at 0.7% made the concrete specimens perform better than the concrete mixture constructed by using Type V cement (from supplier B).

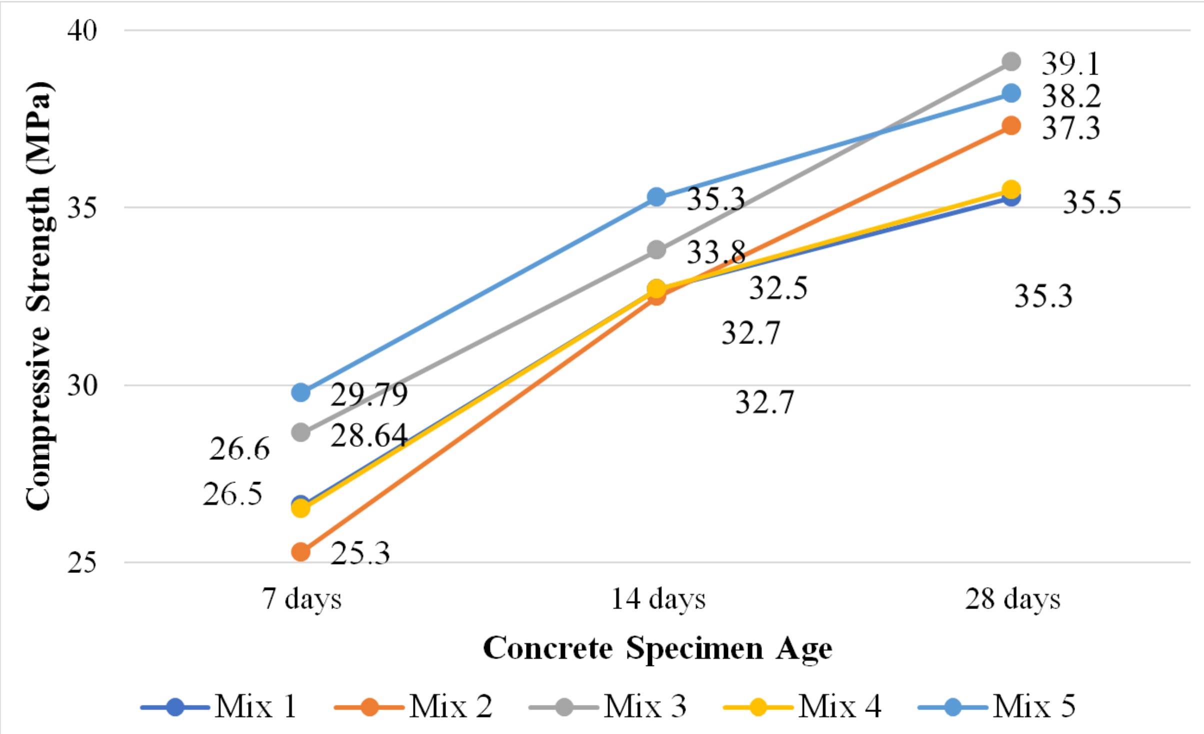

Figure 4. Compressive strength test results for 7-, 14-, and 28-day-old samples

3.2. Permeability Test Results

Figure 5 shows the percentage of water penetrated onto the concrete specimens. The higher the value was, the deeper the water had penetrated the concrete specimens, which means the more permeable the specimen was. It can be seen that Mix 1 or the control sample had the highest percentage of penetration (96.2%) compared to the other samples, which means that the water had penetrated almost all of the specimen. However, it can be seen that adding CA at 0.5% (Mix 2) and 0.7% (Mix 3) onto the samples was able to lower the percentage of water penetrated onto the samples by around 16%. The percentage of penetration of Mix 3 was slightly lower than the percentage of penetration of Mix 2, as Mix 3 had more of the admixtures. This result shows that the usage of the crystalline additive was effective in preventing water to penetrate onto the concrete specimen even further.

Moreover, when comparing the percentage of penetration of the samples constructed by using Type V Cement to the control sample, it can be seen that the usage of Type V cement was able to lower the percentage of water penetrated onto the samples. Based on the results, it can be seen that the usage of Type V cement from supplier A was slightly better than the Type V cement from supplier B in terms of reducing the permeability of the specimens.

Looking at the % Penetration values of Mix 2 and Mix 3 with Mix 4 and Mix 5, it can be seen that adding the crystalline additive was more effective than using the Type V cement in order to reducing the permeability of the concrete specimens. This could be caused by the fact that CA reacted with water and created non-soluble crystalline that would fill the void in concrete. This would stop the water to penetrate through the concrete specimens even further.

4. Conclusions

This research aims to compare and evaluate the performance of concrete mixtures constructed by using Type I cement, by adding CA, and by using Type V cement from two different suppliers. Both compressive strength and permeability tests were conducted to evaluate the performance of the prepared specimens. From the research results, it can be concluded that the usage of CA was able to increase the compressive strength at a faster rate. Mix 3 had the highest compressive strength value compared to the others. In terms of the permeability of the concrete specimens, it can be stated that Mix 3 had the lowest %. Penetration, and hence, the usage of CA was more effective in stopping the water to penetrate through the specimen compared to the specimens that were prepared by using Type V cement. It was also found that different suppliers produced Type V cement at different quality. The specimens that were prepared by using Type V cement from supplier A had higher compressive strength values compared to the ones prepared by using Type V cement from supplier B. However, the ones prepared by Type V cement from supplier B were more resistance to water penetration.

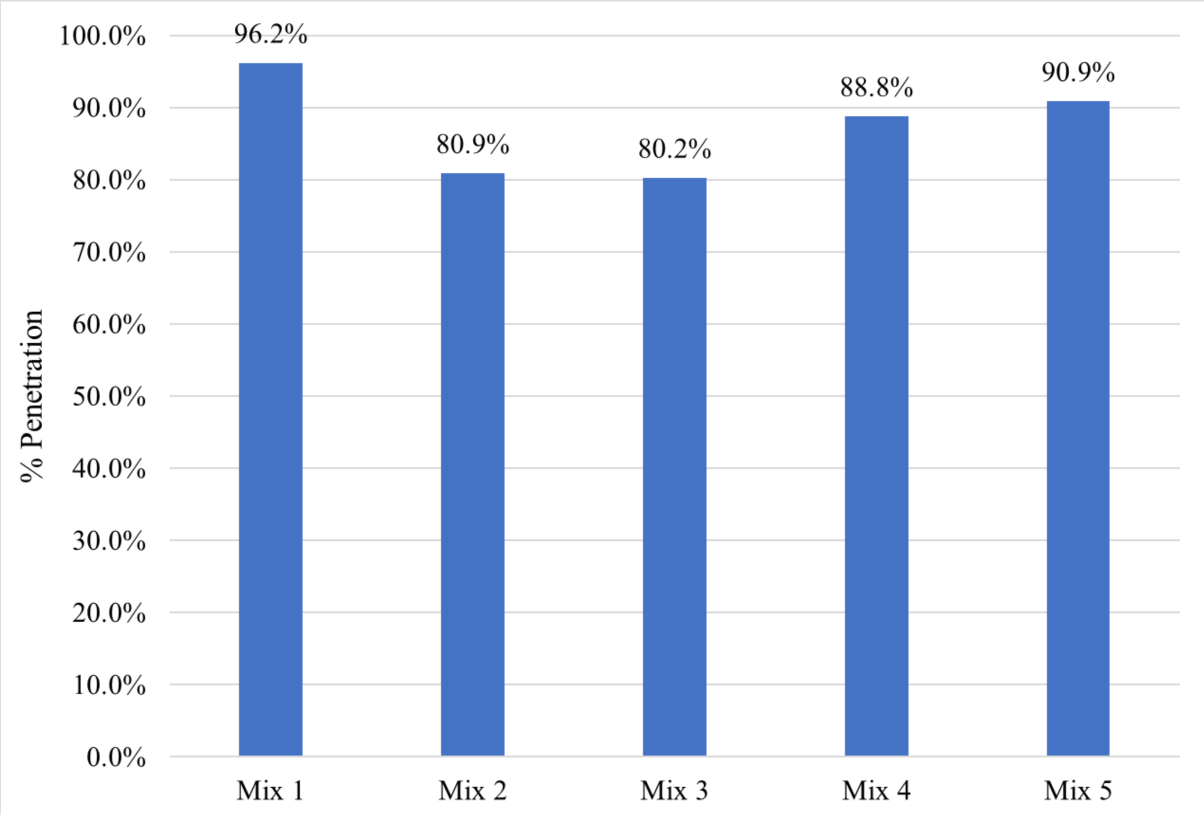

Figure 5. Percentage of water penetration for all mixtures

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