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SOFT SOIL IMPROVEMENT USING CHEMICAL-RUBBER CHIPS MIXTURE

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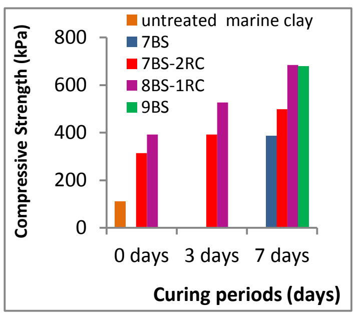
Graphical abstract



Abstract

Soft soils are widely found in many areas around the world as well as in Malaysia. Marine clay is one of the problematic soft soils. The marine clay should be pretreated before the construction to enhance the usability and serviceability of highway constructed on this type of soil. This paper presents the research results on the usability of chemical (SH-85)-rubber chips mixtures as the stabilizing agent in improving the characteristics of marine clay from two engineering perspectives; the strength and the compressibility. Three types of laboratory tests were conducted; index soil test, unconfined compression test and oedometer test. The results show that the treated samples had higher unconfined compressive strength compared to untreated sample. The strength of marine clay increased when the amount of the SH-85 increased. The void ratio reduced in value when the chemical-rubber chips mixture was added to the marine clay. It is due to the chemical that acts as a binder that interlocks the rubber chips and the marine clay particles, reducing the compressibility. It has been concluded that the mixture of chemical-rubber chips with 8 % SH-85 plus 1 % of rubber chips is more effectively improved the characteristics of marine clay.

Keywords: Marine clay; unconfined compressive strength; oedometer

Abstrak

Tanah lembut didapati secara meluas di pelbagai tempat di seluruh dunia dan juga di Malaysia. Tanah liat marin adalah salah satu tanah lembut bermasalah. Tanah liat marin harus dirawat sebelum pembinaan untuk meningkatkan kebolehgunaan dan kebolehkhidmatan lebuh raya yang dibina di atas tanah jenis ini. Kertas kerja ini membentangkan keputusan penyelidikan terhadap kebolehgunaan campuran kimia (SH-85)-cip getah sebagai agen penstabilan dalam menambahbaik ciri-ciri tanah liat marin dari dua perspektif kejuruteraan; kekuatan dan kebolehmampatan. Tiga jenis ujian makmal telah dijalankan; ujian indeks tanah, ujian mampatan tak terkurung dan ujian oedometer. Keputusan menunjukkan bahawa sampel terawat mempunyai kekuatan mampatan tak terkurung yang lebih tinggi berbanding dengan sampel tidak terawat. Kekuatan tanah liat marin meningkat apabila jumlah SH-85 meningkat. Nisbah lompang dikurangkani apabila campuran kimia-cip getah telah ditambah kepada tanah liat marin. Ini disebabkan oleh bahan kimia yang bertindak sebagai pengikat yang saling mengunci cip getah dengan zarah tanah liat marin bersama, yang boleh menurangkan kebolehmampatan. Telah disimpulkan bahawa campuran 8 % SH-85 dengan 1 % cip getah memberi penambahbaikan ciri-ciri tanah liat marin dengan lebih berkesan

Kata kunci: Tanah liat marin; kekuatan mampatan tak terkurung; oedometer

1.0 INTRODUCTION

Soft soils, in particular soft clay, are widely found in many areas around the world as well as in Malaysia. This soft or unstable ground generally means subsoil which has undrained shear strength of less than 25 kPa and the clay can be molded by light finger pressure [1]. The typical characteristic of soft soil is highly compressible and low shear strength. In addition, soft soil subjected to swelling and shrinkage behavior according to its moisture content [2]. These characteristics make soft soils become a problematic soil. Thus, some special technique on the soil improvement is needed to prevent excessive settlements and to enhance the shear strength of soft soils. Such soil improvement techniques includes the in situ earth reinforcement, pilling, ground replacement, utilization of geotextiles, preloading technique, grouting method and deep mixing technique. Although there are many methods to stabilize the soft clay but it is more costly and uneconomical for large projects. As a result, many studies had been conducted to find alternative methods to reduce the soft soil improvement cost

As mentioned earlier, Malaysia is covered by a large area of soft soils which is very problematic towards sustainable construction, in particularly the currently undergoing West Coast Expressway project. A few types of soft soils have been identified along the highway construction alignment but the major soil type is the marine clay. Marine clay is one of the problematic soft soils. The marine clay should be pretreated before the construction to enhance the usability and serviceability of the constructed highway.

There are numerous researchers [3],[4],[5] showed the possibility of utilization of rubber chips in various different civil engineering application Based on the previous research carried out by Latifi and Marto [6], it was identified that the chemical additives of SH-85 could improve the soil characteristics of marine clay significantly. Hence, it was hypothesized that the combination of chemical-rubber chips mixtures is therefore a more effective soil stabilization agent. Thus, this paper aimed to investigate the usability of chemical-rubber chips mixtures as the stabilizing agent in improving the soil characteristics of marine clay from the two engineering perspective; the strength and the compressibility.

2.0 PREVIOUS STUDIES

Marine clay is microcrystalline in nature. The main constituent in marine clay is kaolinite and illite. The physical and chemical property of particular clay depends on its structure and composition. The structure and composition of the major industrial such kaolin and smectites are very different even though each is comprised of octahedral and tetrahedral sheets as their basic building. The characteristics of marine clay in Malaysia had been reported by Rahman [7]. It was mentioned that the marine clay in Malaysia is classified as clayey silt because it contains a large percentages of silt-size particle (approximately 54 % to 58 %), followed by clay-size particle (approximately 23 % to 29 %). The values of the liquid limit and the plastic limit are 58 % and 23 %, respectively. The value of plasticity index is 35 %.

2.1 Rubber Chips

Waste rubber that could be used in engineering application could be further divided into three categories in accordance to their size, which is rubber powder, rubber chips and rubber shreds. In general, rubber chips is a lightweight material which most suitable to be used in the construction project. Rubber chip is advantageous in civil engineering application because of their low density, high durability, high thermal insulation and least cost as the fill materials [5]. It could be used as the infill material for the retaining wall, landfill drainage and thermal insulator. Numerous researches had been carried out to investigate on the use of rubber chips for other engineering application such as drainage media in landfill barrier systems, as foundation layers beneath landfill covers [3], asphalt pavement, water proofing system and membrane liners [4]. Based on the findings, the rubber chips application in embankments shows that, there is no slope stability problem, cracking or erosion on the road [5].

The result of previous research shows that the addition of rubber chips in soil increased the elasticity of the soil [9]. The unconfined compressive strength (UCS) of soil-rubber-chip mixtures tested at 7 days had been increased significantly. It was also observed from the stress-strain curve that the samples exhibits strain softening behavior when subjected to further shearing with the presence of rubber chips.

2.2 Chemical Stabilizer, SH-85

The biomass silica, SH-85 is a powder type chemical additive which is recently been used as chemical soil stabilizer in the geotechnical project. However, the usage in marine clay is still not certain. The main chemical composition in SH-85 is Calcium oxide (CaO), similar to cement and lime [6].

From previous study, the result of SH-85 treated laterite soil sample can be improved from 110 kPa to 610 kPa after 28 days. The soil strength can increase five times greater than untreated soil in the first 7 days of curing. Based on the images showed by Scanning Electron Microscopic, the SH-85 filled within the pore of soil grains, resulting cementation gel [6]. Besides, it contributes to denser soil fabric as the pores between particles were filled with gel formed.

3.0 LABORATORY TESTING

The laboratory testing carried out in this paper was conducted in three stages, the index soil test, unconfined compression test and oedometer test.

3.1 Material

The soil sample (marine clay) tested in this paper were in two forms, the disturbed and the undisturbed samples. All samples were collected at open trench excavation with 0.5 m depth from the ground surface. Undisturbed samples were taken by piston sampler whereas the disturbed samples were collected at the same trench excavation.

The soil stabilizer added to marine clay are the chemical additives (SH-85) in the form of powder, obtained from Probase Soil Stabilizer Sdn. Bhd. while the rubber chips with particle size smaller than 2 mm diameter (cleared of any dust) were obtained from the third party.

The treated and untreated marine clay samples were prepared in accordance to the results of compaction test. The proportional of each soil sample were prepared based on the optimum moisture content (OMC) and the maximum dry density (MDD). In this study the amount of the chemical-rubber chips mixtures was fixed as 9 % by weight.

3.2 Soil Index Test

The soil index tests that carried out were the determination of Atterberg limits, particle size distribution and specific gravity. The compaction test was also conducted. Based on the results of compaction test, the treated and untreated soil samples for the test of unconfined compression test was prepared.

3.3 Unconfined Compression Test

The unconfined compression test was carried out to determine the UCS of treated and untreated marine clay sample. The dry marine clay with addition of the additives and rubber chip was mixed thoroughly using palette knives to form homogeneous soil mixtures. The soil mixtures were then transferred to steel cylindrical mold. Then the mold was compressed in the hydraulic jack to get the cylinder specimen shape. After the compaction, the specimen was removed by using steel plunger slowly to avoid the fracturing of the specimen. The specimen was weight then put in the polythene bottle then placed in the container with room temperature 27 °C. The cylindrical soil samples were tested at three different curing periods of 0, 3 and 7 days. In UCS tests, the soil mixtures were sheared at a constant strain rate of 1.52 mm/min [10] until the soil developed an obvious shearing plane or excessive soil deformations. The maximum load per unit area was defined as UCS.

3.4 Oedometer Test

The consolidation test was conducted on both the treated and untreated soil samples. This test was performed to determine the magnitude and rate of volume decreased when the confined soil was subjected to different vertical pressures. The undisturbed sample was used in the oedometer test. The measurements of vertical deformation were taken at specific intervals. From the results, the graphs of settlement against log time were plotted. From the graphs, the coefficient of compression index (C_c) and swelling index (C_s) were determined.

4.0 RESULTS AND DISCUSSION

4.1 Soil Index Test

The soil characteristics of the marine clay tested in this study were summarized in Table 1, including the Atterberg limits, specific gravity, maximum dry density and optimum moisture content. The particle size distribution curve of the marine clay was illustrated in Figure 1. The result of hydrometer analysis showed that the marine clay samples tested in this study contained 3 % sand, 77 % silt and 20 % clay, by weight. During the hydrometer test, the loss of ignition was performed to determine the presence of organic materials. The loss of ignition value for marine clay sample was low, ranging between 0.6 % and 1.3 %. According to Hoor and Rowe [3], the loss of ignition value for organic material ranged from 1.8 % to 2.1 %.

Table 1 Physical properties of marine clay

Physical properties	Value
Index Properties	
Liquid limit (%)	78
Plastic limit (%)	47
Plasticity index, PI (%)	31
Specific gravity	2.5
Standard Proctor Compaction	
Maximum dry density, MDD (Mg/m^3)	1.21
Optimum moisture content OMC (%)	40

The value for specific gravity of the marine clay was 2.50 in which the result was similar as obtained Hoor and Rowe [3], which was ranged between 2.40 and 2.60. Based on the Site Investigation report, the specific gravity of marine clay at the site was ranged between 2.47 - 2.54. From the Atterberg Limit test, the values of the liquid limit and plastic limit of natural marine clay were 78 % and 47 % respectively. The values of liquid limit ranged between 72 % - 83 %, while the plastic limit value was between 45 % - 47 %. The plasticity index was 31 %. While the consistency index for the liquid limit and plastic limit were 56 % - 80 % and 36 % - 45 %, respectively. These values obtained all were in the range as stated in the study conducted by Hoor and Rowe [3]. From the result obtained, the plasticity index of the marine clay samples was ranged in between 19 % to 37 %.

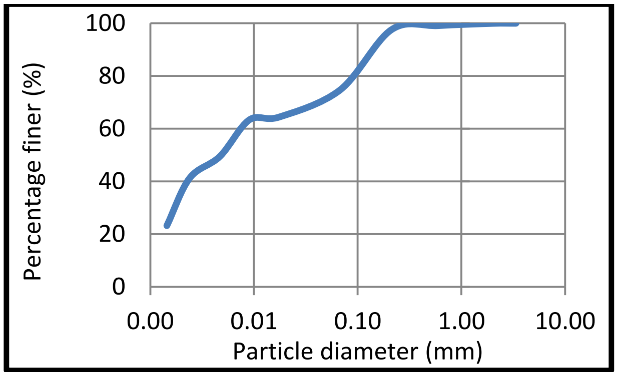


Figure 1 Particle size distribution of marine clay

The value for specific gravity of the marine clay was 2.50 in which the result was similar as obtained by Marto *et al.* [2] which was ranged between 2.40 and 2.60. Based on the SI report, the specific gravity of marine clay at the site was ranged between 2.47 - 2.54. From the Atterberg Limit tests, the values of the liquid limit and plastic limit of natural marine clay were 78 % and 47 % respectively. The values of liquid limit ranged between 72 % - 83 %, while the plastic limit value was between 45 % - 47 %. The plasticity index was 31 %. The liquid limit and plastic limit were 56 % - 80 % and 36 % - 45 %, respectively. The obtained values were all in the range as stated in the study conducted by Marto *et al.* [2]. From the results, the plasticity index of the marine clay samples was ranged in between 19 % to 37 %.

Based on the results of Atterberg limit tests, the marine clay, classified in accordance with Unified Soil Classification System (USCS), is shown in Figure 2, by using the plasticity chart. Based on the chart, the marine clay samples in this study lie below the A-line that in the Casagrande Plasticity Chart which indicates the clay behavior dominates. The soil is classified as MH which is silt of high plasticity.

The standard proctor compaction test was performed on dry sample of marine clay in order to obtain a relationship between the dry density and the moisture content of the compacted samples. The resulted compaction curve is as illustrated in Figure 3. The maximum dry density, ρ_{dmax} of 1.21 Mg/m^3 corresponded to optimum moisture content; w_{opt} of 39.5 % had been obtained from the curve for marine clay.

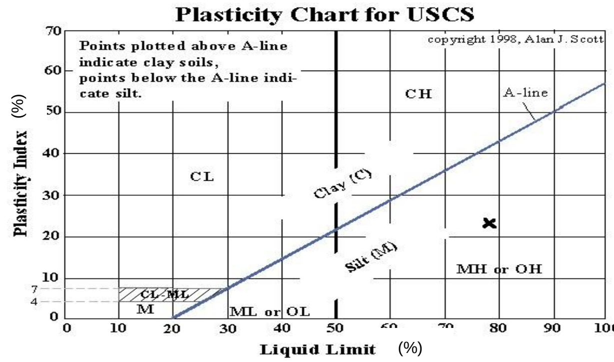


Figure 2 Classification of marine clay using USCS plasticity chart

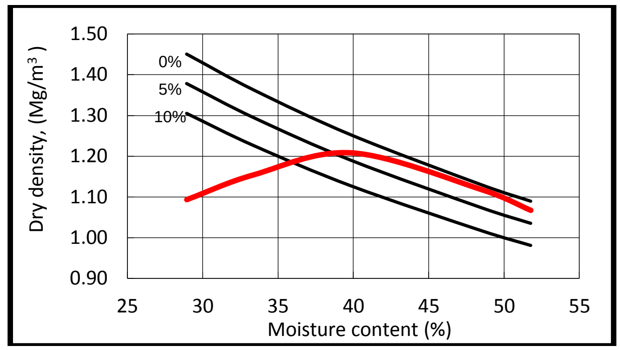


Figure 3 Compaction curve of marine clay

4.2 Unconfined Compressive Strength

The unconfined compression strength (UCS) was used as an index test to investigate the effectiveness of selected additives on the compressive strength of marine clay sample. The UCS of untreated and treated sample (8BS-1RC and 7BS-2RC) was obtained and plotted with various curing periods in Figure 4, Table 2 summarized the UCS of treated and untreated marine clay at three different curing periods. The shear strength values were determined based on the peak stress of respective specimens. The results from the UCS tests are divided by two to give the values of undrained shear strength of the mixtures.

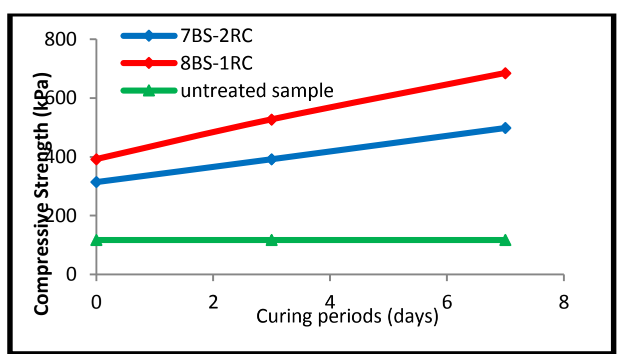


Figure 4 Unconfined compressive strength of treated marine clay at different curing periods

Table 2 Unconfined compressive strength of treated and untreated marine clay

Soil Mixtures	Unconfined compressive strength (kPa)		
	0 day	**3 days**	**7 days**
Untreated		117	
7BS-2RC	314	392	498
8BS-1RC	392	527	685

In Figure 5, the result shows the effect of using different amount of SH-85 content (7%, 8% and 9%) for treated sample. Apparently, the SH-85 treatment significantly enhanced the strength characteristics of the natural soil. These results were compared between the stabilized marine clay with chemical and chemical-rubber chips mixture. There are some different in value of UCS where the highest strength value was obtained by 8BS-1RC which 685 kPa followed by mixing of 9 % BS sample, 680 kPa. From this result, it can be said that the addition of rubber chips also contributes in increasing the strength. Therefore, the addition of rubber chips can be approved as a sustainable stabilized mixture since the chemical content can be used at an optimum amount.

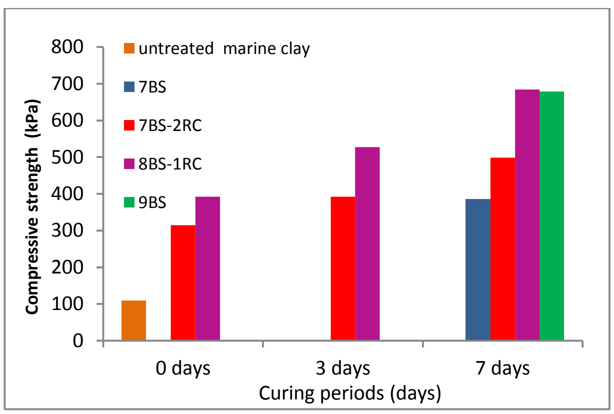


Figure 5 Unconfined compressive strength with different curing periods

4.3 Compressibility Characteristics

Figure 6 and Figure 7 show the compression index C_c and the swelling index C_s of the original marine clay and treated marine clay sample. Figure 6 shows the results of one dimensional consolidation test on undisturbed sample of marine clay. It was depicted from the curve that the compression index C_c and swelling index C_s were 1.53 and 0.049, respectively.

In Figure 7, the swelling index is the slope of e-log p plot during unloading and reloading. The values of the swelling index C_s of undisturbed soil are generally smaller than C_c. Figure 7 shows the C_s curve in parallel pattern, to be slightly increasing with the curing periods. From the figure, the samples of 0, 7, and 14 days give some different pattern and the void ratio has some increase in value. This is due to unforeseen error in the procedure during the laboratory works. As shown in the Figure 7, the void ratio reduced in value when the chemical-rubber chips mixture was added to the marine clay. It is due to the SH-85 filling the pores of the soil grains, resulting with cementing gel. The soil become denser and stiffer, hence the compressibility was decreased. The chemical also acts as a binder that will interlock the rubber chips and the marine clay particles together.

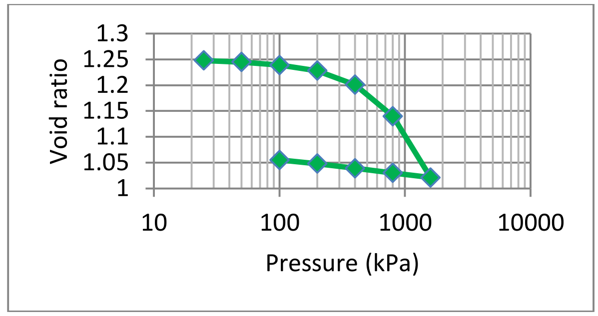


Figure 6 One dimensional consolidation for untreated marine clay sample

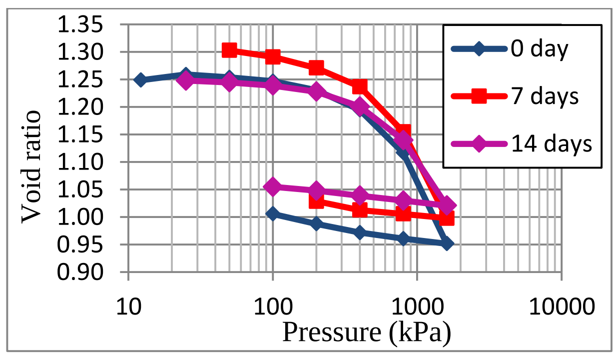


Figure 7 One dimensional consolidation for 8BS-1RC sample at different curing period

5.0 CONCLUSION

From the results of this study, it can be concluded that the chemical-rubber chips mixture affect the strength of the soft marine clay. Therefore, chemical-rubber chips mixture is suitable as an improvement method to be applied in geotechnical engineering works. From the results obtained, the 8BS-1RC mixture was more suitable to be used in stabilization method compared to 7BS-2RC. The conclusions were drawn as follows:

1. The physical and mechanical properties of marine clay were determined by laboratory works. From the result, the value of liquid limit and plastic limit was 78% and 47%, respectively. The value of plasticity index was 31% while the specific gravity was 2.50. For soil classification, he marine clay was classified as MH which is high plasticity silt. For the compaction test result, the maximum dry density and optimum moisture

content obtained are 1.21 Mg/m^3 and 39.5 %, respectively.

2. The unconfined compressive strength value of 8BS-1RC and 7BS-2RC mixture showed significant differences. It showed that the strength of 8BS-1RC was higher compared to 7BS-2RC, which indicated that the addition of SH-85 increased the strength of marine clay. Hence, the 8BS-1RC was selected as the optimum amount mixture for stabilizing of marine clay soils. Besides, the increment of UCS was affected by curing periods. This was due to the chemical SH-85 content in the mixture to act as binders that interlock the rubber chips and the marine clay particles. As the curing time increased the void ratio decreased thus increased the strength of the treated soil.
3. The addition of rubber chips also influenced the strength of marine clay sample. The intention of using rubber chips was to reduce the construction cost as well as to promote the environmental-friendly method of soil stabilization. For the compressibility test, the compression index C_c value was in the range from 0.395 to 0.55 while the value of C_s was in the range from 0.03 to 0.049. The value of void ratio decreased with the addition of chemical-rubber chips mixture into marine clay sample. Based on the result, it showed that the compressibility index of the treated marine clay sample, 8BS-1RC reduced compared to untreated marine clay values. So, it can be concluded that the chemical-rubber chips mixture is a good method for improvement of marine clay.

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