

Relation of Concrete Mix, Porosity to Permeability, and Compressive Strength of Lightweight Concrete without Fine Aggregates

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ABSTRACT: Researches involving porous concrete started in 1995, one of them were by Ghaffori et al. and supported by a journal published by Portland Cement Association (PCA) and National Ready Mixed Concrete Association (NRMCA) in 2004 by Paul D. Tennis et al. said that the strength of light concrete without fine aggregate ranges from 500 psi to 4000 psi (3.5 MPa to 28MPa). The purpose of this research is to find the influence between the mixtures of water cement ratio and the Aggregates/ Cement ratio on the resulting porosity and permeability which came from the resulting concrete mix, and the influence of porosity to permeability of light concrete without fine aggregates linearly with experiment methods. Aggregates used came from Tangerang and the tests used varied water cement ratio of 0.3; 0.35; and 0.4 with Aggregates/ Cement ratio of 3; 3.5; 4; 4.5; and 5. The results of this research showed the increase of porosity is directly proportional with the increase of permeability; and higher water cement ratio gave concrete with lower porosity and permeability.

KEYWORDS: *Light Weight Concrete Without Fine Aggregates, Porosity, Permeability, Pervious Concrete*

I. INTRODUCTION

According to Tjokrodimulyo (2007) no-fines concrete or known as Aerated Lightweight Concrete (ALC) is a simple form of lightweight concrete without fine aggregate. Without fine aggregate, it will create porous concrete therefore the reduce in weight. Lightweight concrete is usually called Aerated Lightweight Concrete (ALC) or also Autoclaved Aerated Concrete (ACC) is a type of concrete with specific gravity not more than 1900 kg/m^3 (SNI-03-2847-2002). The use of this type of concrete is used in the construction of tall buildings to reduce the weight of the building, decrease the size the foundation design, and to be more efficient in construction. The use of lightweight concrete has been applied in Indonesia for a long time. There are many things to be planned to support the growth in this Country, therefore the support from practitioner and researcher to conduct experiments to achieve better results in lightweight concrete is very much required.

The research on lightweight concrete has been developed by many researchers such as Ghaffon et al. in 1995 until today. But basically, porous concrete cannot be used well because of its low compressive strength. Because of that reason there are many researches done to improve lightweight concrete without fine aggregate so it can be applied for road or building construction. Several new researches developed by Khankhie et al. (2016), which say that the best composition for aggregate/ cement for this type of concrete is between 3 to 5 supported by the research of Paul D. Tennis et al. (2004), which says that the material proportion for aggregate/ cement on porous concrete is between 4 to 4.5 with compressive strength between 500 psi to 4000 psi (3.5 MPa to 28 MPa), the value of aggregate/ cement can be set higher with the possibility of decreasing durability and compressive strength which are explained in a research journal published by *Portland Cement Association (PCA)* dan *National Ready Mixed Concrete Association (NRMCA)*.

Research by Zheng et al (2012) says that the effective porosity for no-fines concrete is between 20% - 30% because the increase in porosity will decrease the strength of the concrete, so the best porosity to use is between 20%-30%. Making concrete with porosity below 20% is ineffective because it will decrease the permeability of the concrete, and according to Zhang et al (2012) the decrease in porosity means the specific gravity of the concrete will increase, which means the main function of this type of concrete is not optimal. Porosity more than 30% will make the concrete easy to

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break because the concrete has low compressive strength and the bond between materials is lower because the high air volume on the concrete, which makes it easy to crack and requires constant maintenance.

Bassuoni and Sonebi (2010) developed research on no-fines aggregate concrete which resulted in a Cement Water Factor between 0.28 to 0.40. The recommended value for no-fines concrete must be lower than normal concrete because no-fines concrete does not use sand, so if the Cement Water Factor is more than 0.4, the hydration process is not efficient because there is too much water and it means that the bond between the cements will decrease and the compressive strength also, and if the Cement Water Factor is less than 0.28 it will slow down the hydration process because there is not enough water and the cement won't harden completely and could cause concrete failure.

Tjokrodimulyo (2007) says that the content of dirt on coarse aggregates can not be more than 1%. If it is more than the required content then the aggregates must be washed first using water with $\text{PH} \pm 7$ so it won't be contaminated with organic matter that could weaken the concrete. Aggregates used are aggregates with saturated dry surface condition so that it won't absorb any water that will be added so there will be enough water for the hydration. High dirt content will decrease the bond between aggregates because the cement cannot completely hydrate. From several research from 1995 until today (2018), and supported by several data, this research will find the correlation between porosity and permeability of no-fines lightweight concrete. This research's purpose is to ease the user in field in making this type of concrete, that is why the compressive strength of the concrete must be determined from this research so the finding of this research can be used in most places.

II. LITERATURE REVIEW

Materials

1. Cement

Cement is a bonding material used to “glue” rocks, bricks, and other materials used in construction. Cement itself has 5 types which are:

- a. Portland Cement Type I
This type of cement has low sulfate durability and far from sea, generally used for housing, building, and roadways.
- b. Portland Cement Type II
This type of cement has better durability against sulfate compared to Type I. This cement is used for construction of building in an area with high water content such as beaches, it can also be used for dams or irrigation.
- c. Portland Cement Type III
There is a certain requirement to use this type of cement, because it is weak against sulfate. Early compressive strength is very high that is why this type of cement can be used for tall buildings, flyover, and other structures that need high compressive strength.
- d. Portland Cement Type IV
This type of cement need low hydration heat to avoid cracking in its hardening phase and it has low hardening phase duration so it is good to use on building with high compressive power.
- e. Portland Cement Type V
This type of cement has high sulfate durability. It is used for waterworks such as oil mines, harbors, and bridges.

In no-fines lightweight concrete mix, the cement used according to CRMCA (Colorado Ready Mixed Concrete Association Version 1.2) is Portland Type 1

2. Coarse Aggregates

The coarse aggregates used in the mix came from Tangerang, and has been through testing such as:

- a. Specific gravity test
- b. Absorbtion/ permeation test
- c. Wear and tear test
- d. Organic Content test

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3. Water

Water used for the mix has $\text{PH} \pm 7$ so the hydration on concrete is well.

III. RESEARCH METHODOLOGY

Planned concrete mixture used the combination of cement water factor (CWF) 3; 3.5; 4 and Aggregates/ Cement 3; 3.5; 4.5; 5. Specific gravity of coarse aggregates of 2.463 kg/m^3 . Table 1 below shows the mix design used in this research.

Table 1 : Mix design

CWF	Ag/Cement	Aggregates (Kg)	Cement (Kg)	Water (Kg)
0.3	3	38.5	12.8	3.9
0.3	3.5	38.5	11.0	3.3
0.3	4	38.5	9.6	2.9
0.3	4.5	38.5	8.6	2.6
0.3	5	38.5	7.7	2.3
0.35	3	38.5	12.8	4.5
0.35	3.5	38.5	11.0	3.9
0.35	4	38.5	9.6	3.4
0.35	4.5	38.5	8.6	3.0
0.35	5	38.5	7.7	2.7
0.4	3	38.5	12.8	5.1
0.4	3.5	38.5	11.0	4.4
0.4	4	38.5	9.6	3.9
0.4	4.5	38.5	8.6	3.4
0.4	5	38.5	7.7	3.1

Making of Test Samples

This research used 90 test samples with 45 cube samples (15 cm) and 45 tube samples (dia. 4 inch with height of 20 cm). Every variation has 6 test samples. Variation used in concrete mix for 6 samples were taken from one mix with mixture of each variation of water cement factor 3; 3.5; 4 and aggregates/ cement 3; 3.5; 4; 4.5; 5.

Maintenance of Test Samples

Maintenance was done after the concrete's final setting. After the concrete samples were taken out from the molds, the concretes were drowned for curing until it reaches the age of 28 days. In the drowning process, the water must be changed periodically to maintain the quality of concrete.

Testing of Test Samples

After 28 days of curing the cubical samples is tested for its compressive strength and the tube samples was tested for its porosity and permeability.

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IV. ANALYSIS AND RESULTS

The Results of Specific gravity, Absorption, Wear and Team and Organic Content of Aggregates

Table 2 : Result of Tangerang Aggregates' Testing

Testing	Limit Maximum	Test Results	Results
Dry Specific gravity*	3	2,46	Met the Requirement
Specific gravity Dry Surface*	3	2,48	Met the Requirement
Apparent Specific gravity*	3	2,52	Met the Requirement
Absorption*	5%	0,99%	Met the Requirement
Wear and Tear**	40%	20,74%	Met the Requirement

Results from the coarse aggregates test as seen on table 2 above, shows the specific gravity of $\pm 2,48$ shows that the aggregates used for this research has a good density and fulfilled the criteria of material use. Absorption of aggregates is 0.99% which means the porosity of materials is small, meaning that the materials are dense and almost have no cavity therefore it doesn't have great absorption. The value of wear and tear is 20.74% which means the materials is not fragile to pressures and blows and it has great characteristic, meaning the materials can be used for the test samples.

Data and Anaysis from The Concrete Permeability and Porosity Tests

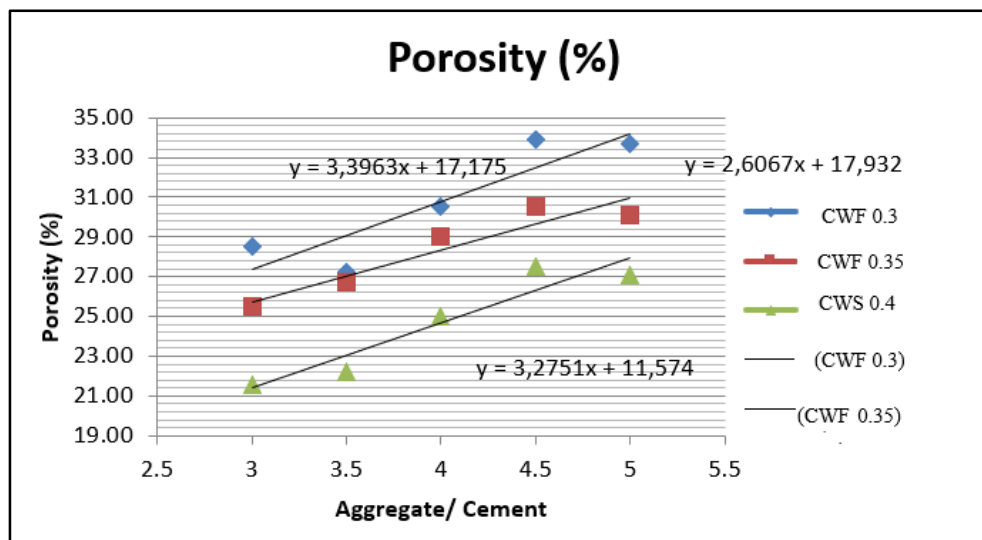


Fig 1: Graphic of Relation Between Aggregate/ Cement and Porosity

From the results of porosity testing for concrete as seen on fig 1, the results can be seen on the graph above, where the average value of porosity will be getting bigger directionally proportional with the rise of aggregate/ cement. Higher cement water factor will cause porosity to decrease. Higher aggregate/ cement means the cement that could fill the

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voids between aggregates will decrease which cause higher porosity, while lower aggregate/ cement will cause the cement on mixture to increase which cause the void to be filled by the cement that will decrease the porosity of concrete. High cement water factor will cause the cement to be watery, which it will fill the void between aggregates and the porosity will be lower, while low cement water factor will cause difficulty for the concrete to flow and fills the void which in the end cause higher porosity.

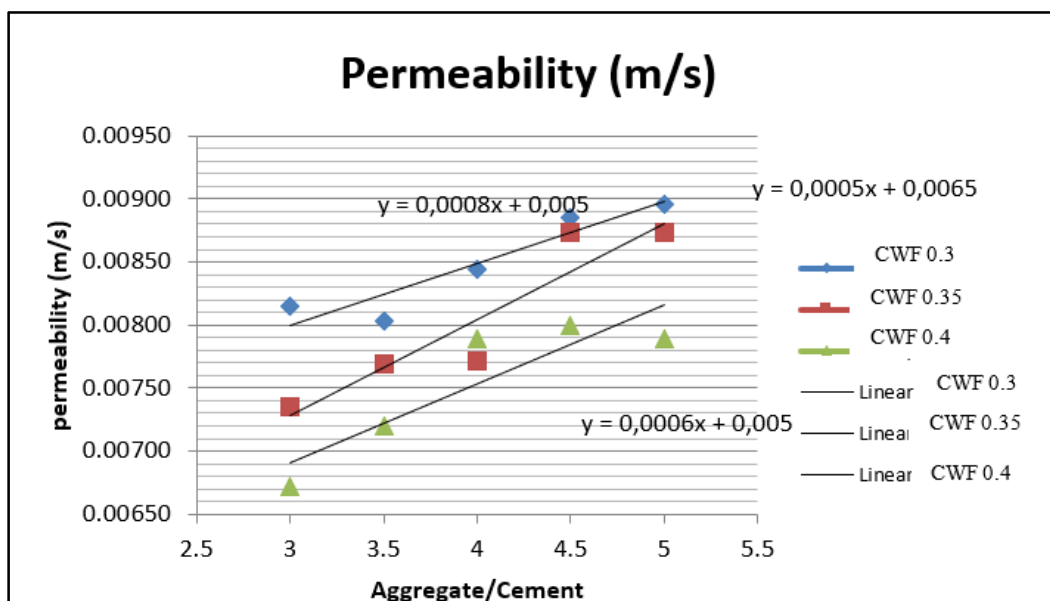


Fig 2 : Graph of Relation Between Aggregate/ Cement and Permeability

From the results of permeability test on concrete samples as seen on fig 2, the results can be seen on the graph above where the ability of the concrete to flow water or known as relative permeability coefficient is directly proportional with the increase of porosity of no-fines porous concrete. From the compressive strength it can be concluded that concrete samples with higher porosity and permeability can resulted in lower compressive strength.

From the value of porosity and permeability acquired from the test, a linear correlation was made between porosity and permeability of no-fines lightweight concrete. From this result, it can be seen that the higher the porosity then the permeability will increase too. The relation with concrete mix can be seen below which shows the higher the value of aggregate/ cement then the value of porosity and permeability will be higher too.

The result of correlation between porosity and permeability is:

CWF 0,3 : $y_2 = 0,000235y_1 + 0,00095$

CWF 0,35 : $y_2 = 0,0002y_1 + 0,003$

CWF 0,4 : $y_2 = 0,00018y_1 + 0,0029$

y1 = Porosity (%)

y2 = Permability (m/s)

Data and Analysis of Concrete Compressive Strength Test

From the results of compressive strength test, the compressive strength is inversely proportional to the results of porosity and permeability. Compressive strength is higher when the mixture of aggregate/ cement is lower and has a lower water cement factor as well. The highest compressive strength result is 9.93 MPa with cement water factor of 0.35 and aggregate/ cement is 3. Below is a graph and analysis of the mixture of no-fines lightweight concrete to its compressive strength:

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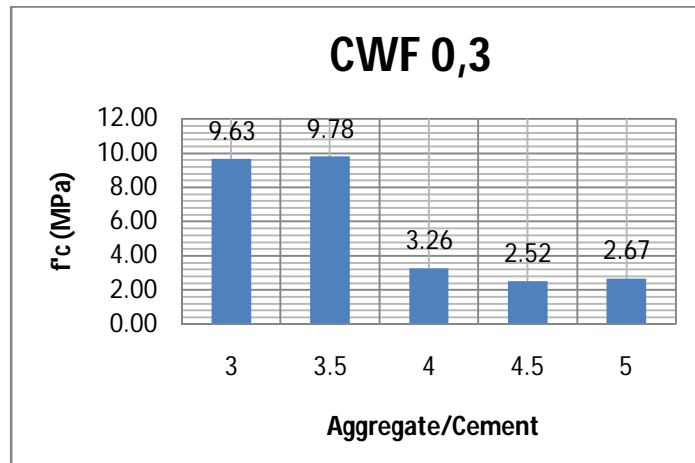


Fig 3 : Compressive Strength of No-Fines Lightweight Concrete With CWF 0,3

Concrete mixture with CWF of 0.3 as seen on fig 3 above has the best compressive strength on mixture of aggregate/cement 3 and 3.5, this is caused by higher cement content which caused an increase in compressive strength. With the right amount of water then hydration on concrete will be perfected which means it won't lack water, therefore it is brittle and watery. On concrete mixture with aggregate/ cement of 4 to 5, there aren't any good results because the cement content can not increase the bonds between aggregates.

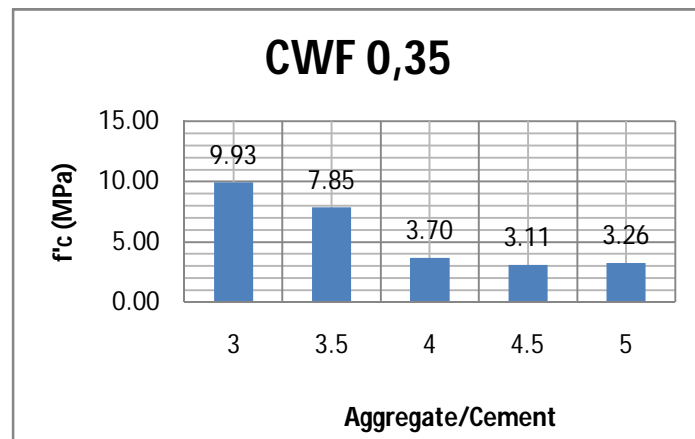


Fig 4: Compressive Strength of No-Fines Lightweight Concrete With CWF 0,35

Concrete mixture with CWF of 0.35 as seen on fig 4 has the best compressive strength on mixture of aggregate/cement 3 and 3.5, this is caused by great hydration process and higher cement content which caused an increase in compressive strength by increasing the bonds between the aggregates. On aggregate/ cement 4 to 5 decreased compressive strength because low cement content and maximum hydration did not occur.

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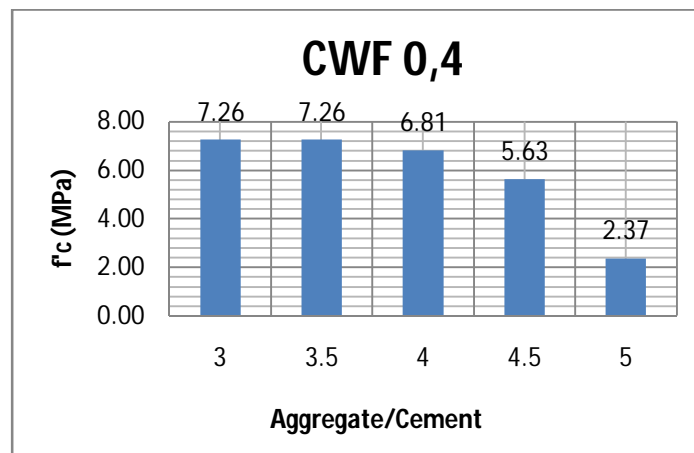


Fig 5: Compressive Strength of No-Fines Lightweight Concrete With CWF 0,4

The concrete mixture with CWF 0.4 as seen on fig 5 did not have as good results as concrete mixture with CWF 0.3 and 0.35 on aggregate/ cement 3 and 3.5, this is caused because an excess of water so the hydration is not perfect because the concrete is too watery which caused lower compressive strength.

Curing also determines the compressive strength of concrete because this process prevents too much hydration so the concrete won't crack, that is why the water used in curing must be changed periodically.

V. CONCLUSION

Based on the test in laboratory and data analysis, it can be concluded that:

1. Increase in porosity is directionally proportionate with the increase of permeability
2. The higher the value of cement water factor will give a result in concrete with lower porosity and permeability
3. Lower aggregate/ cement will result in higher compressive strength but lower porosity and permeability
4. Correlation of porosity and permeability on cement water factor 0.3 is $y_2 = 0,000235y_1 + 0,00095$
5. Correlation of porosity and permeability on cement water factor 0.35 is $y_2 = 0,0002y_1 + 0,003$
6. Correlation of porosity and permeability on cement water factor 0.4 is $y_2 = 0,00018y_1 + 0,0029$
7. The higher compressive strength is on mixture of cement water factor 0.35 and aggregate/ cement 3 with porosity 24.57% and permeability of 0.0073 m/s

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