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Biopolymer as Environmentally Friendly Reinforcement to Overcome Cracked Soil Problems on Expansive Soil:
A Case Study at Karanggede – Juwangi Road

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ABSTRACT
The distribution of soft and expansive soil that is often found in Indonesia often causes problems in the structure above it. To build the infrastructure on expansive soil, it is necessary to improve the subgrade. One method to improve soil is to stabilize it by using biopolymers. Biopolymer was chosen because it is more environmentally friendly than the use of cement as soil stabilization. In this study, Xanthan Gum (XG) biopolymer was used, with concentrations of 1%, 2%, and 4%. Testing was carried out experimentally in the form of testing physical and mechanical properties as well as cyclic drying testing. From the results of the analysis, the XG biopolymer can reduce the number and width of cracks after experiencing a drastic reduction in water content. A positive impact was also obtained on the mechanical analysis with the addition of biopolymers that could increase the compressive strength of the soil up to 432% and the shear strength of the soil up to 482%.

Keywords: *Expansive soil, biopolymer, cyclic drying, crack soil, compressive strength.*

1. INTRODUCTION

Indonesia has various problems regarding soft and expansive soils. Soft soils and expansive soils tend to give direct and situational problems to the building structures erected on them. Soft soils are generally categorized as soils where the properties of the soil are unable to withstand or support the building without repair or special treatment. Expansive soils are soils that expand when saturated with water and shrinks (soil cracks) when dry, causing extreme volume changes and can cause the structure above to become unstable [1]. Figure 1 is a map showing the distribution of problematic clay soils in Indonesia where on each island there are clay formations that are categorized as expansive soils. [2]. In the case of slopes, cracks in the soil can reduce stability through three stages. First, soil cracking can increase the permeability value and decrease soil strength. Second, water can fill voids in soil cracks and provide an additional driving force to the ground. And finally, cracks in the soil become a critical part that reduces the shear stress of the soil [3][4]. Therefore, it is important to prevent cracks due to the drying of the soil.

Figure 1 Distribution of problematic clay soils in Indonesia [2]

As previously explained, this research was conducted on Karanggede – Juwangi Road, Boyolali. The condition of this road infrastructure is at an alarming level. Based on the survey results on February 6, 2021, it was found that the road damage was quite severe, although the road had done repairs in December 2020. Figure 2 shows an example of road damage on the Karanggede - Juwangi Road. Although repairs have been made, in a short time (2 months), the road is damaged again as indicated by the presence of landslides, differential settlement, and cracks.

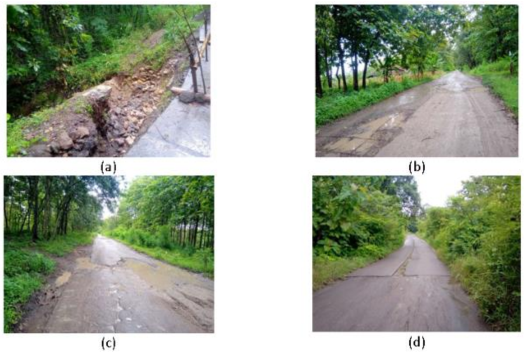


Figure 2 (a) Landslides; (b) settlements, cracks, potholes, and spalling; (c) deflections, cracks, and holes; (d) Fault cracks

Crack soils tend to crack when they dry. However, the precise mechanism of cracking is imperfectly understood [5]. Cracks can be a major unwanted feature in the number of geoengineering applications as well as in some other disciplines. For instance, in geoengineering shrinkage cracking is significant in earth embankments, slopes, foundations, and roads [6]. The conventional cement mixture is a material that is often used in slope stabilization. The use of cement can increase the value of the shear angle in the range of 32^{o}-43^{o}, while the value of the elastic modulus can be formulated by Esoil-cement=12900√qu0.41 [7]. However, this can cause unwanted environmental problems such as carbon emissions, according to [8] the cement industry contributes 1 ton of CO2/ton of production. To minimize these problems, environmentally friendly reinforcement can be an alternative to cement mixtures. Biopolymers are natural biodegradable polymers that are accumulated by microorganisms [9]. The utilization of biopolymers in civil engineering is a sustainable technology because biopolymers can be used as organic additives in traditional cement materials [10]. Tests for the strength of the mixture of biopolymer and soil have been carried out [11], that the addition of biopolymer can provide additional compressive strength from the initial 181 kPa soil to a maximum of 7,087 kPa with 4% XG biopolymer added. However, testing of biopolymers on the swelling and shrinkage of the soil that causes soil cracking due to drying and wetting of the soil has not been carried out.

So far, soil crack testing has not had a standard of reference testing. However, the frequency parameter of the distribution of cracks has been developed to evaluate changes in the test object relative to the area of the initial test object. In addition to cracks in the surface, the depth of the crack can also be analyzed using image analysis techniques [12]. From Figure 3 it appears that the original image was converted into a binary image, then sharpened on the cracked part. For more in-depth analysis using Scanning Electron Microscope (SEM-EDS). Other uses of SEM can be used in analyzing micro cracks. EDS is used to determine the elements contained in the test object.EDS used is in the mapping (distribution) that is to know the distribution of elements contained in the test object [13]. The purpose of this study is to determine the influence of the use of biopolymers as an environmentally-friendly strengthening to overcome the problem of cracked soil on expansive soil through the case study of Karanggede – Juwangi Road.

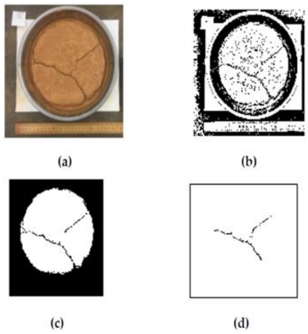


Figure 3 (a) original photo test object; (b) binary image of the original photo; (c) binary image of test objects; (d) binary image of cracks [12]

2. LITERATURE REVIEW

2.1 Crack Soil

Cracks in soil are natural phenomena that involve physical, chemical, mechanical, hydraulic conductivity properties and are related to seasonal variations in the soil environment itself. According to [14] cracks in the soil are caused by an internal energy imbalance in the soil mass caused by uneven soil moisture, temperature distribution, and soil compaction distribution during the construction process.

2.2 Biopolymer

Biopolymers are natural polymeric materials extracted from organisms. The accumulation of monomers forms large macromolecules called biopolymers. One type of biopolymer is Xanthan Gum or can be denoted as XG is a polysaccharide made through the fermentation of carbohydrates such as glucose. Xanthomonas bacteria are used in the fermentation process. XG can be dissolved in cold water or hot water. XG is widely used in the cosmetic industry, agricultural industry, and in civil engineering [15].

2.3 Soil Mechanics

Soil Mechanics is a discipline of Civil Engineering involving the study of soil, its behavior, and application as an engineering material. Soil Mechanics is the application of laws of mechanics and hydraulics to engineering problems dealing with sediments and other unconsolidated accumulations of solid particles, which are produced by the mechanical and chemical disintegration of rocks, regardless of whether they contain an admixture of organic constituents. Soil consists of a multiphase aggregation of solid particles, water, and air. This fundamental composition gives rise to unique engineering properties, and the description of its mechanical behavior requires some of the most classic principles of engineering mechanics. Engineers are concerned with soil's mechanical properties: permeability, stiffness, and strength. These depend primarily on the nature of the soil grains, the current stress, the water content, and unit weight. [16]

3. METHODOLOGY

This research is divided into three main parts, namely testing the physical properties of the specimens, testing the drying cracks of the soil with and without additional materials in the form of biopolymers, and testing the mechanical properties of the soil in the form of compressive strength testing and shear strength testing. The biopolymer added material used is XG with a concentration of 1%,2%,4% of the sample weight. The research method in a flow chart can be seen in Figure 4

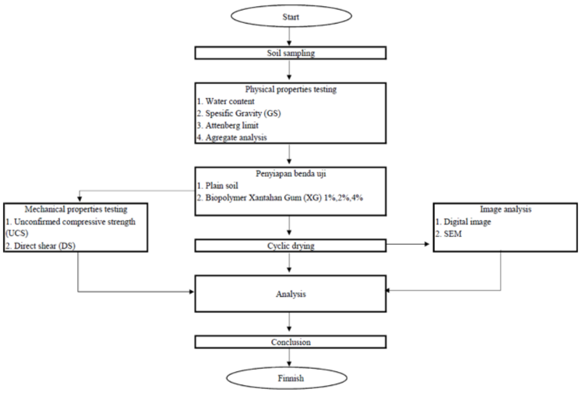


Figure 4 Flow chart

The soil sample used in disturbed soil with a maximum depth of 2 meters and undisturbed soil was taken from the Karanggede - Juwangi Road Section. The sampling technique for this research was carried out directly in the field using the hand boring method. Hand boring is drilling manually by using hands to take undisturbed soil samples which are inserted into standard 4-inch diameter pipe tubes for laboratory investigation purposes. The planned sampling point is two points, namely at STA 8+000 and STA 12+500 with one point of collection a maximum depth of 10 meters. Further retrieval of the required test objects can be seen in Table 1. From these two points, there were 7 tubes of undisturbed soil with varying depths and one full sack of ±20 kg of disturbed soil.

4. ANALYSIS

The results of this study generally include 5 categories, there is soil classification based on USDA, USCS, and AASTHO; the potential for swelling and shrinkage of the soil through the seed diagram; mineral content in SEM experiments; cyclic drying at room temperature and acceleration temperature; and the mechanical properties of the soil, namely the compressive strength and shear strength of the soil. The following is an explanation and discussion of the results of soil testing in the laboratory.

4.1 Soil classification

The results of laboratory tests according to Table 1, shows that the soil on Karanggede - Juwangi Road is homogeneous (overall has the same characteristics) and is a fine-grained soil type with an average grain size percentage of >50% of the soil passing the No. sieve. 200. The liquid limit value (LL) is 45% - 79%, the plastic limit (PL) is 19% - 24%, and the plasticity index (IP) value is 23% - 54%. According to the USDA (United State Department of Agriculture) classification, the soil is clay to loamy clay with high plasticity (CH) properties when referring to the USCS (Unified Soil Classification System) classification. AASTHO (American Association of State Highway Officials) categorizes the soil samples into the soil group A-7-6. Based on laboratory data that refers to the AASTHO classification, the rating or assessment of the soil on Karanggede - Juwangi Road as a subgrade material is poor.

Table 1. Soil classification

Sample -Id.	Attenberg Limit (%)			Classification		
	LL	PL	IP	USDA	USCS	AASTHO
D1	55.0	21.8	33.1	Loam	CH	A-7-6
BH I – 0.5	79.0	24.8	54.3	Sandy Clay Loam	CH	A-7-6
BH I – 2.0	68.0	23.4	44.7	Sandy Clay Loam	CH	A-7-6
BH I – 7.0	50.0	19.1	30.9	Loam	CH	A-7-6
BH II – 1.0	45.5	21.6	23.9	Clay Loam	CL	A-7-6

4.2 Swell and activity potential

Based on Table 2, soil can be categorized into expansive soil groups if it has expansive potential and high activity level. The value is influenced by clay content (CF), plasticity index (IP), and activity level (Ac). The sample data mode has a high expansive potential value and a high level of activity. Judging from the shrinkage properties of the soil, it is shown in Figure

5. The test objects are classified as high to very high swelling and shrinkage characteristics. So, its contribution to damage is very large because through this characteristic it is very likely that changes in water content in the soil will occur as well as the potential for expansive and shrinkage during the climate transition (temperature) from the rainy season to the dry season. this has an impact on road damage in the form of cracks that can be identified through the road surface, namely subsidence damage followed by the release of granules and causing holes so that it has a more severe sustainable impact.

Table 2. Soil potential

Sample - Id.	Swell Potential			Activity Level	
	Chen	Holz & Gibs	Ramen	Skempton	Seed
D1	High	High	Very high	Active	High
BH I – 0.5	Very high	Very high	Very high	Active	Very high
BH I – 2.0	High	Very high	Very high	Active	Very high
BH I – 7.0	High	High	High	Active	High
BH II – 1.0	High	Normal	High	Normal	High

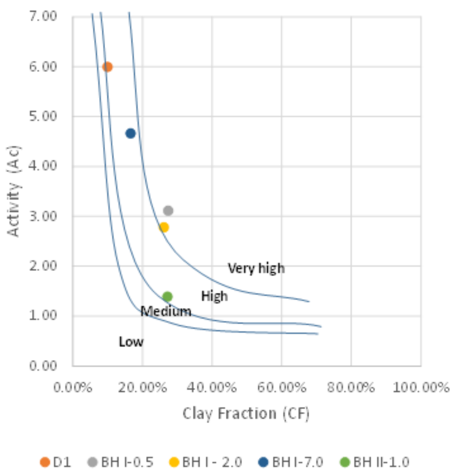


Figure 5 Seed method

4.3 Mineral content

Expansive properties can also be known through the mineral content in the soil. The mineral content of montmorillonite contained in clay is known to have the highest level of activity. In the mineral montmorillonite, the main elements are silica (Si) and aluminum (Al) with a little magnesium (Mg). Based on the SEM experiment according to Table 3 and Figure 5, the Si and Al elements are the dominant elements besides the Oxygen element with the respective percentages being 20.64%, 11.04%, and 57.54% respectively.

Table 3. The elemental content of the sample

Element Symbol	Atomic Conc.	Weight Conc.
O	72.14	57.54
Si	14.74	20.64
Al	8.21	11.04
Mg	1.14	1.32

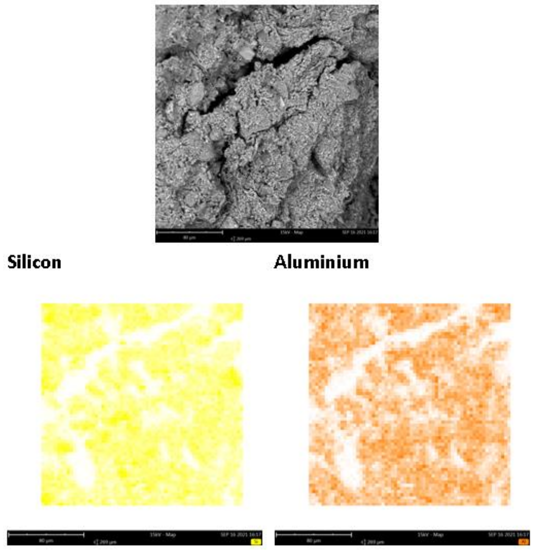
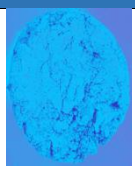
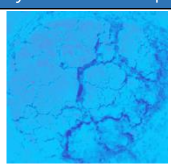


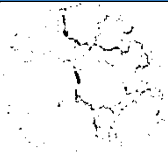
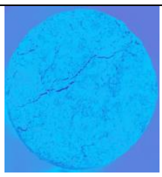
Figure 6 Distribution of Si and Al elements

4.4 Cyclic drying

Table 4 shows the thermal and binary photos of plain soil that have undergone cyclic drying. Biopolymer is proven to reduce the number and width of soil cracks due to reduced water content show in Figure 7, the use of XG biopolymer can reduce the number of cracks by 46.0% at room temperature. While according to Figure 8 XG biopolymer can reduce crack width from an average of 2.6 mm to 0.9 mm at room temperature.

Table 4 Cyclic drying

Cyclic room temp.	Cyclic acc. temp.
 Plain soil thermal photo	 Plain soil thermal photo

Cyclic room temp.	Cyclic acc. temp.
 Plain soil biner photo	 Plain soil biner photo
 XG added a thermal photo	 XG added a thermal photo
 XG added biner photo	 XG added biner photo

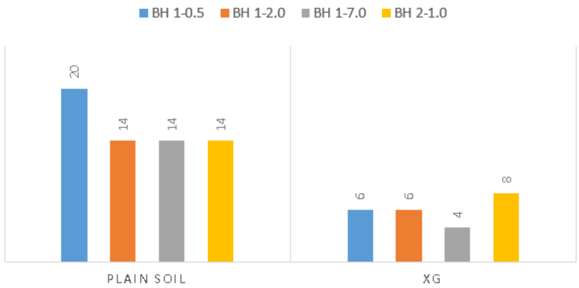


Figure 7 Number of cracks on cyclic drying (room temperature)

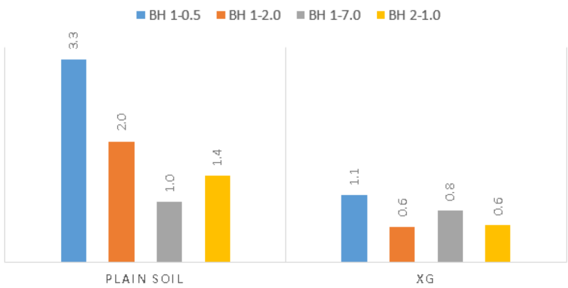


Figure 8 Average width of crack on cyclic drying (room temperature)

Figures 10 and 11 show cyclic drying at an accelerated temperature. the use of XG biopolymer proved to be good in reducing the number of cracks by 46.0%. Meanwhile, in terms of reducing the crack width of the XG biopolymer, it is also equally good, the resulting width is 0.9 mm from the average crack width without biopolymer is 2.6 mm.

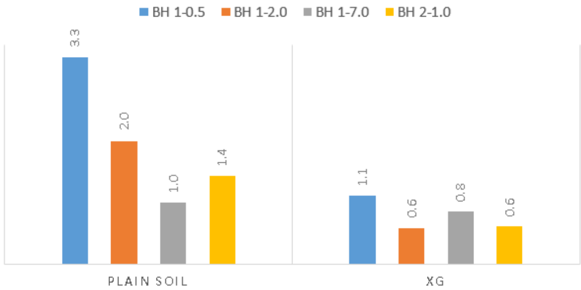


Figure 9 Number of cracks on cyclic drying (accelerate temperature)

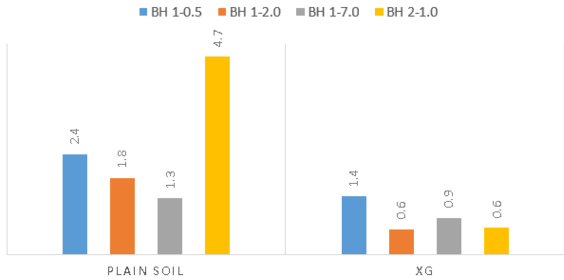


Figure 10 Average wides of crack on cyclic drying (accelerate temperature)

4.5 Mechanical properties (compressive strength)

In Figure 11 the application of XG biopolymer with a concentration of 4% can increase the average strength from 16.50 KPa to an average of 123.86 KPa or an increase of 432%. However, the increase in compressive strength from the addition of 2% XG to 4% is not significant, which is 34%. The addition of 2% XG is considered the best choice because the increase from adding 1% to 2% XG is very large, which is 257%. The application of biopolymers also increased the soil consistency from very soft (qu < 0.25 ton/ft^2) to stiff consistency (1<qu<2 ton/ft^2).

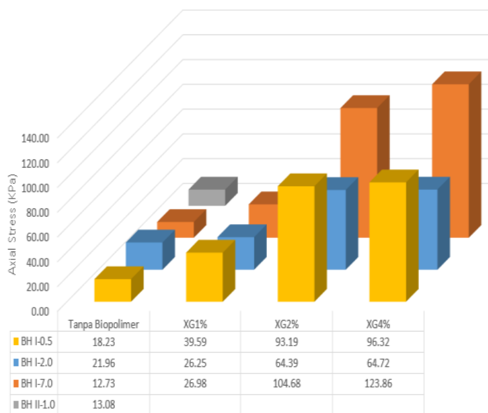


Figure 11 Axial stress

4.6 Mechanical properties (shear strength)

In this study, the specimens were mixed with 2% biopolymer which was then printed in a cylindrical container with a height of 1-2cm and a diameter of ±6cm.

The choice of 2% biopolymer mixture was due to the previous free press test it was known that the use of 2% biopolymer was the most effective. In Figure 12, the application of XG biopolymer can increase the average shear strength value by 482%. The consistency of the specimens from soft also increased to stiff consistency on the use of XG.

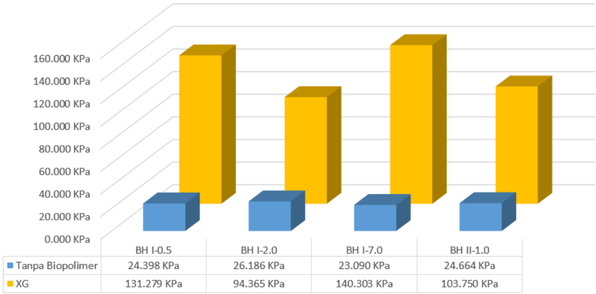


Figure 12 Shear strength

5. CONCLUSION

1. The soil on Karanggede - Juwangi road is expansive soil with high to very high swelling potential and activity.
2. In addition, XG biopolymers were proven to reduce the crack width and number of cracks after the cyclic drying process.
3. The application of XG biopolymer with a concentration of 4% can increase the compressive by about 432%. The application of XG biopolymer can also increase the average shear strength value by 482%.
4. The increase in compressive strength from the addition of 2% to 4% biopolymer was not significant, which was 34%. Meanwhile, the addition of a 2% biopolymer is the best choice because the increase from the addition of 1% to 2% biopolymer is very large, which was 257%.

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