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Article

The Potential of Polyacrylamide Polymer to Reduce Cracking During Wetting-Drying Cycles

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Abstract. This paper presents the potential of polyacrylamide (PAM) polymer to reduce cracking during wetting-drying cycles. Several experiments have been conducted to investigate PAM polymer in high plasticity silt soils to reduce soil cracks and increase soil strength properties. In this study, Polymer was mixed in soil with different PAM variations (0.2%; 0.4%; 0.6%, 0,8% and 1% by weight). The behaviour of each soil sample was measured by a thermal imaging technique and confirmed by microstructural analysis. The patterns of the soils captured by the camera were quantified using image processing. The experimental results show more cracks in the initial soils than in treated soils. This was confirmed by the SEM test, which showed pores of soil particles. The results also show the role of PMA in reducing the initial void ratio could lead to an increase in bearing capacity. The interaction between PAM and soil particles could also reduce the crack potential. This is because there is solid bonding within soil mass after PAM treatment. In general, this study demonstrates the potential of PAM to reduce cracking and increase soil strength, as well as bring new insights into the design and assessment of sustainable infrastructure under climate change.

Keywords: Cracks, thermal imaging technique, silt soils, polyacrylamide.

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1. Introduction

Soil characteristics could influence physical and engineering properties. Soils with loose saturated conditions could undergo the impact of earthquake shaking [1-2], whereas soil with low shear strength could undergo slope failure [3]. Therefore, the effort to improve the soil shear strength and reduce the potential failure damage to the environment, in terms of natural and artificial improvement could be implemented [4]. In addition, the waste material could be employed to reduce environmental damage and to improve other materials characteristics, such as concrete [5].

In line with the environmental issue, Indonesia is a tropical nation with heavy rainfall, which increases the risk of landslides on slopes. Compared to other natural catastrophes like floods, earthquakes, and hurricanes, landslides are the most destructive and can result in more considerable material loss [6-7]. In addition to rain, the soil condition can also contribute to landslides. Cracked soil conditions can hasten precipitation infiltration and maintain water pressure along the soil fissures, putting the slope in critical condition [8]. Low bearing capacity can present in critical slope circumstances. Based on these issues, stabilising is required to enhance the soil.

Ground improvement has become a new concern in geotechnical and environmental engineering because of the development of technology to improve and modify soil characteristics. The use of additional materials such as fibre could be implemented for soil improvement [9, 10], materials. Other waste materials such as fly ash [11, 12, 13], and palm oil fuel ash [14] could be also used for soil improvement. Chemical stabilisation can enhance soil performance as measured by the bearing capacity of soil [15-16]. In recent years, many researchers have developed innovative additives that are easy to find and can reduce pollution [17-19]. Polymer is one of several substances that can be utilised as soil stabilising agents. Polymers are more environmentally friendly than cement and lime in terms of greenhouse gas emissions and consumption of natural resources and energy [20-21]. Polyacrylamide (PAM) is an increasingly popular polymer as a soil-stabilizing agent and is most widely used for controlling soil erosion, maintaining high water infiltration rates, and improving vegetation growth [22-23]. PAM has recently been introduced into the soil treatment processes in geotechnical engineering [24-25]. PAM is divided into three types (cationic, anionic, and non-ionic) which are used to improve soil with poor quality [21, 24, 27-28]. Several studies have found that anionic polymers are suitable for admixtures in all cohesion soil (clay and silt). This is evidenced by an increase in soil density and ionic mechanism, as seen from the microstructure images [23-24, 29]. Therefore, soil with high water content (clay and silt) is more suitable for stabilisation with anionic PAM.

Many researchers have studied the behaviour of PAM-treated soils in the laboratory [22, 24, 30-35]. It has been concluded that adding PAM can effectively improve the mechanical and physical properties of soils from the compressive, shear strength, and permeability tests. Previous studies have investigated PAM behaviour only on soil mechanical and physical properties. Considering Indonesia's environmental tropic conditions, it is expected that seasonal phenomena such as wetting and drying often occur, so further study is needed towards the desiccation crack of soil. The drying process allows for proper tracking of strain and shrinkage cracks, even as cracks continue to propagate until the water content reaches the shrinkage limit [36-37]. Shrinkage cracking in soils can cause cracking of the subsoils. It is a general damage to the operation of roads and building structures which leads to an increase in construction cost for maintenance of unstable soil [38].

Cracks are a common natural phenomenon that often occurs during soil wetting and drying [39-40]. This happens because the soil loses water due to evaporation [41-43]. In general, the formation and enhancement of cracks can reduce soil strength properties and soil stability, which tend to damage buildings and geotechnical structures (foundations, embankments, and waste storage) [20, 29, 44]. Considering the effects of soil desiccation cracks, the quantitative analysis of cracks is of great significance to the study of soil cracking. Several studies have introduced the crack intensity factor (CIF), which was defined as the ratio of crack area to the total surface area of the dry soil mass [19, 29, 41, 45-46]. However, the initial crack patterns are often distributed by human activity, environmental influences, and tools, leading to significant measurement errors [20]. With the continuous improvement of computer technology and the development of software and image processing techniques, using computers to process and calculate crack pattern images and obtain related crack parameters has gradually become a research focus.

This laboratory study examines the potential use of anionic PAM as an environmentally sustainable material for stabilising a high plasticity soil from West Bandung Regency, West Java, Indonesia. The main objective is to investigate the effects of PAM mixture on soil consistency, shrinkage limit, and desiccation cracking in silt soils under the wetting and drying processes. The effect of the PAM mixture on the improvement of soil properties is also presented. A Scanning Electron Microscope (SEM) analysis has been carried out to support the laboratory results data and better insight into the stabilisation mechanism in microstructural. In addition, this study could provide a better understanding how the performance of PAM to reduce cracking during wetting-drying cycles.

2. Materials and Methods

2.1. Materials

2.1.1. Soil

The West Bandung area (Cihanjuang Village) is 12,8 km from the capital city of West Java Province, Indonesia.

The location of soil samples for this study is shown in Fig. 1. Soil samples were obtained from Cisasawi Road at depths of 0 – 1.5 m and 2.0 – 2.5 m. The soil properties, such as density, natural water content, optimum water content, plasticity, and soil classification, are shown in Table 1. As shown in Fig. 2, soil classification based on the Unified Soil Classification System (USCS), the soil materials were classified as high plasticity silt (MH) with an optimum moisture content of 36.6% and plasticity index of 18.98%. The gradation curve of the soil sample is presented in Fig. 3.

2.1.2. Polyacrylamide Polymer (PAM)

An anionic PAM is used in this study because of its suitability as a soil stabiliser (Fig. 4). The main chemical structure of anionic PAM is composed of the long chain of hydrocarbons ($\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-}$) and their amide chain groups (-CONH_2) [16]. PAM is a water-soluble polymer with a white powdery texture. The PAM used in this study has a pH of 6.5 ≤ 1.0 and a viscosity of 50 ± 25 Cps. Figure 1 shows the PAM morphology images obtained from the SEM test described in previous studies [47]. It can be seen that the mono-polymer elements are placed close to each other when magnified 500 times. There are relatively small gaps indicating no connections in the polymer group. The mono-polymer is snow-like chunks consisting of an acrylamide chain in PAM.

First, PAM is dissolved in water with a mixer. It was conducted for 15 minutes. Then, mixing the PAM with the soil for 8 minutes is carefully mixed by hand. To have homogeneity and better absorption, the mixture was transferred to a plastic bag sealed firmly and kept for 24 hours before the moulding step. After one day, the soil was compacted by the standard proctor method for consolidation, UCS, CBR and thermal imaging tests based on ASTM D-698-89 standard. An extruder was prepared for sample extraction (consolidation, UCS, and thermal imaging). The shrinkage limit test samples were made without compaction method and curing time. The curing process was conducted by wrapping the samples tightly using plastic wrap and aluminium foil and then saving them at room temperature. Compacted soil samples were crushed into small pieces and dried to prepare the samples used in the SEM tests. Before the SEM test, the sample was polished and then coated with gold for 300 seconds to improve conductivity.

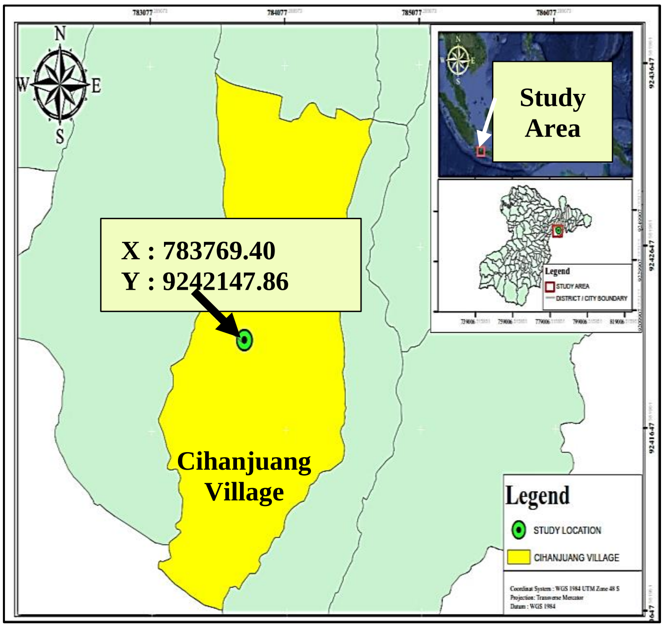


Fig. 1. Sampling site.

Table 1. Properties of selected soil.

Description	Value
Density (kN/m^3)	16.4
Water content (%)	41.28
Optimum moisture content (%)	36.6
Plasticity index (%)	18.98
Shrinkage limit (%)	32.43
Unified Soil Classification System	MH

2.2. Sample Preparation

Initial sample preparation was carried out by passing the soil with Sieve No. 4 and 40. The soil sample that has been made as the treated sample was added with an optimum water content of about 36.6% because the soil strength is affected by this parameter so it can produce effective results [48]. PAM was used in the required percentages (0.2%, 0.4%, 0.6%, 0.8%, and 1%) from the dry weight of the soil. The notation of variables can be seen in Table 2.

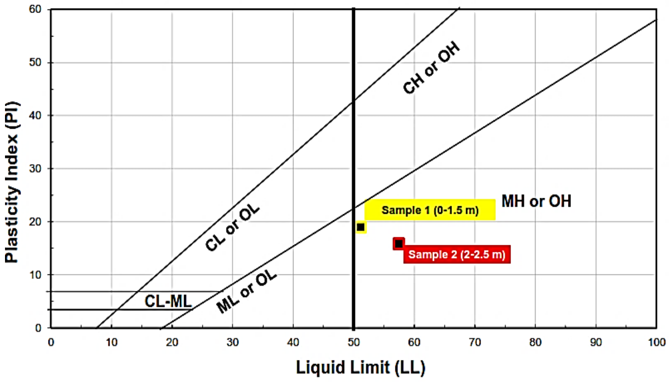


Fig. 2. Plasticity chart for soil sample.

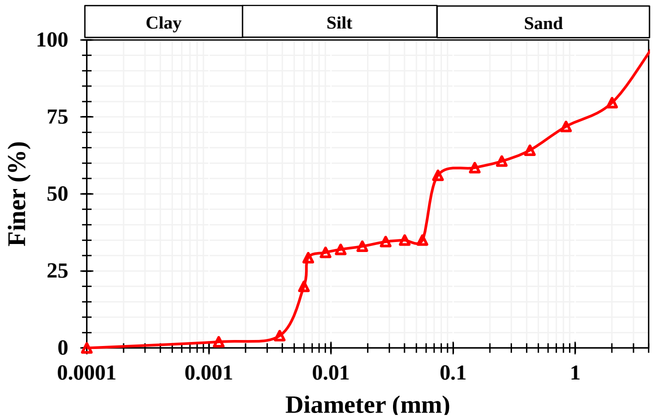
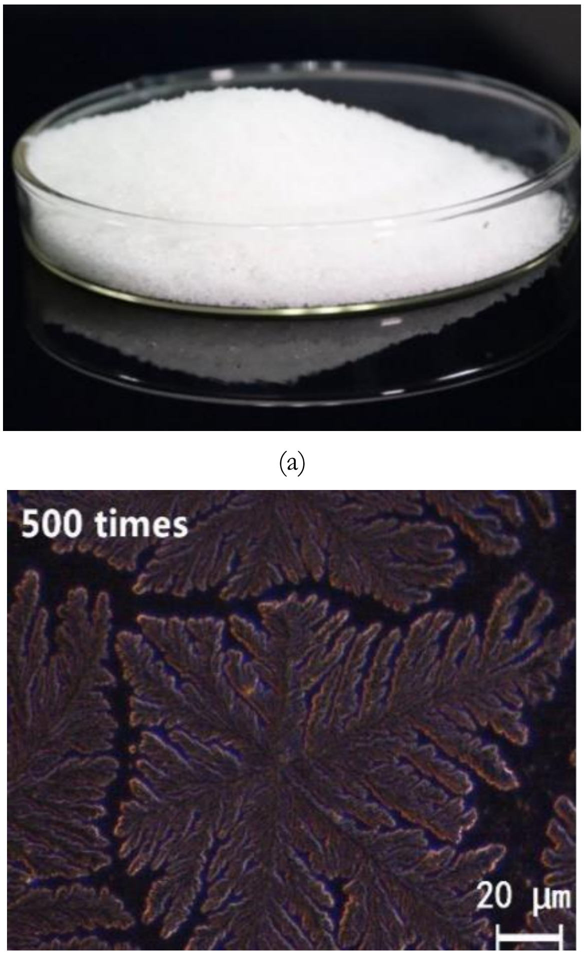


Fig. 3. Grain size distribution of soil sample.

For UCS and consolidation samples, the soil was cured for seven days. Meanwhile, the thermal imaging test was cured for 14 days. Six compacted samples were prepared for the CBR test—three samples for soaked and three for unsoaked. CBR samples are made without curing time.



(a)

(b)

Fig. 4. PAM as an additive in this study. (a) Physical PAM and (b) SEM image.

2.3. Test Methods

Table 3 presents the summary of tests that are conducted in this study. The list of tests presented in Table 3 refers to the general procedure implemented for standard testing. The test is performed under two conditions, i.e., with PAM and without PAM. The test procedures for each item are based on the American Society for Testing and Materials (ASTM).

2.3.1. Shrinkage Limit Test

The procedure of the Atterberg limits test was tested according to ASTM D-427-89 for determining the shrinkage limit of soils.

2.3.2. Unconfined Compressive Strength Test

Unconfined compressive strength (UCS) test according to ASTM D-2166-89. Soil samples have a height of 74 mm with a diameter of 37 mm. Samples were observed using a load capacity of 10 kN and a strain rate of about 1%. From the UCS test, the compressive strength value (q_u) has been plotted in the curve of the relationship between q_u and PAM variation.

Table 2. Variable in this study.

Description	Variable
Initial soil	P0
Soil + 0.2% PAM	P1
Soil + 0.4% PAM	P2
Soil + 0.6% PAM	P3
Soil + 0.8% PAM	P4
Soil + 1% PAM	P5

Table 3. Summary of Experimental Tests.

Experimental Test	Reference Standard	Under condition	
		With PAM	Without PAM
Shrinkage Limit	ASTM D-427-89	√	√
Unconfined Compressive Strength	ASTM D-2166-89	√	√
Compressibility Test	ASTM D-2435-89	√	√
California Bearing Ratio	ASTM D-1883	√	√
Thermal Imaging Test	ASTM E1213-14(2018)	√	√
Scanning Electron Microscope Test	ASTM E 1508	√	√

2.3.3. Compressibility Test

Compressibility tests were carried out by using a one-dimensional consolidation compression test. It was conducted according to ASTM D-2435-89. Soil samples have a height of 2 cm and a diameter of 50 cm. Loading is carried out in stages by applying pressure of 25, 50, 100, 200, 400, and 800 kPa. Manometer readings are carried out at time intervals of 0, 0.25, 0.5, 1, 2, 4, 8, 15, 30, 60, 120, 240, 480, and 1440 minutes. The axial deformation of the sample was measured with a dial gauge with an accuracy of 0.01 mm. The coefficient of compressibility was calculated using the following question:

$$C_c\ (\%) = \frac{e_1 - e_2}{p_2 - p_1} \qquad (3)$$

where a C_c is the coefficient of compressibility, e_1 and e_2 are a void ratio, p_2 and p_1 are pressure

2.3.4. California Bearing Ratio Laboratory Test

The strength of the soil was tested by the California Bearing Ratio (CBR). Specification of CBR machine with a capacity of 50 kN and a dial gauge with 0.01 mm accuracy. It was tested based on SNI 1744-1989 and ASTM D-1883 standards with 10, 30, and 65 hits for each sample. CBR samples were prepared with OMC conditions from standard proctor test results [49].

2.3.5. Thermal Imaging Test

The thermal imaging technique is the following procedure, done after cycle drying. This drying cycle uses a picture to assess the thermal photo produced. The thermal imaging technique was applied to obtain quantitative and accurate data for cracking behaviour analyses. In this study, the analyses of image processing are introduced by the previous method [29, 41]. The procedure transfers the original colour image to grayscale – image binary - image denoising – crack skeletonising. This process uses Matlab MathWorks software by importing digital pictures to take the form of a file with the extensions *.gif, *.jpg, or *.png. The photos are analysed in a matrix arrangement. The squares that make up the matrix are known as pixels; a picture with excellent resolution has a high pixel density. The black area represents cracks, and the white areas represent the soil clods. Closed operations repair individual fracture gaps and remove the good spots. The crack node can be determined for crack regions based on the number of surrounding pixels. By tracing and identifying adjacent nodes, the central axis of the crack, which is also considered the skeleton of the crack, can be determined. The determination of crack intersections, length and number is based on the skeletal network formed by the crack skeleton [29, 47].

2.3.6. Scanning Electron Microscope Test

They were scanning Electron Microscope (SEM) tests to investigate the microstructure and the pore characteristics of treated soils. The samples were cut into pieces with approximately one cm^3, gold coated, and then scanned by a high-resolution SEM machine. The SEM test referred to Hitachi SU3500 SEM Manual Book with EDAX Octane Pro. The SEM instrument had a voltage acceleration of 10 kV. During testing, the room temperature was 22°C with 40% humidity.

3. Result of Analysis

In this study, the method of soil wetting-drying cycles was adopted based on the previous study [19, 41, 50] and used to collect the patterns parameter of soil samples under dry shrinkage conditions. In addition, to support crack parameters, physical and mechanical soil tests and microstructure image analyses have been carried out.

3.1. Analysis of Shrinkage Limit Test Results

The untreated and treated soils' shrinkage limit (SL) was analysed. SL occurs when soil samples are oven-dried at 105°C - 110°C. Table 4 summarises the SL results. It can be seen that the SL of the initial soils is lower than that of the treated soils. The SL decreased from 32.43% to 25.58%, consistent with previous studies [19]. The decrease of the SL in the PAM-treated soil has occurred due to the bonding strength of the soil particles due to a substance produced in the soil by the hydration reaction between PAM and water.

The reaction between PAM and soil can be explained based on this reaction, $2Al(OH)_3 + 3(COOH)_2 \rightarrow Al2((COO)_2)_3 + 6H_2O$. Based on ionic characteristics, MH soils consist of carbon (C), alumina (Al), silicon (Si) and oxide (O). When PAM is added to high-plasticity silt soil, the soil microstructure changes. This happens because PAM reacts with water to form Aluminium Oxalate ($Al2((COO)_2)_3$). From the chemical reaction of the soil mixture with PAM, it is known that the chemical compound Aluminium oxalate has reduced the water layer on soil particles. The reason for the increase in soil strength can be explained briefly PAM reacts with CO2 in the air to form an acidic chain structure. Aluminium Oxalate compounds can likely improve the mechanical behaviour of soil as evidenced by increasing friction between particles and soil-bearing capacity.

Table 4. Shrinkage Limit of Initial and Treated Soils.

Variable	Water Content (%)	Shrinkage Limit (%)
P0	69.52	32.43
P1	59.16	29.20
P2	61.77	28.73
P3	57.17	27.74
P4	55.67	26.07
P5	50.53	25.58

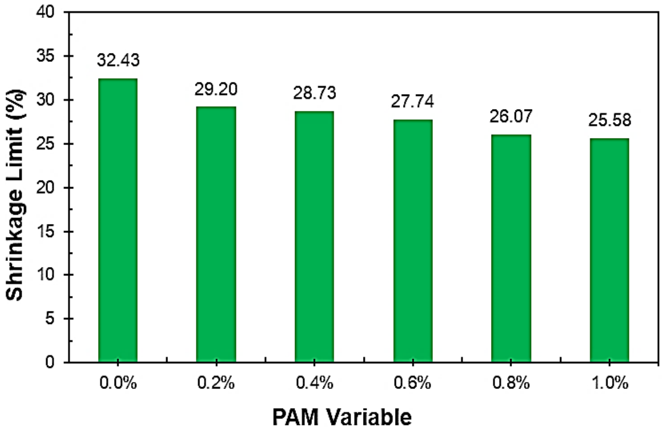


Fig. 5. Effect of PAM on Shrinkage Limit of Soils.

The effect of PAM on treated soils is shown in Fig. 5. Based on the analysis, the SL decreases when the percentage of PAM decreases. The SL of the 1% PAM is higher than other samples. The SL dropped from 32.43% to 29.20%, 28.73%, 27.74%, 26.07, and 25.58% when the soil is partially treated by 0.2%, 0.4%, 0.6%, 0.8%, and 1% PAM respectively. Generally, it can be concluded that soil stabilisation by PAM effectively reduces soil shrinkage.

The decreases in the SL under PAM adding may be explained by the absorption process of PAM in soil particles; PAM chains displace water molecules on the external surface of soil particles [51]. The influence of PAM on soil consistency is related to the water absorption process by PAM that occurs on the soil surface. The PAM mixing process takes place relatively quickly and then becomes a larger suspension so that it can absorb water in a relatively short time, this was explained by Soltani et al. [54]. From Soltani et al. [54], the suspension formation process had affected PL, LL, and SL. In terms of PI, the addition of PAM indicates a shrinking of the pore space in the soil so that the soil particles approach each other and cause the soil to become compacted which results in the PI value decreasing. This phenomenon is also observed by Zhou et al. [22] who show PI is reduced by adding PAM.

3.2. Analysis of Unconfined Compressive Strength Test Results

UCS samples were measured. Obtained data are shown in Fig. 6. UCS increases with decreasing water content samples. As shown in Fig. 6, the mechanical properties of soils are poor (at P0) because the initial soil has a high water content, so the soil is saturated due to water. The maximum UCS of 531.47 kPa was obtained in treated soil samples with 1% PAM content. Soil samples in treated conditions generally have higher UCS than untreated soil. The UCS decreases with increasing wetting-drying cycles, even at the same water content. The strength reduction is observed between the first drying stages after the water content reduces to less than 50%, and the reduction increases with further decreasing water content (Fig. 7). When compared, the variation of strength reduction from P1 up to P5 was quite significant over the whole drying period.

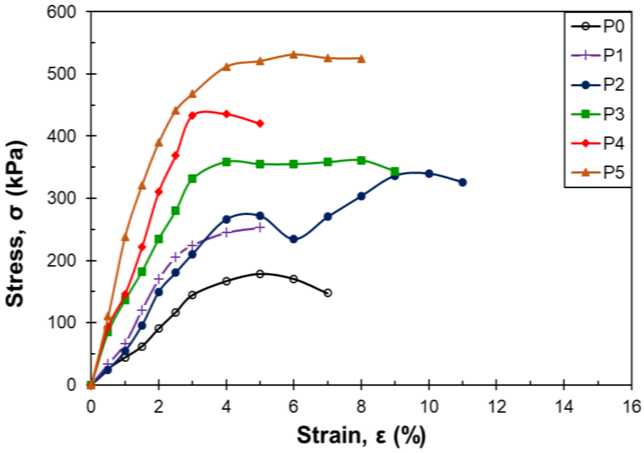


Fig. 6. Effect of PAM on UCS test.

However, more than these results are needed to be used as a reference for measuring soil-bearing capacity on a field scale because this study is still being carried out at a laboratory scale using the UCS test machine. PAM soils are generally unsuitable enough to support engineering construction, such as roads, buildings or hydraulic structures. The properties of PAM can be improved by adding additional materials such as aggregate, cement, or other materials that have high strength [24, 26, 52].

3.3. Analysis of Compressibility Test Results

Figure 8 shows the void ratio compelling stress plots for the seven days of cured untreated and treated soil. All samples showed a complete transition from initial over-consolidated behaviour to normally consolidated behaviour toward the latter loads. From the void ratio and Log P curves, C_c values have been obtained, which have been calculated using the empirical Eq. (3), as shown in Fig. 8.

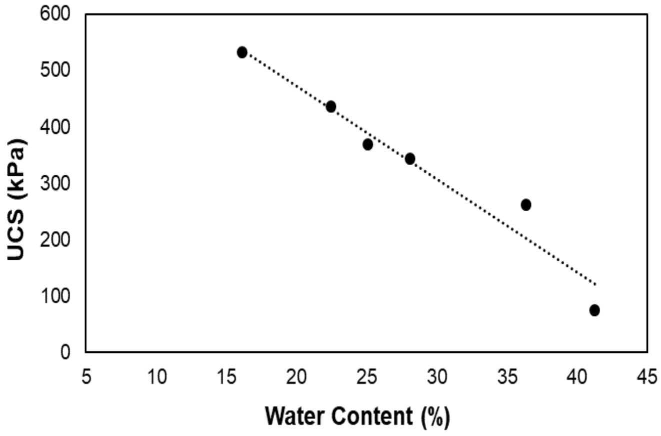


Fig. 7. UCS of samples in Each Drying Stage.

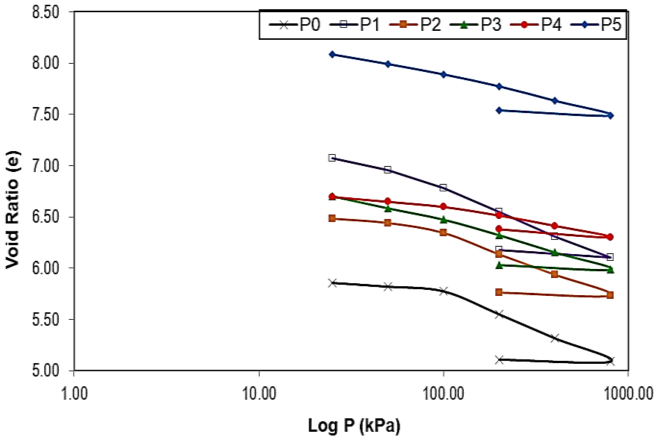


Fig. 8. Effective Stress Curves on Compressibility Test.

Since the silt soil used in this study is very responsive to settlement, achieving a constant or precisely over several stress increments was impossible experimentally [53]. From Fig. 8, it is apparent that the change in the void ratio with increasing axial stress was significantly less for the treated soils than the untreated soil (P0). Therefore, the curves show a higher compressibility resistance to loading. However, in the last two, the voltage increases, namely 200–400 kPa and 400–800 kPa; the slope of the pore ratio effective stress curve for all observed samples is almost the same, and therefore the test is stopped to calculate the compression index. Consequently, from Fig. 9, it was observed that with the addition of PAM, the compression index of the PAM-treated soils was reduced by about 34.19%.

The reduction of compressibility index, upon hydrated PAM addition, may occur due to the formation of soil particles during curing, the formation of acrylamide bonds that bind soil particles together during hardening and form bridge between mixed particles (such as cation exchange and flocculation), which strengthens and improves the soil to compression [54]. In other observation, the reductions of compressibility caused by the inclusion of 0.2% to 1% PAM could be related to the formation of an element due to the mixing of soil and PAM, where PAM acts as a reinforcing element in binding soil particles together, thus facilitating a better resistance to compressional loads.

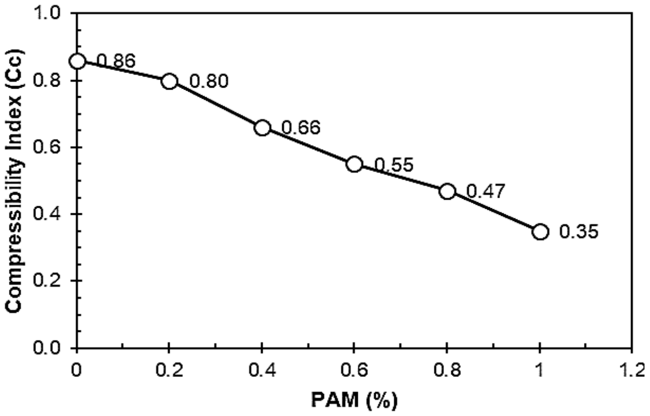


Fig. 9. Variation of Compression Index.

3.4. Analysis of CBR Laboratory Test Results

The results of the CBR test of treated and untreated soils are presented in Fig. 10. CBR value of the soil increases with an increase in the addition of PAM. The CBR value increases with the addition of PAM concentration. Based on the results, the CBR value for initial soil is 1.1% (determined from the Dynamic Cone Penetrometer test). This value is considered very low for road construction but perfectly normal for silt soils with high plasticity (MH). CBR-soaked produces a value of 5.7% to 8.1%.

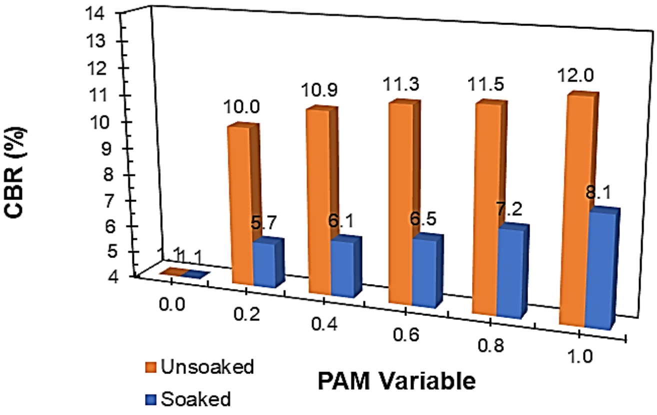


Fig. 10. Effect of PAM on CBR Laboratory Test.

Adding PAM increased the CBR value by 8.7 – 55.8% based on the CBR laboratory test. From this, it can be concluded that adding PAM to silty soil with high plasticity significantly impacts CBR values. Therefore, it was concluded that the mixture of PAM and silt soils significantly improved the CBR of soil, ensuring safety and maintenance free for pavement [55].

In general, the highest CBR can be reached by adding PAM of about 1%. As presented in Fig. 10, a 1% PAM could increase CBR value up to 8.1%. The increase in CBR value can be caused by changes in soil structure to flocculate and fill soil voids due to the addition of PAM as well as stronger soil adhesion between the soil and PAM [56]. Apart from that, Farooq and Mir [57] explained that increasing CBR is related to relatively high soil shear strength so it can be said that PAM as an added material has good efficiency which is sufficient to increase the strength of the subbase material. Soltani et al. [54] explained that the increase in CBR value is due to the influence of PAM viscosity which is higher than water so that when compacted it produces a high dry weight of soil. Overall, this study is consistent with those previous studies.

3.5. Analysis Cracking from Wetting-Drying Cycle Results

The effect of cracking has been observed in soil samples tested wetting-drying at room and higher temperatures. The final crack was recorded at each time during the test. In general, the development of cracking throughout the drying cycle of standard and higher temperature tests can be seen in Fig. 11 and Fig. 12.

Figure 11(a) shows the soil cracking at room temperature during the wetting-drying process. It can be seen that the crack in P1 spreads, which tends to radiate and forms the letter Y. Figures 11(b) to 11(d) show that the cracks tend to decrease and only form in 1 to 2 directions. The effect of cracking with treated 1% PAM is shown in Fig. 11(e). Almost no cracks were found on the soil surface with variable P5. Cracks were investigated on the tested soil with acceleration (Fig. 12).

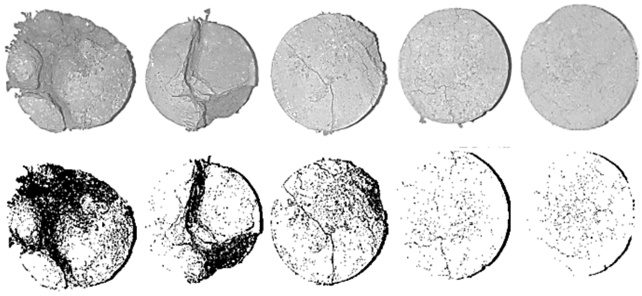


Fig. 11. The crack images of treated soil in higher temperatures: (a) P1, (b) P2, (c) P3, (d) P4, and (e) P5.

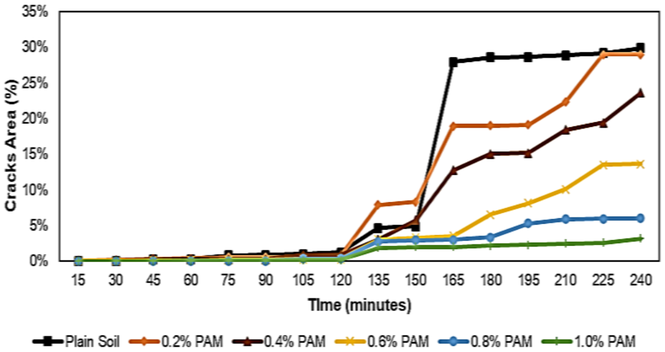


Fig. 13. Development of the cracks in the wetting-drying test.

The crack data for the accelerated test can be seen in Fig. 13. That figure shows that in the first drying cycle, no cracks developed in the treated soils. In the samples where cracks did develop, they generally appeared between 75 – 240 minutes. After the re-wetting process, the PAM-improved soil sample was the only sample that did not develop any cracks.

Due to the pressure differential between the air and water voids, known as the meniscus, the drying process in the soil can cause negative pore water pressure in the soil's top layers. In semi-saturated soils, negative pore water pressures are typical. In certain circumstances, the pore water pressure could be harmful, resulting in an absorption force and modifying the soil's shear angle. A water meniscus that forms from stress on the soil surface results from partially saturated pore space.

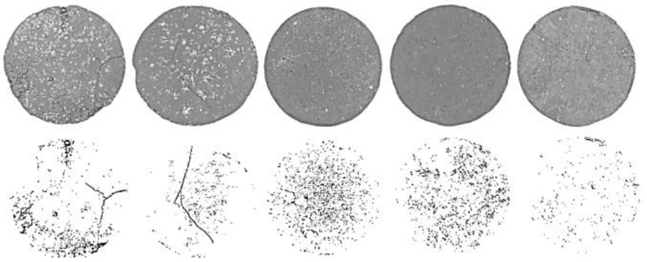


Fig. 12. The crack images treated soil at room temperature: (a) P1, (b) P2, (c) P3, (d) P4, and (e) P5.

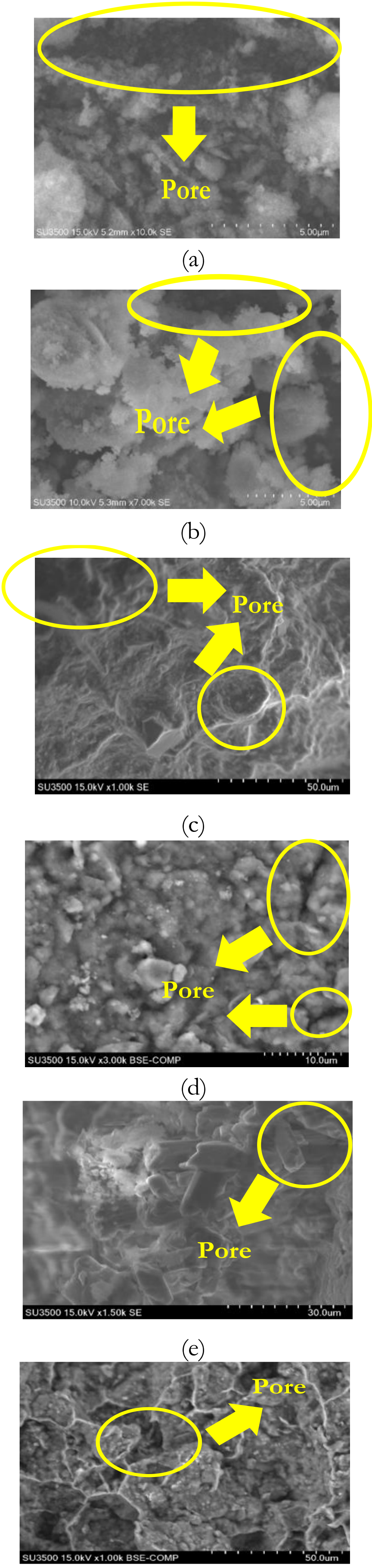
The intense interaction between soil particles will force the particles to move closer to one another, resulting in a new arrangement of soil particles due to the addition of PAM. It leads to the conclusion that, with each variation's addition of PAM, the tension caused by the different arrangements of soil particles might lessen the size of cracks on the soil surface. These results can be related to the influence of the soil mixture with PAM on the shrinkage and cracking due to shrinkage from the wetting-drying process.

3.6. Microstructure Analysis of the PAM-Treated Soil

Figure 14 shows the SEM results of the soils. From Fig. 14, it can be seen that under the drying shrinkage conditions, the bonds between soil particles are broken, the distance between particles increases, some of the particles in the cluster of soils are separated, and cracks in the soil increase. The cracks are widely distributed, the soil particles are loosely arranged, the distance between particles is significant, the size of the soil particles is not equally distributed, and the shape of the particles is mostly plate-like and spherical. There are only geometric accumulations of soil particles between the silt soil particles with no fixed connection.

The SEM images at different magnifications show each variant of treated soils with PAM. In variable P1, the pore space has been reduced, which is most likely filled with PAM. However, there are still irregular particles called amorphous [58]. According to a previous study [59], amorphous particles indicate that a substance's absorption process is not optimal on the soil surface. Also, the same result has been described by another study [47], which has explained that adding PAM has reduced the pore space [60]. As seen in the SEM images, a variation of 0.4% to 0.8% results in a closer distance between the particles.

Additionally, in P5, it can be seen that the pore space is reduced from the previous condition. This indicates that the influence of PAM is well distributed to form acrylamide bonds which can increase soil strength.



(a)

(b)

(c)

(d)

(e)

(f)

Fig. 14. SEM image of dry shrinkage test. (a) P0; (b) P1; (c) P2; (d) P3; (e) P4; and (f) P5.

According to a previous study [18, 33] reduced soil pores impact surface cracks due to the wet-dry process. Filling pores occur due to evaporation and water infiltration so that water is transported to the surface layer of the soil. This process causes a reduction in moisture in the internal pores of the soil samples. From this process, it can be confirmed that the mechanical properties test results at 1% PAM have the highest value compared to other percentages.

In terms of macrostructure perspective, PAM could potentially cause a strong increase in attractive force (cohesion) so that the strength value of soil particles also increases. This is directly proportional to the reduction in soil erosion which results in soil that has high adhesive power (cohesive) and has a high cation capacity so that it can bind PAM as an anion well. This is what causes the cohesion value and internal friction angle to increase.

4. Conclusions

This paper presented a preliminary study of the effect of polyacrylamide polymer on reducing cracks in silt soils with high plasticity. Experiments on six soil samples were conducted, and their cracking behaviours were reviewed over time. An analysis of crack patterns and changes in moisture content over time was carried out considering the addition of a polyacrylamide (PAM) stabiliser. Several concluding remarks can be drawn in the following,

1. PAM inclusion reduced the initial void ratio and compressibility of soils. This is mainly because PAM fills the pores within the soil and seals them against water ingress. Soils experienced a significant down in compression when PAM was increased.
2. Crack analysis results showed that PAM entrapment resulted in a significant reduction. This is mainly due to electrostatic interactions between PAM and soil particles, resulting in solid bonding within the soil mass.
3. Analysis of the SEM images proved that the adsorption of PAM molecules to the surface soil significantly changed the soil structure. When PAM content is increased, more particles accumulate, and the pores become smaller.
4. This study highlights the potential of using PAM for improving high-plasticity silt soils for cyclic wetting-drying conditions. In conclusion, PAM polymers are considered to be highly efficient stabilisers for cohesive soils with high plasticity characteristics due to their excellent standard features such as being economical, environmentally, and able to be easily implemented, is considered to be a high-efficiency stabiliser for It important to note that treated soils by PAM could be utilised in practical engineering projects such as road embankments, erosion, soft soil improvement and other earth-related construction materials.
5. The implementation of PAM on a large scale still needs to be investigated to observe the role of PAM in macrostructure.

6. Further research needs to be done regarding variations in adding larger percentages to get optimal results because the maximum percentage (1%) has not yet found a turning point value from all laboratory tests.
7. Chemical tests to obtain appropriate chemical reactions with the soil and PAM mixture need to be carried out

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