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Analysis of concrete permeability with additional waterproofing admixture

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Abstract. Cracking in concrete structures is one of the most commonly structural defects that could occur. This research aims to analyse the performance of an admixture to make concrete mix to be waterproofed. In this research, a Xypex C-1000 was used. It was claimed to have the ability to improve the compressive strength of concrete structures and to reduce the permeability of concrete structures. From this research, it was found that there was a reduction in compressive strength for the concrete samples at 28 days compared to the compressive strength of the concrete aged 7 days. The reduction was significant for the concrete samples with Xypex C-1000. However, for the concrete samples aged 7 days with Xypex C-1000, it was found that there was a reduction in permeability of concrete structures, but only at certain dosage. For the concrete samples aged 28 days, the permeability of the samples were all below the allowable limit. In conclusion, based on these preliminary results, it can be seen that the Xypex C-1000 is effective in reducing the permeability of the concrete structures, but it is important further study the effect that the Xypex C-1000 has on the compressive strength of concrete structures.

Keywords: concrete, permeability, additive, waterproofing, compressive strength

1. Introduction

There are a number of structural defects that could occur in concrete structures, such as blisters cracking, curling, delamination, discoloration, and dusting [1]. This research focuses on only one of them, which cracking. Cracking in concrete structure can be caused by a number of factors, such as shrinkage, thermal contraction, and/or applied loads [1], [2].

Concrete is mixture of cement, aggregates, and water. However, it is often found that additional material is required to help improving the concrete performance. There are many research projects that have assessed the effects of certain materials or additive to increase the concrete compressive strength, such as fly ash, expanded polystyrene, polycarboxylate based superplasticizer and other materials [3], [4].

Moreover, additives are usually added to improve another performance of concrete, which is the impermeability of concrete as if there is an excess amount of water in the mixture, it could lead to crack development due to hydration process. Cracking in concrete structure could lead to further damage in the structure due to the possibility of water intrusion into the concrete, which could cause the reinforcement bars to corrode, and it will eventually lead to strength reduction of the structure [5]. To



solve this issue, there are a number of admixtures that have been studied and commercialized that has the ability to make concrete structure to be waterproofed, such as Conplast and Nitoproof AW [6]. This research aims to analyze the performance of a crystalline admixture, Xypex C-1000, to make concrete mix to be waterproofed. There were two tests that were conducted in this research, namely the compressive strength test and the permeability test.

While concrete has been widely used as the main construction material, there are a number of requirements that have to be designed and observed when using concrete structures, such as strength, abrasion, and absorptivity [7]. In this research, there are two main parameters that were considered in the concrete structures, namely the compressive strength and the permeability, as they are highly related to the water intrusion into concrete structure.

2. Experimental design

2.1. Materials

In this research, there are four main materials that were mixed to make the concrete samples, including aggregates, cement, water, and Xypex C-1000. The concrete mix was designed to reach 25 MPa.

2.1.1. Cement

There are different types of cement can be used in concrete mix. In this research, Portland cement type I is the general purpose Portland cement that is suitable for all uses [8]. It was chosen to be used as this research project does not require any specific type of cement.

2.1.2. Water

The water used in the concrete mix had a pH of 7, which is suitable to be used for concrete mixture.

2.1.3. Aggregates

Both fine and coarse aggregates used in this research were chosen based on the most commonly used and available aggregates to be used in the concrete mixture. The fine and coarse aggregates are shown in Figure 1 and Figure 2, respectively.



Figure 1. Fine Aggregates



Figure 2. Coarse Aggregates

To assess the suitability of both fine and coarse aggregates to be used in the concrete mix, they have to satisfy the requirements stated by Standar Nasional Indonesia (SNI) 03-2834-2000 [9] and the test results for both fine and coarse aggregates are presented in Table 1 and Table 2.

It can be seen from the results for fine aggregates in Table 1 that, in general, the materials satisfy the requirements as stated in the standard. However, the water content and the absorption level did not meet the requirement, and hence, the fine aggregates were left longer in the bag to dry out. Similarly, the

coarse aggregates, as seen in Table 2, also satisfy the requirement stated in the standard, although there are two parameters that do not meet the standard, which are the clay and fine silt content and the absorption level. Therefore, the coarse aggregates were washed and left to dry before they were being used in the concrete mixture.

Table 1. Fine aggregate test results

Tests	Value	Limit
Loose unit weight	1.075 kg/dm ³	
Dense unit weight	1.660 kg/dm ³	
Water content	5.22 %	<5 %
Dry weight	2.547 gr	
Organic content	No. 2	No. 2
Saturated-dry weight	2.671 gr	
Absorption	4.87%	<2 %

Table 2. Coarse aggregate test results

Tests	Value	Limit
Unit weight	1.075 kg/dm ³	
Water content	2.76 %	<5 %
Clay and fine silt	2.94 %	1 %
Dry weight	2.306 gr	
Saturated-dry weight	2.398 gr	
Absorption	4.01 %	<2 %

2.1.4. Additive

Xypex is a self-healing crack additive and is available in three types, depending on the setting time [10], [11]. This additive is a type of crystalline admixture that contains Portland Cement, silica sand (reactive silica), and other chemical additives (reactive components) that could help increasing the compressive strength and reducing the permeability of concrete structure [11], [12]. The other chemical additives for this admixture are kept confidential by the producer [13]. These chemical additives will react with $\text{Ca}(\text{OH})_2$ to produce a non-soluble crystalline formation throughout the pores and capillary tracts of the concrete that permanently seals the concrete and prevents the penetration of water and other liquids from any direction [11], [12]. This reaction can only occur with presence of moisture in concrete. For this purpose, the Xypex C-1000 used was the one that is formulated for normal and mildly delayed set.

The product must be used within its shelf life for optimum technical performance. The recommended dosage is typically between 1% and 1.5% by weight of cement, but under certain conditions, the dosage rate can be reduced to 0.8% depending on the quantity and type of total cementitious materials. There are also other research projects that have attempted to investigate the effect varying the dosage (between 0.8% and 1.2%) on the concrete permeability. In this research, the Xypex C-1000 was used at the dosage of 0.2%, 0.4%, 0.6%, 0.8%, 1%, and 1.2%. The performance of the concrete samples with Xypex C-1000 at varying dosage was compared to the control samples or the concrete samples without Xypex C-1000. A number of research projects that have shown that Xypex products have the ability to improve both permeability and strength of concrete with various percentage of dosage rate and different materials by filling up the cracks [10], [12], [14], [15].

2.2. Sample Making

The concrete samples were prepared according to SNI 03-2834-2000 [9]. All materials were mixed by using a concrete mixer and the concrete mix was poured into cylindrical moulds, which will yield concrete samples with diameter of 15 cm and height of 30 cm. The concrete mix were left to dry for 24

hours in the moulds before being taken out for curing. There were 28 samples prepared with the details as listed in Table 3. It is important to note that there was only one set of the concrete samples aged 28 days that were being immersed for 24 hours due to the limitation of materials.

Table 3. Number of concrete samples prepared

Xypex (%)	Compressive Strength Test		Permeability Test			
	7 days	28 days	7 days		28 days	
			10 minutes	24 hours	10 minutes	24 hours
0	3	3	3	3	3	1
0.2	3	3	3	3	3	1
0.4	3	3	3	3	3	1
0.6	3	3	3	3	3	1
0.8	3	3	3	3	3	1
1.0	3	3	3	3	3	1
1.2	3	3	3	3	3	1

2.3. Compressive strength test

To determine the compressive strength of each concrete sample, the compressive strength test of the concrete was conducted according to SNI 03-1974-1990 [16]. This test was conducted three times for all concrete samples, when the concrete samples aged 7 days and aged 28 days. For each test, there were three samples used. The device used is shown in Figure 3. The average compressive strength test results for the concrete samples aged 7 days, which is denoted as F_7 , and for the concrete samples aged 28 days, which is denoted as F_{28} .



Figure 3. Compressive strength test device

2.4. Permeability test

The permeability test for these samples was conducted according to SNI 03-2914-1992 [17]. In this test, the samples were fully immersed in the water for 10 minutes and 24 hours, and then being dried in the oven for 24 hours after each immersion. There three samples for each concrete variation for 10 minutes immersion and for 24 immersion. The average permeability of the samples was calculated by measuring the percentage difference in the weight of the wet samples (after being immersed in water for 10 minutes) and the dry samples (after being dried in the oven for 24 hours), which is denoted as P_{10} , and the percentage difference in the weight of the wet samples (after being immersed in water for 24 hours minutes) and the dry samples (after being dried in the oven for 24 hours), which is denoted as P_{24} . The allowable absorption limits as stated in [17] are 2.5% and 6.5% for the concrete samples that are being

immersed in water for 10 minutes and 24 hours, respectively. It is important to note that there was only one set of the concrete samples aged 28 days that were being immersed for 24 hours due to the limitation of materials.

3. Results and Discussion

3.1. Compressive strength test results

The test results of the compressive strength tests for the concrete samples aged 7 days and aged 28 days that were conducted according to the method as explained in Section 2.2 are shown in Figure 4. The x-axis shows the variation of dosage of Xypex C-1000 added to the samples and the control sample (0% Xypex C-1000) and the y-axis shows the compressive strength test results in MPa. The blue set of data shows the data for concrete samples aged 7 days and the orange set of data shows the data for concrete samples aged 28 days.

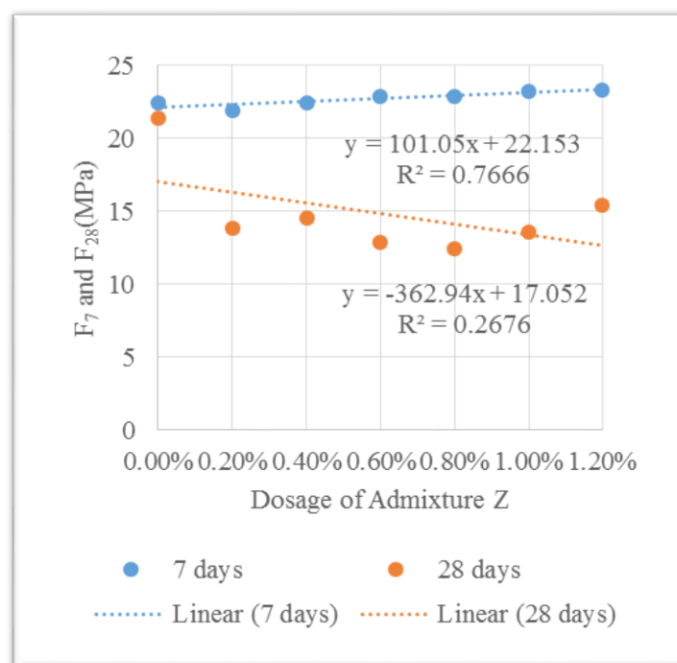


Figure 4. The compressive strength test results

The concrete mix was designed to reach a compressive strength of 25 MPa. However, from Figure 4, it can be seen that there was none of the concrete samples reached 25 MPa. The maximum average compressive strength was 22.49 MPa, which was achieved by the control sample aged 7 days. Usually, the compressive strength of concrete will increase after the concrete being cured for 28 days. However, it was found that the average compressive strength for the control sample aged 28 days was approximately 21.4 MPa, which was lower than the control sample aged 7 days.

It can be observed in Figure 4 that, in general, the average compressive strength of concrete samples mixed with Xypex C-1000 at varying dosage aged 7 days were higher than the concrete samples mixed with Xypex C-1000 at varying dosage days for the concrete samples aged 28 days. It can also be seen that, for concrete samples mixed with Xypex C-1000 aged 7 days, there was an increase in compressive strength in concrete samples as the dosage of Xypex C-1000 added to the concrete samples increases and the relationship between them can be well explained by linear equation. However, this trend cannot be found for the concrete samples mixed with Xypex C-1000 aged 28 days.

The significant reduction of compressive strength of concrete aged 28 days is against the established theory. There are a number of factors that could contribute to this issue, including the quality of the

aggregates used, the concrete making process, and the characteristic of the Xypex C-1000 itself. For the control samples, the reduction of compressive strength could be due to the quality of the aggregates used. As explained in Section 2.1, both fine and coarse aggregates used in this research exceeded certain requirements allowed by the standard. Even though the aggregates have been treated further, including drying and washing, as an attempt to reduce the potential effects that might arise due to the usage of those aggregates, but there was not any further testing to confirm that the treated aggregates satisfy the requirements. Therefore, it is possible that the prepared samples still have a high water absorption level. This could bring a significant effect on the results, especially for the control sample aged 28 days, because the control samples were fully immersed in water for 28 days before they were being tested. If the aggregates could absorb water during the immersion process, the compressive strength of the concrete samples at 28 days could decrease.

Moreover, in the concrete mixing process, the fresh concrete for the control samples were mixed by a mortar mixer. However, the next processes, including dividing the concrete mix into the moulds and compacting the concrete mix, were done manually. This could affect the homogeneity of the prepared concrete samples.

Regarding to the compressive strength of concrete samples with added Xypex C-1000 could be affected because of the nature of Xypex C-1000. As explained before, the Xypex C-1000 is available in powder form. However, mixing the Xypex C-1000 well with the other materials was not an easy procedure. The Xypex C-1000 could not be immediately mixed to the materials in the mortar mixer because the Xypex C-1000 would coagulate or harden when it met the water, and hence the Xypex C-1000 will settle at the bottom of the mortar mixer and cannot mix well with the other materials. Therefore, the mixing process needed to be done manually. This could cause problem in homogeneity of the concrete samples. However, it is important to note that, in several unpublished research projects, it was also found that the addition of Xypex C-1000 reduced the compressive strength of the concrete.

3.2. Permeability test results

The permeability test results for both concrete samples aged 7 days and 28 days are shown in Figure 5 and Figure 6, respectively. The tests were conducted according to the methodology explained in Section 2.3. The x-axis shows the variation of dosage of Xypex C-1000 added to the samples and the control sample (0% Xypex C-1000) and the y-axis shows the average percentage of water being absorbed, shown as P_{10} and P_{24} . The orange set of data shows the data for concrete samples aged 7 days and the blue set of data shows the data for concrete samples aged 28 days. In Figure 5, it can be seen that, for concrete samples aged 7 days that were immersed for 10 minutes and 24 hours, as the dosage of Xypex C-1000 increases, the P_{10} decreases, which shows that the Xypex C-1000 was effective to reduce the permeability of the concrete samples.

According to [17], the maximum water absorption for concrete samples that have been immersed in the water for 10 minutes and have been dried in the oven for 24 hours is 2.5%, while the maximum water absorption for concrete samples that have been immersed in the water for 24 hours and have been dried in the oven for 24 hours is 6.5%. For the control samples, the P_{10} and P_{24} are 3.85% and 7.12%, which exceeded the allowable limit stated in the standard. However, with the addition of Xypex C-1000, it can be seen that the P_{10} and P_{24} decrease. For the concrete samples with Xypex C-1000 at dosage of 0.2%, 0.4%, 0.6%, and 0.8% that were immersed in the water for 10 minutes, the P_{10} values were still above the allowable limit and the P_{10} values did not vary much, except for the value with 0.8% Xypex C-1000 (there was a reduction of approximately 25%). However, when Xypex C-1000 was added at dosage of 1% and 1.2%, the P_{10} values were similar and were below the allowable limit. The relationship between the P_{10} values and the dosage of Xypex C-1000 can be well explained by a linear equation with a coefficient of determination of 0.87.

Moreover, for the concrete samples with Xypex C-1000 at dosage of 0.2%, 0.4%, 0.6%, and 0.8% that were immersed in the water for 24 hours, the P_{24} values decrease in stages and the relationship between the P_{10} values and the dosage of Xypex C-1000 can be explained by a linear equation with an even better coefficient of determination of 0.96. The P_{24} values for the concrete samples with Xypex C-1000 were

below the allowable limit, except for 0.2% Xypex C-1000, which was just above the limit with P_{24} value at 6.51%.

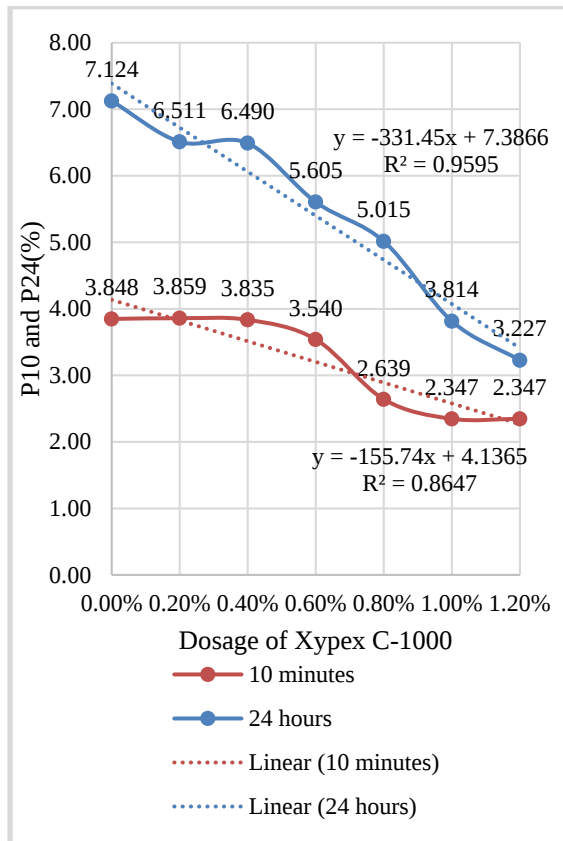


Figure 5. The permeability test results for concrete samples aged 7 days

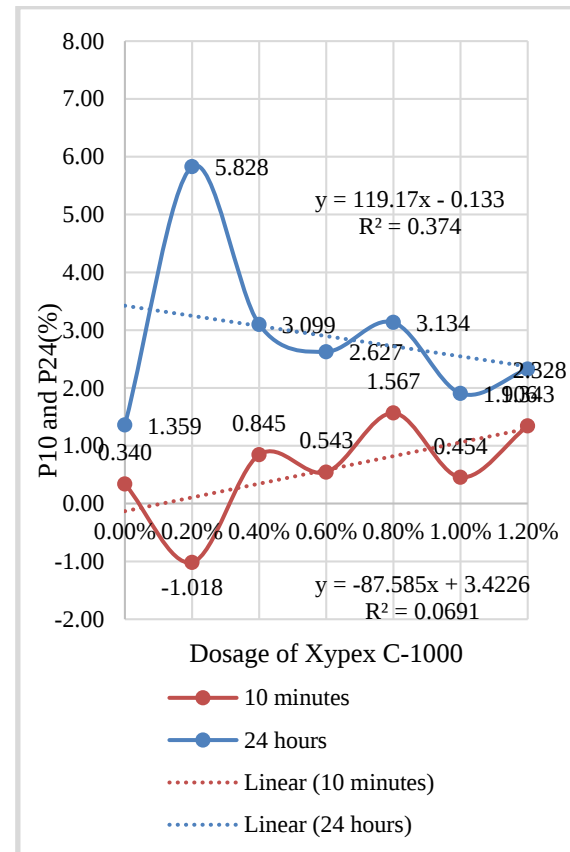


Figure 6. The permeability test results for concrete samples aged 28 days

In Figure 6, for the control samples aged 28 days, it can be seen that the P_{10} and P_{24} values were below the allowable limit. This is an interesting finding because there was a reduction in compressive strength, but there was also a reduction in permeability of the samples. This could be related to the factors that have been explained in Section 2.1, namely the quality of the aggregates used and the concrete making process.

Looking at the P_{10} and P_{24} values of the concrete samples aged 28 days with 0.2% Xypex C-1000, it can be seen that the values were unusual and should not be considered to be meaningful for this research.

Moreover, it can be seen from Figure 6 that the P_{10} values of the concrete samples with 0.4%, 0.6%, 0.8%, 1% and 1.2% Xypex C-1000 increase as the dosage of Xypex C-1000 increases as well, although all the values were below the allowable limit, which is 2.5%. For the P_{24} values of the concrete samples with 0.4%, 0.6%, 0.8%, 1% and 1.2% Xypex C-1000 decrease as the dosage of Xypex C-1000 increases and the values were all below the allowable limit, which is 6.5%. Even though there was not any clear relationship can be observed between the two parameters, but looking at the P_{10} and P_{24} values for the concrete samples with Xypex C-1000 above 0.2%, it can be said that the Xypex C-1000 has been effective in reducing the permeability of the concrete structure. However, it is important to note that there are certain factors that still needed to be studied regarding to the methodology to mix Xypex C-1000 into the concrete.

4. Conclusions

One of the most commonly occurring structural defects in concrete structures is cracking. This defect could be caused by a number of factors, including presence of excess water and overloading. In this research, it is aimed to handle the effect of excess water in the concrete in an attempt to reduce crack development. Xypex C-1000 at the dosage of 0.2%, 0.4%, 0.6%, 0.8%, 1%, and 1.2% was added to the concrete samples and the prepared samples were tested for their compressive strength and permeability. The concrete samples were tested when they were 7 days old and 28 days old. Xypex C-1000 was claimed to be able to improve the compressive strength of concrete structures and to reduce the permeability of concrete structures.

From this research, it was found that for there was a reduction in compressive strength for the concrete samples at 28 days compared to the compressive strength of the concrete aged 7 days. The reduction was significant for the concrete samples with Xypex C-1000. These results were unusual because as the concrete samples age, their compressive strength usually increases. This could be caused by a number of factors, including the quality of the aggregates used, the concrete making process, and the characteristic of the Xypex C-1000 itself.

However, there was a desirable outcome found from the permeability test results. For the concrete samples aged 7 days with Xypex C-1000, it was found that there was a reduction in permeability of concrete structures, but only at certain dosage. This trend was unable to be clearly seen in the test results for the concrete samples aged 28 days with Xypex C-1000. However, for the concrete samples aged 28 days, the permeability of the samples were all below the allowable limit.

In conclusion, based on these preliminary results, it can be said that the Xypex C-1000 is proven to be effective in reducing the permeability of the concrete structures, and hence, has the potential to reduce crack development. However, it is important to study the aggregates used in the concrete mix and the concrete mixing process further, to analyze the effect that the Xypex C-1000 has on the compressive strength of concrete structures.

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