Fatigue Study of Ijuk-Aren Interaction on Soil Cement Pavement Model for Elastic Foundation

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Abstract — This study examines the behavior of fatigue interaction-palm fibers in the soil-cement as an elastic foundation pavement. Experimental behavior in sandy-clay type soil stabilized cement, with 6% and the amount of cement mixed-palm fibers as reinforcement to the number of 0% and 0.50% of the dry weight of the soil. Fatigue with repeated load testing using a UTM-5P / 14P and type testing Confined Repeated Strain Axial Load Test and visual interaction microstructure-palm fibers examined by Scanning Electronic Microscopy (SEM). The test specimen is done at 28 days, the loads are applied: is loading stress = 1500 kPa, confining stress = 100 kPa, loading frequency 1.5Hz. The results obtained showed reinforcement palm-sugar 0.50% increase resilience modulus degradation of 6.50% and microstructural observations indicate cement hydration bind soil particles cover the surface of palm fibers. The results of the other is the interaction of the fibers improve the strength of soil-cement and pavement a long time.

Keywords— Soil-cement, Ijuk-aren, SEM, Resilient modulus

1. INTRODUCTION

Technological developments pavement material can be modified to improve and increase its strength. Repeated load of vehicular traffic on the highway can accelerate the damage and improve their cracks and visible cracks on the reflective surface layer. These cracks if allowed to happen, then the water can get into the pavement, thus potentially reducing the bearing capacity. Although not the maximum workload if repeated can decrease the strength can even damage is significant and long-term permanent deformation [3]. Stresses that occur by repeated load may cause failure cracks (fatigue failure), it can be controlled based on a critical stress. Modification material with soil cement pavement in the long term can increase resistance to material fatigue. This is because the soil cement showed good resistance to permanent deformation accumulation [13]. In soil cement needs to be known of the cement hydration reaction could change the nature of the soil becomes plastic, rigid or brittle and can ultimately arise due to shrinkage cracking and drying. Repeated load that causes fatigue, stress reached in the pavement is the total number of cycles required to achieve fatigue.

Fatigue is the process of a material damage caused by the repeated stress. Such conditions will go through several stages cracking, that is: a) initial crack, b) crack propagation due to the application of advanced load, c) rapid crack is no visible the condition of the application of cycle of a significant load because time is so quick cause cracks. Stress occurs, the possibility of magnitude smaller than the static load, but because of the repetitive, it can result in damage to the material. Just about every case of road damaged the superstructure begins with fatigue, cracking and then deformation. Repeated load started by the initial stress and then stress deviator, because the load applied constantly then decreased stiffness. Scheme repeated load cycles as shown in the Figure 1 with repeated load cycles N is applied in the frequency (Hz) of certain [12]. The basic equation resilient modulus, the test is repeated triaxial: \( M_r = \sigma_d / \varepsilon_r \), with \( M_r = \text{resilient modulus}, \sigma_d = \text{deviator stress}, \varepsilon_r = \text{resilient strain} \) [2]. Fatigue testing conducted to achieve the application of repeated load with a fixed amplitude, which is based on the maximum and minimum pressure at each cycle.
Total cycle fatigue achievement is \( N_f \) and failure stress that happened was \( M_c \). Modulus resilience with axial creep strain accumulation based on repeated testing, the axial strain-flexural and vertical stress peaks as in the model: \( \varepsilon_c = (L_3 - L_1)/G; \) 
\( \varepsilon_v = (L_2 - L_3)/(G - (L_3 - L_1)); \) 
\( \sigma = F/A; M_t = \sigma / \varepsilon_c \) and \( M_v = \sigma / \varepsilon_v \), with \( \varepsilon_c \) is the accumulation of axial stress, \( \varepsilon_v \) is the axial strain flexural, \( \sigma \) is a vertical peak stress (kPa), \( L_3 \) is the end of the displacement transducers for pulse \( n \) shortly before the application of stress to pulse \( n+1 \) (mm), \( L_1 \) is the initial zero to guide decrease of the transducer (mm), \( G \) is the initial length of the test specimen (mm), \( L_2 \) is the maximum displacement transducer stress applied to pulse \( n \), \( F \) is a vertical peak load (N), \( A \) is the sectional area of the specimen (mm²), \( M_t \) is a resilient modulus (MPa), \( M_v \) is the creep modulus of stiffness (MPa) [7].

Technologies to prevent and reduce cracks occur by way of mixing the fibrous material made of natural or artificial. Fibrous material can resist tensile force functioning, increasing shear strength between grains of soil and increase bearing capacity of soil-cement. The use of carbon fiber, pineapple fiber, fruit fiber palm bunches, polypropylene and plastic fibers can improve strength without affecting the density, reduces cracks in the pavement road [10][8][5]. Natural fiber-palm fibers produced from palm trees (Figure 2) is good enough soil cement is used as a reinforcement in the pavement. These fibers have a composition the chemical content, are: cellulose, hemicellulose, lignin, and ash. Beside that also contains 10 metal elements, are: silica (Si), phosphorus (P), calcium (Ca), chromium (Cr), manganese (Mn), iron (Fe), ytterbium (Yb), nickel (Ni) and copper (Cu) and the metal element is qualitatively not influenced alkali solution [11].

**Fig. 1 Wave pattern of the repeated load (Sarsam et al., 2013)**

**Fig. 2 Sugar palm tree**

### II. EXPERIMENTAL PROGRAM

#### A. MATERIALS USED

This study is an experimental research conducted in the laboratory to determine the characteristics of the soil as a sub-base material stabilized with cement reinforcement fibers. Laboratory tests to determine the physical properties, grain size, consistency and plasticity and density. Testing of mechanical properties includes compaction test is used as the basis for preparation of samples for testing. The equipment used must be checked and calibrated in good condition. To obtain accuracy and avoid the error testing equipment working procedures studied carefully. Repeated Axial Load Testing to obtain resilient modulus and microstructural behavior was tested by SEM and EDS. Testing SEM to obtain micro-interaction interface conditions in the soil stabilized fibers, and the EDS test to obtain the composition of elements and compounds.

Material soil for research in the category classification USCS of type sandy clay (SC). Properties in laboratory testing conducted to obtain the physical and mechanical properties of the soil result: Specific Gravity (Gs) = 2.65 (ASTM D-854-92); liquid limit (LL) = 18.45%; plastic limit (PL) = 11.25%; plasticity index (PI) = 7.20% (ASTM D-4318-95); grain size distribution (ASTM D-422-93) be obtained: coarse sand = 2.00%; medium sand = 8.00%; fine sand = 55.00%; silt = 22.50% and clay = 12.50%. Testing compaction modification (ASTM D-1557-91) values obtained maximum dry bulk density \( \gamma_{d, max} \) 1.98 kN/m³ and the optimum water content \( w_{opt} \) 12.00%. Added as a stabilizing material used cement type I the type of PCC and used materials-palm reinforcement fibers.
B. SAMPLE PREPARATION AND TESTING

The test specimen is based on ASTM D 3999 cylindrical diameter of 50 mm and a height of 100 mm. Components and proportions of soil cement in the mix, there are three variables: levels of cement 6% of the dry weight of soil, fiber-palm fibers 0% and 0.5% by weight of dry soil 1/6 length x diameter of the test specimen and the water content ranged optimum moisture content. Each specimen has mixed between the fibers of palm (Figure 3), soil and cement first and then the water be stirred until homogeneous. Mixing is done by hand, making of test specimens be required time ranged from 30-45 minutes and then placed in a room temperature remained during the 28 days. Tolerance example: γd ± 1% of the plan, w ± 0.5% of the plan, the diameter and height of ± 1mm, unit weight of density ranged 2,22 ± 0,5 kN/m³.

![Fig. 3 Palm-sugar](image3)

Resilient modulus (Mr) obtained by repeated testing using test equipment UTM-5P/14P (Figure 4) and the type of testing Confined Repeated Strain Axial Load Test. The repeated load test method based on ASTM D 3999-91 (1996). This equipment is capable of applying repeated load at a frequency of 0-10 Hz. The test specimen mounted on a cylindrical and a triaxial test chamber is installed. A deflection sensing transducer (LVDT) installed to read the specimen deformation. Load cell (confining pressure) = 100 kPa is applied to the surface of the specimen. The control unit has a special software as a tool to enter the initial data and did running the application load and frequency. Then carried calibration and proceed start of the process of applying the load on the specimen of 1500 kPa. Observations Scanning Electronic Microscope (SEM) was used Bruker instrument, the test specimen after repeated testing of axial load confined strain at 28 days.

![Fig. 4 Test equipment UTM-5P/14P](image4)
Soil stabilized with cement to form pozzolan, properties are the properties owned pozzolan materials containing silica (SiO₂) and alumina (Al₂O₃) which have no binding properties of such as cement. But these materials when mixed cement and react with water, it forms a compound CSH and CAH, so that a pozzolan material which have properties such as cement [9]. Pozzolan quality standards in accordance with ASTM C618-92a there are three classes of N, F and C, and have a good quality pozzolan when SiO₂+Al₂O₃+Fe₂O₃ ≥ 70%. Based on the above characteristics, then the physical properties and the chemical compound content were investigated soil test results obtained a spectrum as shown in Table I.

### TABLE I - CHEMICAL COMPOSITION OF SOIL USED IN THIS STUDY

<table>
<thead>
<tr>
<th>MINERAL COMPOSITION</th>
<th>VALUE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe₂O₃</td>
<td>3.83</td>
</tr>
<tr>
<td>SiO₂</td>
<td>51.75</td>
</tr>
<tr>
<td>MgO</td>
<td>4.46</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>22.80</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>4.16</td>
</tr>
<tr>
<td>SO₃</td>
<td>4.01</td>
</tr>
<tr>
<td>CAO</td>
<td>5.34</td>
</tr>
</tbody>
</table>

Chemical compounds in the soil for research as shown in Table I shows that the chemical compound contained is dominated SiO₂ = 51.75% and Al₂O₃ = 22.80%, this type of soil is good for stabilized with cement. Silica and alumina when mixed cement and reacted with water will form a pozzolan, in which the soil will be harder and more dense. The amount of a chemical compound contained: SiO₂+Al₂O₃+Fe₂O₃ = 78.38% is greater than 70%, it indicates high-quality pozzolan.

The increase in the strength of soil-cement for their primary and secondary reaction processes of the chemical cement. The primary process is the hydration of cement where cement particles form bonds between grains of soil around him. Secondary process is a process that is influenced by the increase in the strength of cement soil mix that is the reaction between soil particles with calcium hydroxide, which is free for the duration of hydration of cement. Silica and alumina will react with lime and water, the compounds form calcium silicate hydrate (CSH) that does not dissolve in water. The occurrence of these compounds has been slow, causing the soil to become harder, is denser and more stable. The test results of chemical compounds in the soil cement the amount of cement 6% and 10% as shown in Table II below.

### TABLE II - CHEMICAL COMPOSITION OF CEMENT-STABILIZED SOIL

<table>
<thead>
<tr>
<th>MINERAL COMPOSITION</th>
<th>VALUE (%)</th>
<th>CEMENT CONTENT 6%</th>
<th>CEMENT CONTENT 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe₂O₃</td>
<td>0.82</td>
<td>1.42</td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>45.40</td>
<td>37.89</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>1.58</td>
<td>1.56</td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>18.43</td>
<td>17.99</td>
<td></td>
</tr>
<tr>
<td>P₂O₅</td>
<td>1.22</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>SO₃</td>
<td>1.36</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>CAO</td>
<td>28.63</td>
<td>35.40</td>
<td></td>
</tr>
</tbody>
</table>

Shown in Table II, increasing the amount of cement resulted in chemical compound content silica and alumina in the soil has decreased, but calcium increased in accordance with the addition amount of cement. As shown in Table I the amount of calcium sandy clay soil types are relatively small, but they're stabilized with cement showed the cement hydration process in a mixture of soil and the amount of calcium increases. This process is the compound of calcium, silica hydrate (CSH) covers around granular soil with a slow time so that the soil becomes solid and hard.

Soil cement reinforced fibers can improve strength, resist deflection of crack initiation, slow deformation and increases the resistance of the shock. Serves to hold the fiber tensile force, increasing the shear strength between grains of soil so that the fiber can resist the level of cracking that occurs [6]. The increase in strength is due to the interaction interface palm fibers and cement absorption in the soil cement. Palm fibers containing cellulose and hemicellulose chemical compounds and their metals of mineral [11] that can potentially react with the cement. The results of SEM observation of the interaction interface-palm fibers in the soil cement the amount of cement 6% and 10%, as shown in Figure 5 and 6.
Fig. 5 Microstructure of the reinforcement fibers in the soil cement 6%

Fig. 6 Microstructure of the reinforcement fibers in the soil cement 10%

Shown in Figure 5 and 6 shows the behavior of cement hydration on-palm fibers. At the beginning of 50x a magnification of is not so visible clearly their behavior is only seen cement hydration calcium silica gel that surrounds the fibers. But at 500x a magnification of can be seen clearly their interaction behavior of palm fibers interface with the soil cement. Adhesion calcium silicate gel covers the entire surface of the fibers shown to increase the amount of cement, shown in Figure 5 adhesion amount of cement 6% less compared to Figure 6 the amount of cement 10%. Attached to properties of cement is also due to palm fibers have a chemical compound content cellulose and hemicellulose and metal minerals [11]. This suggests that the very palm fibers can potentially improve the strength and resilience of soil-cement to the work load static and repetitive.

Fatigue is a process of material damage due to repeated stress so that the material has decreased stiffness. Repeated load cycles with an applied load are lower than the ultimate strength can reduce stress (stress), thus causing the stress failure and flexural strength of soil-cement [4]. The resistance to deformation of the pavement due to repeated load can be measured by the resilient modulus (M_r) which is a stress-strain relationship such as modulus of elasticity. Resilient modulus, or modulus of stiffness in general is deviator stress ratio (σ_d) applied to the strain (ε_r) happened (M_r = σ_d/ε_r). To obtain the effect of the reinforcement fibers in the soil-cement-palm against the modulus of stiffness in the soil cement testing on soil cement the amount of cement 6% with and without reinforcement fibers. The results of resilient modulus testing using test equipment UTM-5P/14P, as shown in Figure 7 below. Figure 7 shows the full model experimental approach, resilient modulus visible degradation as a result of repeated load by 50% static load on the reinforcement fibers greater than without reinforcement fibers. Differences degradation resilient modulus shows that there is influence the behavior of the fibers in the cement interaction.
enforcement fiber, because the fibers contain chemical compounds of cellulose and silica [11]. Thus, fibers can make a longer lifespan of pavement made of soil cement on the load and a fixed frequency. Obtained resilient modulus increased degradation of the soil cement with and without fibers is equal to 6.50%.

IV. CONCLUSIONS

Based on test results, can be concluded as follows:

- Increase the amount of cement in the soil cement resulted in a decrease in the amount of chemical compounds of silica and alumina in the soil because there is a process of calcium silica hydrate compound surrounding soil particle.
- Interface interactions occur on a soil cement reinforcement fiber, because the fibers contain chemical compounds that can interact with cement so as to increase the strength of soil-cement.
- Palm fibers increase the resilience modulus degradation in soil cement so that the soil cement able to withstand repeated loads and long life of pavement.

REFERENCES