A Study on Durability for Rigid Pavement Against Acid Environment and Displacement Model

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Abstract. An acidic environment commonly found in peat soils or expansive soil will harm the quality of rigid pavement by considering its use at long-life plan, traffic load, and minimization of damage to the crossroad due to vehicle braking. As a concrete provider, chemical admixture as mixed materials today is widely used with the reasons of workability, initial strength, as well as saving of material used. This research aimed to find out the durability of concrete admixture using sika-NN and plastocrete (retarding and water reducing admixture) at the acid environment and knowing the displacement that occurred using ABAQUS software modeling. It used the laboratory experimental method and the cube concrete sample 15x15x15 cm with the compressive strength of 33.2 MPa. A total of 18 concrete samples were immersed using normal pH water and H2SO4 at pH 1 ± 1 tested at 3, 7, 14, 28, 60, and 90 days using the Duplo method. In this research, the concrete durability was carried out using, Ultrasonic Pulse Velocity Test (UPVT) to test the density, compressive test, and modeling concrete displacement on peat soils with vehicle loads in acidic environments using software ABAQUS. The mixed design results show an average setting time value of about 112 minutes. Coarse aggregate and cement decrease due to additives is approximately 24% and 18% respectively, increasing the use of fine aggregate to 16.49%, but the value of concrete density increases base on soaking time. Besides that, there is a decrease in compressive strength up to 16% at the age of 90 days. The value of displacement in the modelled pavement uses a maximum load of 8 tons each 2.994 mm for concrete with normal water and 3.045 mm for concrete with an acid environment respectively. Concrete soaked in acid water is the greatest deformation that occurred in rigid pavement using ABAQUS and indicates that acid water has an impact on decreasing concrete quality.

1. Introduction
Rigid pavement is a type of pavement made from cement, aggregate, and water as the main materials; it is usually used in a road project that requires pavement advantages such as long-life and resistant to car braking damage.

The problem in the land transportation sector that often occurs in big cities, especially in Indonesia, is that the road is often experience damages which are usually caused by excessive loads, the natural environment in Indonesia which tends to vary, and poor drainage that causes roads to be inundated – or even flooded–, unstable soil conditions, and soil conditions that can damage the road.

With the water factor inundating the road, especially rigid pavement, it is necessary to optimize rigid pavement made from high-strength concrete with additional materials (admixtures). The main function of additional materials (admixtures) is to suppress the strength of rigid pavement; therefore, many projects that require high-strength concrete compressive strength use additional material
The several advances that corporations have made in the supply of concrete have contributed to the high use of addictive substances in the form of chemical mixtures. With chemical admixture, at least the level of material used is much more economical which results in less exploitation of nature. The additives that are always used are plastocrete RT06 and sikament-NN. Both of these additives are included in chemical admixtures. Plastocrete RT06 is a concrete additive that has water-reducing properties and slows down set retarders. Meanwhile, sikament-NN is a superplasticizer liquid that has the function of reducing concrete water, to help produce concrete with high initial strength and final strength and is chlorine-free. Effect of dosage of the admixtures, both admixtures present different behaviours on the compressive strength of concrete [1].

This research wants to know the durability of the acid environment on concrete, which will simulate the vehicle load in the static pressure test and see the displacement that occurs in peat soil by modeling using software ABAQUS. Acidic environments are usually easy to find on peat soils, factory waste or expansive soil that are often found in the Indonesian environment, the use of acid water will certainly have an effect that may harm or decrease the quality of the concrete. Exposure to acidic conditions affecting the performance, lifetime, and maintenance costs of vital structural infrastructures is a major problem regarding the strength and durability of concrete structures. Acids solved in groundwater and chemical wastewater can attack specific infrastructural materials and affect their durability.

2. Research Methods
The research method used was direct observation, laboratory experiments.

2.1. The Specimens and material
The number of samples of the specimens was 36 samples consist of 18 samples in normal water curing and 18 samples in acid using H₂SO₄ immersing (curing). The data analysis used was the Duplo method which aimed to get better results with periodic checks which maintained the stability of the pH number.

The fine aggregate (sand) and coarse aggregate used in this research is Progo sand. The cement used for the research was OPC (Ordinary Portland Cement) cement with the brand Holcim. The water used was normal water with a pH of 7 from the civil engineering laboratory of UMY.

2.2. Admixture
The additional materials used were plastocrete RT06 and Sikament-NN. Plastocrete RT06 is a concrete mixture that can reduce the use of water in the concrete mixture and control the hardening time. This admixture belongs to type D (water reducing and retarding admixture) according to [2] with a dosage of ± 0.2% - 0.6% by weight of cement. While sikament-NN is a superplasticizer that can reduce the large amounts of water use but can accelerate the hardening (time) and produce concrete with high initial and final strength. This admixture belongs to type F according to [2] with a dosage of ± 0.3% - 2.3% by weight of cement. Thus, the use of these admixture materials can reduce the use of the amount of water by 25%. There are few advantages obtained when superplasticizer is used: produce high workability concrete with constant cement content and strength, with objective for easy placing and compaction; produce concrete with normal workability, but lower water requirement; production of concrete with combination of high workability and low water content; and designing a normal strength and workability concrete with less cement content [1].

2.3. Mix Design
The Mix design is a selection of concrete proportions including the balance between economics and requirements for placeability, strength, durability, density and appearance. The Mix Design refers to the [3]. The proportion of the mixture has decreased after using sikament-NN – after being compared with the proportion of Fc’ 33.2 MPa concrete mixture without admixtures [4]. The use of coarse aggregate (gravel) decreased by ± 24.07% and cement by ± 17.91%. However, the use of fine aggregate (sand) increased by ± 16.50% thus the concrete texture was slightly gritty. The mix design in this research is as shown in Table 1.
Table 1. Proportion of 1m³ concrete mix

| Material            | Total   |
|---------------------|---------|
| Water               | 153.68 kg |
| Cement              | 426.88 kg |
| Sand                | 814.33 kg |
| Gravel              | 766.89 kg |
| Plastocrete RT06 0.6% | 2561.25 ml |
| Sikament-NN 2.3%    | 9818.13 ml |
| W/C                 | 0.48    |

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2.4. The Slump Testing [5] and Setting Time [6]
The slump test was carried out to obtain the concrete viscosity value. Fresh concrete slump according to [1] or rigid pavement is a minimum of 2.5 cm and a maximum of 7.5 cm. The setting time is the time required for cement setting to the aggregate. This test aimed to determine the effect of variables such as water, type, the amount of cement material or added material (admixture) when determining the setting time of concrete.

2.5. Modulus Elasticity
The modulus of elasticity in equation (1) is the comparison ratio of the normal stress to the strain arising from that stress.

\[ 4700 \sqrt{f_c} \text{ 28 days} \]  

(1)

2.6. The Density Testing of Concrete
The density test of concrete is a non-destructive test to determine the characteristics, quality and density of concrete, one of which is by using Ultrasonic Pulse Velocity Test (UPVT). UPVT aims to determine the uniformity value and relative quality of concrete, detect the presence of cavities and cracks and evaluate the effectiveness of crack repair with the following calculation formula [7]

\[ V = \frac{L}{T} \]  

(2)

Note:
\[ V = \text{speed (velocity) of the wave propagation (m/s)} \]
\[ L = \text{distance between transducer surfaces (m)} \]
\[ T = \text{travel time (s)} \]

Table 2. Qualification of concrete based on UPV value [7].

| Wave Speed (km / s) | Results     |
|---------------------|-------------|
| > 4.57              | Very good   |
| 4.57 - 3.67         | Good        |
| 3.66 - 3.06         | Pretty good |
| 3.05 - 2.13         | Moderate    |
| < 2.13              | Less        |

Based on [7], this test uses ultrasonic wave velocity which is influenced by the homogeneity of the concrete mixture and the density of the concrete. The faster the ultrasonic waves pass through the test sample, the tighter and denser the test sample is. If the ultrasonic waves pass slower through the test sample, the homogeneity and density of the concrete are smaller.
sample, the test sample is said to be less dense and there are cavities or cracks classified as in Table 2 above.

2.7. *The Static Compressive Strength Testing*
In every concrete mix design the compressive strength of the concrete must meet the required characteristic strength, where the characteristic strength is the value of the concrete strength of large number of specimens. The strength of this value is limited to 5%. Based on [8], the compressive strength is the magnitude of the load per unit area of the cross section which causes the concrete specimen to disintegrate with a certain compressive force exerted by a press machine. In this research, the researchers used [8], as a reference for determining the compressive strength. The concrete with cube-shaped specimens made in the laboratory.

2.8. *Modelling Using ABAQUS Software*
The rigid pavement modeled is normal concrete and concrete with the addition of additives in the form of Plastocrate and Sika NN (Retarding and water reducing admixture). Modeling was performed using ABAQUS ver. 6.11 Cross section of the road body modeled measuring 1 x 1 x 1 meter and a depth of 1 meter with a plate thickness of 30 cm and soil layer 50 cm thick expansive clay is on bottom of a 20 cm thick layer of sand. The loading used is a point load of 8 tons (78.5 kN) placed right in the middle of the pavement. The parameters obtained and used in this study are then used to perform modeling simulation on the plate system [9] and laboratory results. Parameter data can be seen in Tables 3, 4 and 5.

**Table 3.** Soil material parameter data

| Material          | Soil Parameter       | Value          |
|-------------------|----------------------|----------------|
| Drucker Prager    | Angle of friction (°) | 2              |
| Hardening         | Initial tension      | 0.005          |
|                   | Dilation angle (°)    | 2              |
|                   | Yield stress (MPa)    | 0.005          |
|                   | Abs. Plastic Strain   | 0              |
| Elastic           | Young modulus (MPa)   | 1.25           |
|                   | Poisson ratio         | 0.32           |

**Table 4.** Fine aggregates parameter data

| Material | Soil Parameter       | Score |
|----------|----------------------|-------|
| Elastic  | Young modulus (MPa)   | 5     |
|          | Poisson ratio         | 0.3   |
Table 5. Concrete parameter data

| Material       | Normal Concrete Parameter | Score | Acid Concrete Parameter | Score |
|----------------|---------------------------|-------|--------------------------|-------|
| Elastic        | Young modulus             | 34540,31 | Poisson ratio            | 0,2   |
|                | (Mpa)                     |       |                          |       |
| Plasticity     | Dilatation angle          | 3     |                          | 3     |
|                | Eccentricity              | 2     |                          | 2     |
|                | b0/fc0                    | 1,16  |                          | 1,16  |
|                | K                         | 0,67  |                          | 0,67  |
|                | Viscosity Parameter       | 0,005 |                          | 0,005 |
| Tensil Behaviour | Yield stress (Mpa)       | 0,008 | 0,00016                  | 0,008 |
|                | Cracking Strain           | 0     | 0,0245                   | 0,00016 |
| Concrete Damage | Damage Parameter         | 0,99  | 0                        | 0     |
|                | Cracking Strain           | 0,0245| 0,99                     | 0,0245|
| Compressive Behaviour | Yield stress (Mpa) | 0,00387 | Inelastic Strain | 0,00387 | 0,00011 |
|                | 0,00774                   | 0,0011| 0,0074                   | 0,0011|
|                | 0,00116                   | 0,0024| 0,00156                  | 0,0024|
|                | 0,00155                   | 0,00343| 0,00155                  | 0,00343|
|                | 0,00194                   | 0,0046| 0,00194                  | 0,0046|
|                | 0,00232                   | 0,00847| 0,00232                  | 0,00847|
|                | 0,00271                   | 0,011 | 0,00271                  | 0,011 |
|                | 0,07                      | 0,027 | 0,07                     | 0,027 |
| Concrete Compressive Damage | Damage Parameter | 0      | 0                        | 0     |
|                | Inelastic Strain         | 0,005 | 0,05                     | 0,008 |
|                | 0,1                       | 0,016 | 0,1                      | 0,016 |
|                | 0,75                      | 0,027 | 0,75                     | 0,027 |

3. Research Result and Discussion

3.1. The Slump and Setting Time

One concrete mix was used for 3 samples of acid water immersion concrete specimens and 3 samples of normal water immersion concrete specimens at each age of the concrete. The results of the slump test are presented with an average slump value of 7.2 cm, thus it can be concluded that the concrete slump has met the requirements specified in [3].

The setting time of concrete with (admixtures) in the form of plastocrete RT 06 with a concentration of 0.6% and sikament-NN with a concentration of 0.23% resulted in an average setting time of concrete ranging from 111 minutes to 113 minutes. At the age of 7 days, the average setting time was 111 minutes and at the age of 28 days, the average setting time was 113 minutes. Therefore, the average setting time of the age of 7 days and 28 days is 112 minutes.

3.2. The Density Testing Results of Concrete

Figure 1 show density graph results that continues to increase along with the length of immersion. The result shows all the samples in a good category density [7]. Two concrete samples with additives at the age of 3 days showed a value of 3.73 km/s for acid admixture and also normal concrete and 3.71 km/s
and 3.67 for normal admixture concrete and acid admixture [they] continued to increase until it reached 4.12 km/s for acid admixture concrete and 4.17 km/s for normal admixture concrete.

Figure 1. Graph of Concrete Density Values

This is in accordance with the research conducted by [10], in which the results of that study show a decrease in density value due to damage to the inside of the concrete and an increase in pores. On the research by [11] – it states that the use of admixture can increase the quality of the density value by 10%.

3.3. The Compressive Strength and Modulus of Elasticity

This test samples used the Duplo data collection because the differences in the results were too far. This method was used to get better and more accurate values.

The ages of concrete were 3, 7, 14, 21, 28, 60 and 90 days. The following are the results of the concrete compressive strength test. The names in the table are defined as N for the concrete immersed with normal water and A for the concrete immersed with acid water. The numbers after the letter N are designated for the days and the last digit is for the sample number. The results obtained from the actual dynamic compressive strength [testing] of concrete are shown in Figure 2.

Figure 2. (a) Graph of Concrete Static Compressive Strength. (b) Modulus of Elasticity

From Figure 2, it can be interpreted that the decrease in the quality of the concrete caused by acid water is ± 16%.

This quality degradation is also found in the research by [10]. Which states a decrease 35%. In the research by [12] and [13] – it is stated that the degradation of concrete quality in acid water comes from mass loss.
Figure 2b shows that the modulus of elasticity of the normal concrete is at a value of 29524.08 – 34281.02 MPa and 27215.39 – 30841.46 MPa for the acid concrete. The modulus of elasticity is usually directly proportional to the value of compressive strength, thus the modulus of elasticity of the acid additive concrete is lower than the modulus of elasticity of the normal additive concrete. The decrease in the modulus of elasticity in accordance with the research by [12] and [14] which indicate that a decrease in the modulus of elasticity has a very close correlation with corrosion time, pH value, and microcracking.

3.4. Deformation Modelling
Deformation Rigid pavement with normal water concrete by 2.992 mm with a strain of 0.006. Meanwhile, rigid pavement with a variety of concrete with acid water greater about 3.045 mm with a strain of 0.007 with the size of the mesh is 60. The condition occurs because of the effect of the acid content which causes a decrease in durability in compressive strength.

![Graph showing modulus of elasticity of normal and acid concrete](image1)

**Figure 3.** (a) Correlation between load and strain (b) load and deformation on the normal rigid pavement respectively.

![Deformation patterns in concrete and soil](image2)

**Figure 4.** Deformation that occurred on the rigid pavement with acid.

Modeling using ABAQUS can also show the pattern in concrete and soil. Figure 3a and 3b shows the curves, and Figure 4a and 4b shows the deformation patterns that occur in concrete and soil. The different colors in the deformation pattern indicate the reaction in the material when it is loaded and the amount of deformation that occurs.

In this modeling, the settlement occurs only on the concrete plate without touching the layer below is due to the concrete's density due to additives that can still resist the load above. The mesh size of the modeling performed with the ABAQUS program significantly affected substantial plastic damage.
sustained. The concrete mix resulting from the study, which is in acid with expansive soil conditions, is still suitable when applied to the field because, in this study, the load given is considered the extreme load, but the deformation is not too significant.

4. Conclusion
In this research, it was found that there were unique concrete characteristics due to the decrease in water content in the mix design. This is due to the reduction in water by 25% of the sikament-NN content which results in a decrease in the use of coarse aggregate and an increase in the use of fine aggregate in concrete and it will be reduce exploitation of nature. This concrete has several unique characteristics, namely, the texture of the concrete is gritty, and this concrete has a long setting time due to the retarding [properties] of Plastocrete. However, UPVT testing on the acid additive concrete and the normal additive concrete experienced a positive trend as the concrete ages. The acid solution used in the curing or immersion process slightly affects the additive acid concrete pulse rate. This is due to the increased porosity of the concrete due to its acidic nature, which is corrosive. Meanwhile, the static compressive strength testing showed a decrease in the additive concrete immersed in acid water by 16% from the normal water additive concrete. The greatest deformation that occurred in rigid pavement using ABAQUS is concrete soaked in acid water and proves that acid water impacts decreasing the quality of the concrete.

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