

Effect of Emulsified Asphalt on Expansive Soil Strength and Swelling

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Abstract. Some clay soils classified as extended soils threaten the structures resting on them. Many additives are available to improve the properties of expanded soils. This study tries to investigate the consequences of wetting-drying cycles on the swelling behavior of modified expansive clayey soils under laboratory conditions by modifying expansive clayey soil samples using emulsified asphalt. Five different percentages of emulsified asphalt were used: (2, 4, 6, 8, and 10) %. The natural and treatment soils were tested for classification, specific gravity, compaction characteristics, free swell and swell pressure, consolidation, and compressive strength. The liquid limit and plasticity index have been lowered by adding Emulsified Asphalt. After that, the effects of Emulsified Asphalt on undrained shear strength characteristics (cohesion and friction angle) have been studied. The results revealed that when the emulsified asphalt content was increased to 10%, the swelling pressure and swelling potential decreased by 58 and 78 %, respectively. The swell and shrink improvement factor for the 10% emulsified asphalt addition is always larger than 75%. As the duration of wetting-drying cycles increased, the swelling pressure and swelling potential values were also reduced. The plastic limit, on the other hand, increased as the Emulsified Asphalt content increased. Increasing the amount of Emulsified Asphalt increased the maximum dry unit weight values, whereas the optimum water contents increased. It was concluded that emulsified asphalt stabilization may be useful for expansive clay as it improves compressive shear strength.

Keywords: Expansive soil; swelling; emulsified asphalt; soil stabilization; clay soil; shear strength.

1. INTRODUCTION

One of the most prevalent issues worldwide is the location of civil engineering projects on unstable soils. The traditional approach to stabilizing soil involves removing the brittle soil and replacing it with a stronger substance. The high expense of this technology has prompted academics to hunt for cheaper alternatives, one of which is the soil stabilization procedure. A technique called soil stabilization was first used to make soils capable of satisfying the demands of particular engineering projects many years ago [1]. Expansive soil is problematic soil due to its volume change (swell, shrink) with a change in moisture content. It increases in size (swells) when the moisture content increases and decreases in size (shrinks) when its moisture content is reduced [2]. Additionally, soils may need to be stabilized if they are poor or have unwanted characteristics that make them inappropriate for geotechnical projects [3]. Numerous scientific methods for stabilizing soil have been developed recently. Numerous researches have been conducted on soil stability utilizing various additives, such as lime and cement. These additives are frequently used in soil stabilization procedures as cementing agents. Historically, lime, cement, and specialized additives like pozzolanic materials have been used to treat the soils that make up the pavement subgrade to stabilize them. Fly ash, silica fume, and rice husk ash, considered wastes, are pozzolanic materials that can enhance soil [4-8].

Since there is little information on emulsified asphalt stabilization, silica fume could be used to build a hydraulic barrier in a landfill. They discovered that a stronger bond between clay and silica fume particles resulted in a higher shear strength and a lower swelling characteristic. The main goals of this paper are to assess the impact of cycles of soaking and drying on the swelling properties of modified expansive clayey soil and to investigate the impact of silica fume on parameters of undrained compressive strength (cohesion and internal friction angle). Additionally, research has been done on how emulsified asphalt affects the geotechnical features of clay, such as its consistency limitations, specific gravity, compaction traits, swell and swell pressure, consolidation, and compressive strength [9-11]. Chemical stabilization is one of the causes of the low swelling pressure and swelling potential values of stabilized clayey soil samples. The nano-silica fume inclusion causes a chemical stabilization that raises the ideal water content while lowering the maximum dry unit weight. Swelling pressure and potential are reduced due to the increased optimal water content and lower maximum dry unit weight [12].

2. MATERIALS

2.1 Soil

The samples used for laboratory tests were collected from 1 m below the ground level from Karbala City to the south of Baghdad, Figure 1. The geotechnical soil properties before the addition of emulsified asphalt are presented in Table 1. Figure 2 shows the grain size distribution of the untreated samples.

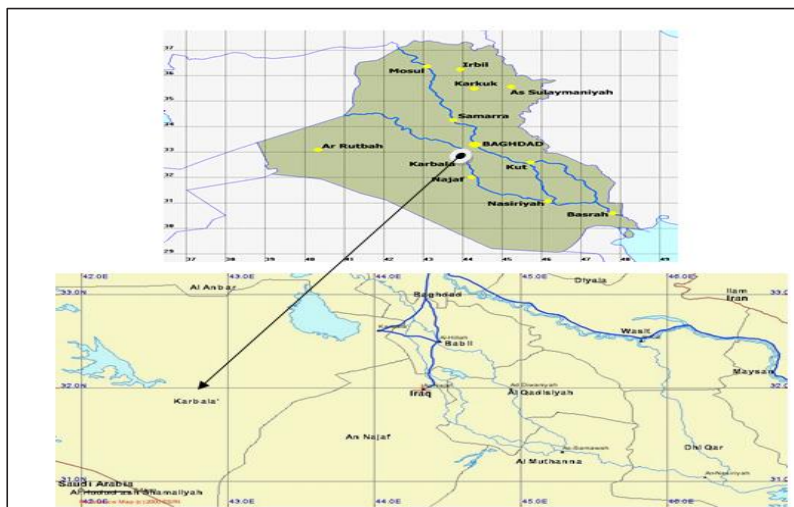


Figure 1: Location of the Karbala city.

Table 1: Physical properties of the soil.

Property	L.L (%)	P. L (%)	P.I (%)	G _s	Sand (%)	Silt (%)	Clay (%)	USCS	γ_d kN/m ³	O.M.C %	Activity (%)
Natural Soil	76	32	44	2.66	11	24	65	CH	13.67	28	0.81

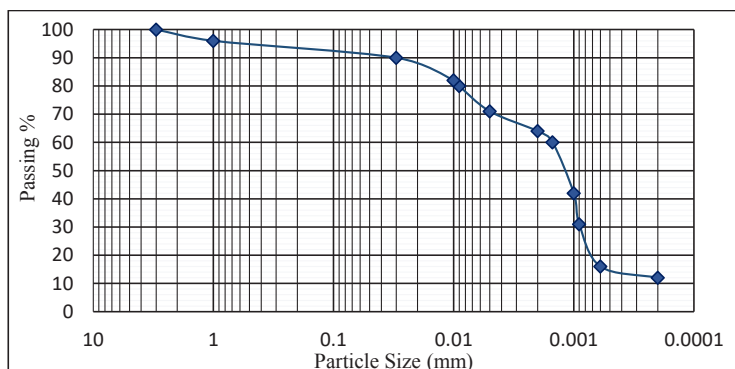


Figure 2: Particle size distribution of soil used.

2.2 Emulsified Asphalt

The asphalt emulsion is matrix asphalt is KunLun AH-70, and the emulsifier is MQK-1D manufactured by MeadWestvaco Corporation in the United States MQK-1D is primarily composed of amino amide compounds formed by the condensation of fatty acids and polyamines [13]. The major step in making emulsified asphalt is forcing matrix asphalt, liquid soap formed from emulsifiers, additives, and water through a small colloid mill. The liquid soap was made by dissolving the emulsifier and diluting additives in water at (40-60) °C and heating the matrix asphalt to (130-140) °C. Emulsified asphalt is just a suspension of tiny globules of asphalt cement in water that has been helped by an emulsifying agent (such as soap). The emulsifying ingredient helps by giving the asphalt cement globules' surface an electrical charge so they do not agglomerate. Emulsions are employed because they efficiently lower asphalt viscosity for applications requiring lower temperatures (stabilization material, slurry seals, fog seals, bituminous surface treatments (BST), and tack coats). Typically, two types of Emulsions are available: cationic (asphalt particles are positively charged) and anionic (asphalt droplets are negatively charged). Emulsions often have a thick, dark liquid appearance when first applied. Emulsified asphalt performance tests are shown in Table 2.

Table 2: Emulsified asphalt performance tests.

Property	value	Property	value
Appearance	Light brown liquid, uniform	Ductility (5°C) (2)/cm	"≥20"
Particle ion change	Cationic	Ductility (15°C)/cm	≥50
viscosity (25°C)	5–15	Softening point (globe law)/°C	"≥42"
Evaporation residue%	58–63	Solubility /%	≥97
Penetration (25°C, 100 g)/0.1 mm	60–120	Cement hybridism%	0.45

2.3 Preparation of Test Samples

To demonstrate the influence of emulsified asphalt on prepared soil, it is important to establish the soil's initial water content and dry density to facilitate comparison. The swelling features of compacted soils are measured using static compaction samples. These samples are compacted to attain the same dry densities as those determined by the dynamic approach. Consequently, the needed quantity of water was mixed into each produced sample completely and then statically compacted to the required initial dry density using a loading machine. While the shear strength properties are assessed on samples extruded by a hydraulic jack from a mold compacted using a conventional proctor compaction test, the shear strength characteristics are determined on samples extruded by a hydraulic jack from a Specimens are obtained by applying a 50mm-diameter clean and oiled Shelby tube to the samples; the length of the sample was (100mm). The specimens are subjected to a load with a constant strain rate; the test is terminated whenever a continuous increase in strain is detected while the stress does not increase or when the strain reaches 20 percent.

3. METHODS OF TESTING

3.1 Specific Gravity Tests

The specific gravity of soils was calculated using a 50 ml density container in line with BS 1377: part2: 1990: 8.3.

3.2 Atterberg Limits Tests

Liquid Limit testing was conducted in accordance with BS 1377: part 2:1990:4.5 and ASTM D 4318, 11, 12 utilizing Casagrande equipment. According to BS 1377: part2:1990:5.3 and ASTM D 4318, 15, Plastic Limit tests were undertaken [14].

3.3 Compaction Tests

The method specified in BS 1377: Part 4:1990: 3.3 utilizing the "Ordinary" compaction test (2.5 kg rammer method) was used to estimate the soil's maximum dry density and ideal moisture content. The soil mixtures, with and without adding additions, were thoroughly combined. The initial round of compaction tests aimed to determine the compaction characteristics of the untreated soils. Secondly, the compaction properties of treated soils with varied quantities of asphalt emulsion were determined through testing.

3.4 Swelling Tests

3.4.1 Free swell and swelling pressure

A predetermined soil weight, with its optimum moisture content, was compacted statically inside the odometer consolidation ring of 50 mm internal diameter and 20 mm in height. The specimen height was made to be 5 mm less than the height of the consolidation ring in order to ensure that the specimen well remains laterally confined during swelling. This was achieved using a metal disk of thickness equal to the difference in height between the consolidation ring and specimen is 5 mm [15]. The diameter of the disc was 1 mm less than the internal diameter of the ring. The specimen's height is measured using a dial gauge with a Sensitivity of 0.002 mm. The percent of swell (swell %) is a function of the height of the specimen.

$$\text{Swell (\%)} = (\Delta H / H) \times 100 \tag{1}$$

Where ΔH: Swell due to saturation, H: Original height of the specimen.

After installation of the specimen into the oedometer apparatus, a load was placed at the top of the weight hanger to provide a stress of 7 kPa, distilled water was added, and the free swell was started. When the final swell was reached, the sample was then consolidated back to the original height. The pressure required to bring the specimen back to its original height is called swelling pressure [16].

3.4.2 Cyclic swell-shrink tests

The wetting–drying cycle test was conducted to determine the influence of emulsified asphalt on the swelling behavior throughout cycles of soaking and drying. The main benefit of this test is that it may be repeated on the same sample [17]. Each sample was submerged in pure water. Using a dial gauge with a sensitivity of 0.002 mm, the rise in sample height is determined after allowing the samples to fully swell for five days. After draining the water, the consolidation cell with the wet samples was moved from the odometer apparatus to an oven set to 45 to 50 degrees Celsius. The samples required approximately three days to dry. After the whole shrinkage has occurred, the amount of shrinkage is recorded (The sample's height has not

changed further). After drying, the height of each sample was meticulously measured using an electronic vernier. The odometer device was reinserted with the dried clayey soil for both natural and stabilized samples, and these samples were allowed to be completely swell over five days by wetting them. The samples were saturated in the consolidation cell and dried in the oven to perform the wetting-drying cycle test. In these tests, samples of clayey soil that is naturally stabilized were put through five cycles of alternating soaking and drying within consolidation cells. After five wetting-drying cycles, it was noted that the test results remained unchanged. In light of this, the wetting–drying method was discontinued after five cycles.

3.5 Shear Tests

3.5.1 Unconsolidated Undrained Triaxial Tests on Partially Saturated Soils

On treated and untreated materials, ASTM D2850 triaxial compression tests were performed. With confining pressures of 75, 150, and 225 KPa, the unsaturated Unconsolidated Undrained (UU) tests were carried out in the triaxial compression apparatus.

3.5.2 Unconfined Compressive Strength Tests

This study adopted the ASTM D2166 Standard to perform the unconfined compressive strength tests on compacted specimens.

4. RESULTS AND DISCUSSION

4.1 Atterberg Limits Tests

The liquid and plastic limits of asphalt mixes containing varied proportions of clay-emulsified asphalt were tested. Immediate findings for consistency limitations were obtained from testing. Figure 3 depicts the effects of emulsified asphalt concentration on the liquid limit, plastic limit, and plasticity index of stabilized clayey soil samples. The liquid limit and plasticity index values dropped as the emulsified asphalt concentration increased up to 10 percent. The plastic limit increased somewhat as the emulsified asphalt component climbed up to 10 percent. Depending on the type of soil, the cation exchange capacity (CEC) and the amount of low-plastic material that was put to the soil may vary. The categorization of composite samples reclassified the soil groups from very high plasticity clay to high plasticity clay Due to this modification in consistency limitations.

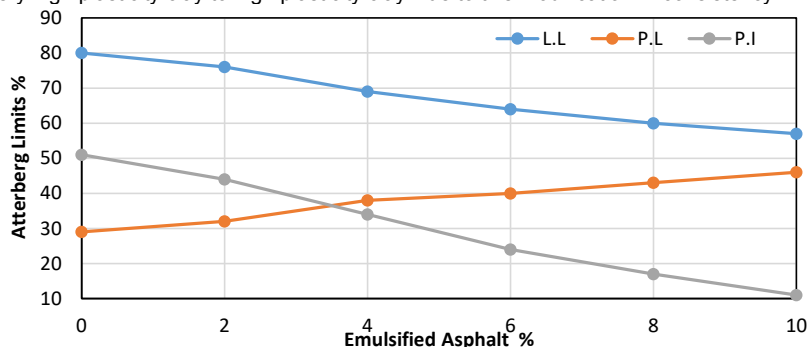


Figure 3: Effect of emulsified asphalt content on consistency limits.

4.2 Specific Gravity

The emulsified asphalt content increases the specific gravity of the soil at 2, 4, and 6 %, and there is a slight decrease at 8%, then it returns to the increase by 10%, as shown in Figure 4. This indicates that the emulsified asphalt mixtures for soil are higher than those in natural conditions.

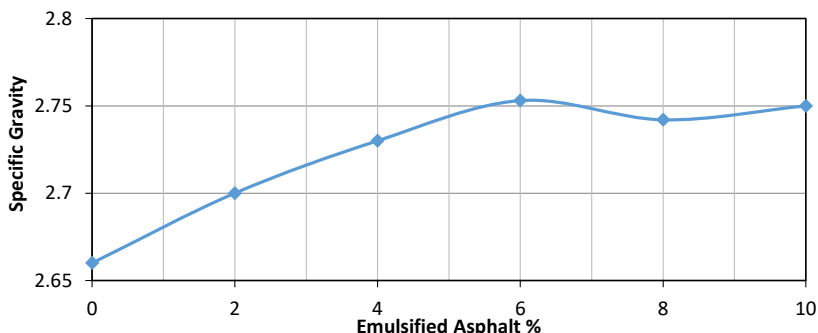


Figure 4: Effect of emulsified asphalt content on specific gravity.

4.3 Compaction Parameters

The compaction curves are shown in Figure 5, and values for the ideal water content and maximum dry unit weight are established. Adding emulsified asphalt impacted the characteristics of clayey soil-emulsified asphalt mixtures' compaction. It was observed that the maximum dry unit weight increased with the addition of emulsified asphalt, and the optimum water content increased. The change in the surface area of composite samples caused an increase in the ideal water content. Adding emulsified asphalt altered the stabilized fine-grained soil samples' particle size distribution and surface area. Additionally, as more water is needed to dissociate emulsified asphalt, it is believed that optimal moisture content rises as emulsified asphalt concentration increases. Moreover, the increase in OMC is caused by a chemical interaction between the emulsified asphalt and the soil's clay content. Similarly, there are two possible explanations for the decline in the maximum dry unit weights: The emulsified asphalt largely changes the effective grading of the soils by aggregating the particles (produced by the cation exchange process) and making them occupy bigger spaces, modifying the soils' actual grading.

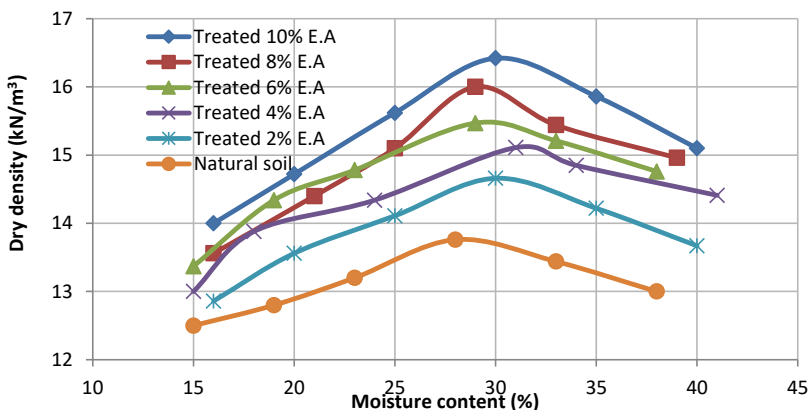


Figure 5: Effect of emulsified asphalt content on compaction parameters.

4.4 Free Swell and Swell Pressure Using the Oedometer Cells

4.4.1 Swell-Time Relationships for the 1st Cycle

Emulsified asphalt decreased the swelling of clayey soil-emulsified asphalt mixtures, as shown in Figure 6. The free swell decreased from 15% to 3% for the clayey soil-emu mixtures containing 0% and 10% emulsified asphalt, respectively. It can be seen that the used expansive soils need over five days to reach a steady state. The swelling may follow different rates with respect to time for different emulsified asphalt percentages. However, the presence of emulsified asphalt would decrease the permeability of expansive soil and hence may increase the time to reach the maximum value of free swell.

4.4.2 Swell-Pressure Relationships for the 1st Cycle

As the amount of emulsified asphalt increased, the values of the swelling pressure fell continuously. Ten percent emulsified asphalt compositions produced the lowest readings. Adding emulsified asphalt lowered the swelling pressure of stabilized samples containing 10 percent emulsified asphalt from an initial value of 600 kPa for the prepared clay to 350 kPa, as seen in Figure 6. Including low-plastic components and the interaction between clay and emulsified asphalt particles decreases the swelling pressure of stabilized samples [7]. Several studies reveal that the Specific Surface Area (SSA), Cation Exchange Capacity (CEC), and pH govern various engineering features of clayey soils. CEC and liquid limit are proportional in a linear relationship. Likewise, a linear relationship exists between SSA and liquid limit [18]. The drop in CEC and SSA values caused by adding asphalt emulsion lowered the liquid limit values. The pH values increase when asphalt emulsion is applied to natural clayey soil, causing the emulsified asphalt from the clay minerals to dissolve. The percentage clay mineral concentration of combinations of clayey soil and emulsified asphalt reduces as the pH increases. The swelling pressure and potential of the stabilized samples with low relative clay mineral content and a low liquid limit were low. To modify clayey expansive soils, the most essential aspects are the emulsified asphalt quality and quantity applied to the soil and the clayey soil chemical composition. Significant amounts of calcium compounds in the clayey soil react with water molecules to generate Ca^{2+} ions and hydroxyl ions. The samples of stabilized clayey soil material were stronger and more brittle than the samples of natural clayey soil due to this basic reaction of emulsified asphalt in the clayey soil. Figure 7 shows the effect of emulsified Asphalt content on swell pressure.

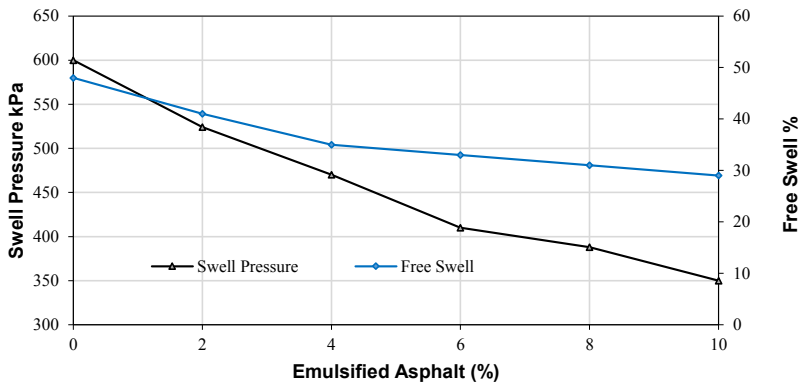


Figure 6: Effect of emulsified asphalt content on free swell percentage and swell pressure for the 1st Cycle.

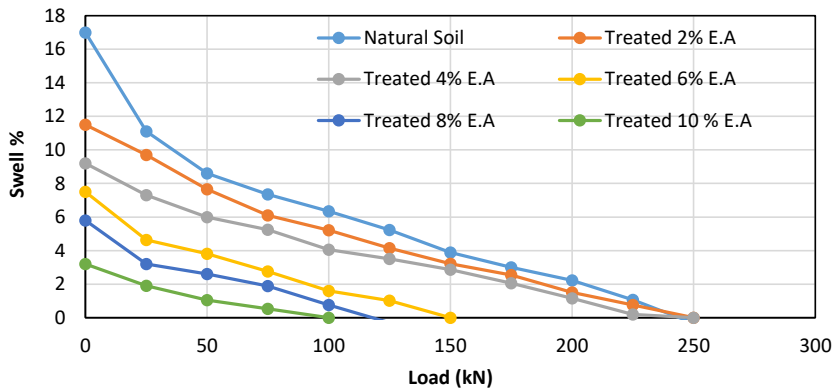


Figure 7: Effect of emulsified asphalt content on swell pressure.

4.4.3 Cyclic Behavior

The wetting-drying cycle experiments were used to examine how wetting-drying cycles affected swelling potential and pressure. The wetting-drying cycle results of testing for prepared and treated soils are presented in Figures 8 and 9. These statistics show that when the number of wetting-drying cycles increases, both the swelling pressure and potential decrease. Within the first three cycles of wetting and drying, there is no significant difference in the behavior of the untreated soil with the soil treated with 4 and 6% emulsified asphalt in the form of swelling pressure, and potential is seen with the advancement of wetting and drying cycles, and this is evident in Figure 9.

The fourth Cycle for the natural clayey soil samples resulted in equilibrium for the swelling pressure and swelling potential, which decreased with increasing wetting-drying cycles. The stabilized clayey soil samples containing 10% emulsified asphalt achieved equilibrium in the second Cycle, whereas the modified clay samples with 6 and 8% of emulsified asphalt reached equilibrium in the third Cycle. The fact that the swelling potential and pressure diminish with increasing wetting-drying cycles when emulsified asphalt is added is a significant discovery. The cyclic swelling process, which causes the clay structure's matrix to gradually be destroyed, is thought to be responsible for the decline in swelling pressure and potential. Simultaneously, the cyclic swelling process leads to reconstructing and reorientating the large micro aggregates structure by disorienting structural elements. Due to the increasing frequency of swelling-shrinking cycles brought on by the wetting-drying cycles, all these processes alter the expansive behavior of clayey soil samples. Additionally, following the initial wetting-drying Cycle, the basic reaction of the emulsified asphalts in the stabilized clayey soil samples may be finished, making the samples more fragile and stronger.

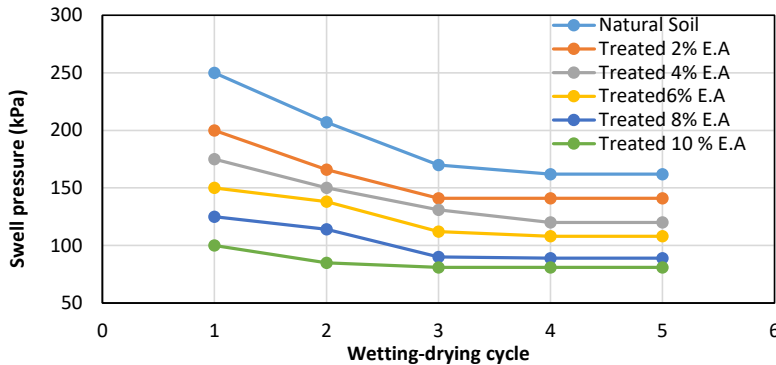


Figure 8: Effect of emulsified asphalt on the swelling pressure after wetting-drying cycles.

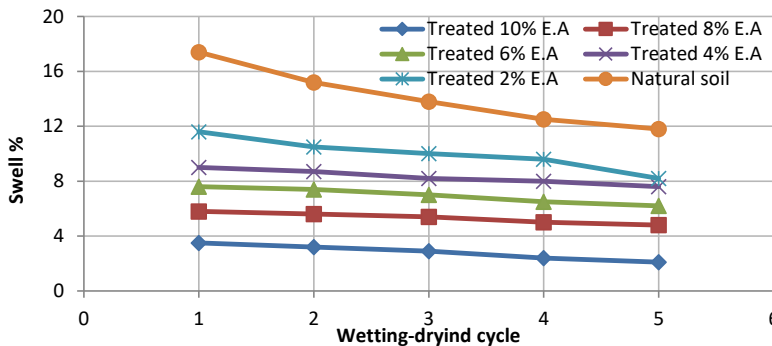


Figure 9: Emulsified asphalt effect on the swelling potential after wetting-drying cycles.

4.5 Consolidation Tests

Results of consolidation tests for the six samples with different percentages of emulsified asphalt are drawn in Figure 10. When the swell pressure of samples is assessed, the load is applied on the specimen by double increment to allow the specimen to consolidate. It is seen that emulsified asphalt decreased the initial void ratio and, hence, the compressibility of composite samples. Low compressibility values were yielded in the composite samples with (6 – 10) % emulsified asphalt as compared to those of the reference sample. When applying effective stress between 25 - 2000 kPa, the void ratio and compressibility decreased gradually with increasing emulsified asphalt contents. Whereas the void ratio values of natural clayey soil samples were between 0.79 - 0.6, these same values were between 0.758, 0.54, 0.702, 0.487, 0.665, and 0.423 for 0, 2, 4, 6, 8, and 10% emulsified asphalt contents respectively. The decrease in the compression and swelling of composite samples is due to the addition of low-plastic material and the interaction between clay minerals and emulsified asphalt particles. This chemical modification reduces the clay mineral contents of composite samples.

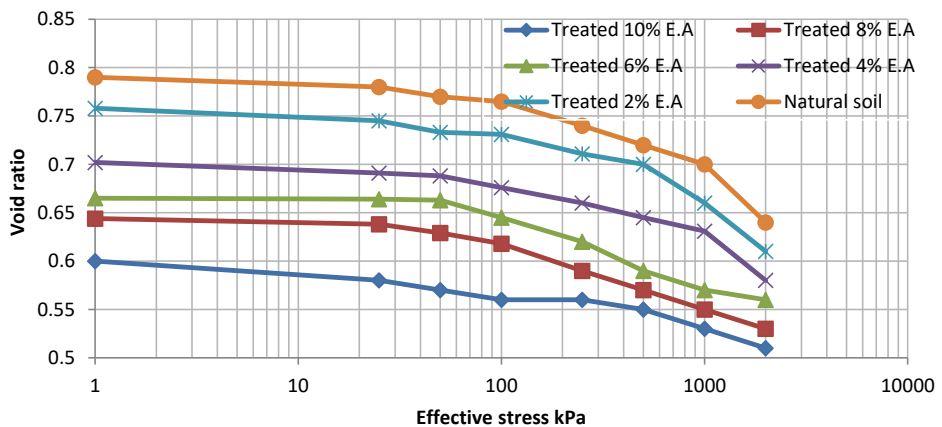


Figure 10: Effective stress versus Void ratio curves using the consolidation tests.

4.6 Shear Strength

To determine the shear strength parameters, the shear strength tests were carried out in two series using different percentages of emulsified asphalt.

4.6.1 Unconfined Compressive Strength

The effects of emulsified asphalt on the unconfined compressive strength of stabilized clayey soil samples are shown in Figure 11. The unconfined compressive strength of stabilized samples increased by 10%, increasing emulsified asphalt content from 0 % to 10 %. However, the unconfined compressive strength is then slightly increased by another 3%, increasing the emulsified asphalt percentage. Clayey soil samples' maximum unconfined compressive strength has occurred at 8% emulsified asphalt content. This is attributed to the emulsified asphalt reaction, which forms cementitious material compounds that bind soil aggregates and may be attributed to the internal friction of emulsified asphalt particles and the chemical reaction between emulsified asphalt and clayey soil. The unconfined compression test is widely used as a quick, economical method of obtaining the approximate compressive strength of the cohesive soil. It is noticed that the unconfined compressive strength has been reduced with increasing emulsified asphalt to 10%.

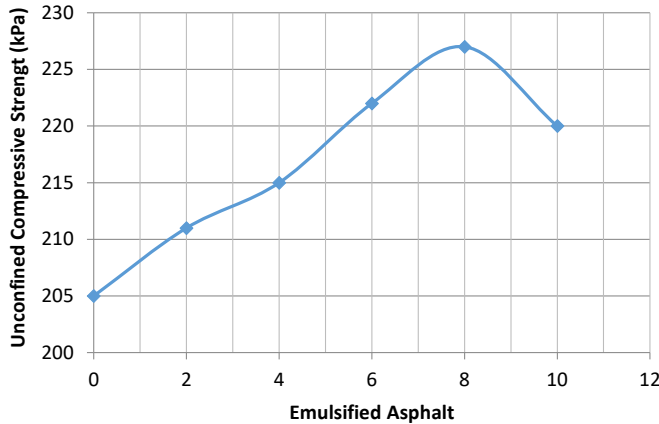


Figure 11: Effect of emulsified asphalt content on unconfined compressive strength.

4.6.2 Unconsolidated Undrained Triaxial Tests

Brittle failure was observed in the shear failure mode for specimens stabilized with emulsified asphalt. Moreover, for the confining pressure of 75 kPa, adding a 5% emulsified asphalt has a marginal increasing effect on shear stresses. In contrast, the other two percentages (8 and 10%) cause the shear stress to decrease slightly. Similar behavior was observed for confining pressures of 150 kPa and 225 kPa. Figure 12 shows the undrained cohesion (c_u) and undrained angle of friction (ϕ_u) against emulsified asphalt content. The undrained cohesion increased at 2% -10% of emulsified asphalt; at the same time, the internal angle of friction increased in addition to 8% and 10% of emulsified asphalt content.

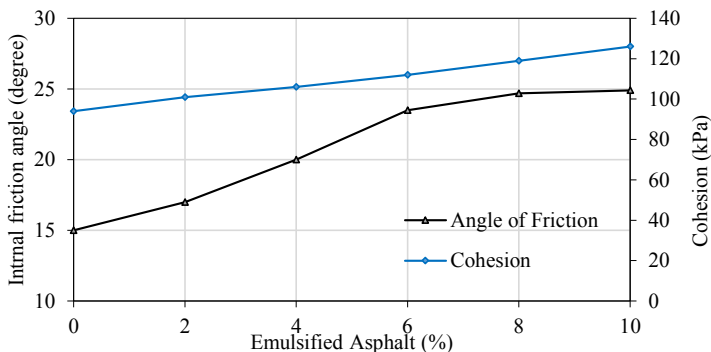


Figure 12: Effect of emulsified asphalt on the undrained cohesion and undrained angle of internal friction.

5. CONCLUSIONS

The present research investigated the effect of emulsified asphalt on the engineering characteristics of expansive clay. The following conclusion may be drawn:

- The liquid limits and the plasticity index decreased by 25% and 75%, respectively, by adding up to 10% of emulsified asphalt, and the plastic limits increased by 40%. For this reason, the soil types of composite samples with high emulsified asphalt content changed from very high-plastic clays (CV) to high-plastic clays (CH).
- Increasing emulsified asphalt content caused a steady decrease in the swelling pressure and swelling potential values, and the stabilized samples with the lowest values finally reached 10% emulsified asphalt content.
- By increasing the wetting–drying cycles, both swelling pressure and swelling potential decreased with the addition of emulsified asphalt. The required cycle number to reach a steady state was decreased with the addition of emulsified asphalt.
- The unconfined compressive strength improved by 10% by increasing emulsified asphalt content from 0% to 6%, and then it increased slightly by another 4% to 8% for emulsified asphalt. Any further addition of emulsified asphalt after 8% is caused by a decrease in the unconfined compressive strength.
- With the unconsolidated undrained triaxial tests, the addition of 10% emulsified asphalt has a marginal increasing effect on shear stress.
- There is an increase of 27% in the undrained cohesion (c_u) at samples containing 10% emulsified asphalt, then the undrained cohesion somewhat decreased with the addition of emulsified asphalt after that percentage.
- The undrained angle of friction (ϕ_u) slowly decreases with increasing emulsified asphalt content.

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