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COMPARISON OF SOIL INDEX PROPERTIES VALUE FOR DIFFERENT PRE-DRYING CONDITIONS ON CLAYEY SOIL

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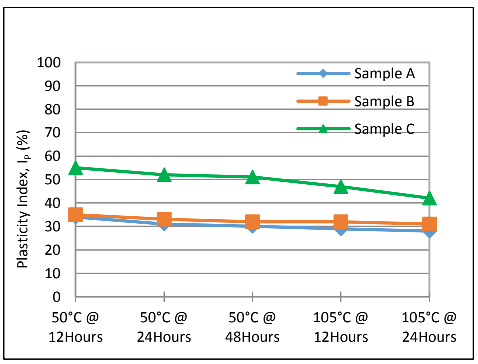
Graphical abstract



Abstract

Pre-test treatment prior to soil index properties testing particularly pre-drying plays an important role in order to obtain accurate and reliable results. According to British Standard, BS1377:1990-Part 1, soil sample shall be dried by either air drying or oven drying before testing. However, permanent alteration of soil physical properties will eventually influence the characteristic and behavior of the soil. Hence, effect of pre-drying conditions on the soil index properties is studied on three number of disturbed clayey soil samples pre-treated in five (5) different pre-drying conditions at different temperatures and drying duration. Soil specimens were tested based on index properties in accordance to BS1377:1990-Part 2. The results obtained revealed that increase of pre-drying temperature and duration has significant effect on the plasticity index of about 13%, shrinkage limit of about 4% and the classification of the clayey soils consisted higher percentage of fine particles. Conclusively, oven drying method should not be used in soil preparation for plasticity and shrinkage testing.

Keywords: Air dry; oven dry; clay; index properties

Abstrak

Rawatan pra-ujian sebelum ciri-ciri indeks tanah dilakukan terutamanya pra-pengeringan memainkan peranan yang penting untuk mendapatkan keputusan yang tepat dan boleh dipercayai. Menurut Standard British, BS1377: 1990-Bahagian 1, sampel tanah hendaklah dikeringkan sama ada dengan pengeringan udara atau pengeringan ketuhar sebelum ujian. Walau bagaimanapun, pengubahan Tetap sifat fizikal tanah akhirnya akan mempengaruhi sifat dan tingkah laku tanah. Oleh itu, kesan daripada keadaan pra-pengeringan pada sifat-sifat indeks tanah dikaji pada tiga jenis tanah liat terganggu sebelum dirawat pada lima (5) keadaan pra-pengeringan yang berbeza pada suhu yang berbeza dan jangka masa pengeringan. Spesimen tanah telah diuji berdasarkan ciri-ciri indeks mengikut khusus kepada BS1377: 1990-Bahagian 2. Keputusan yang diperolehi menunjukkan bahawa peningkatan suhu pra-pengeringan dan tempoh mempunyai kesan yang besar ke atas indeks keplastikan kira-kira 13%, had pengecutan kira-kira 4% dan klasifikasi tanah liat yang mempunyai peratusan partikel halus yang tinggi. Kesimpulannya, kaedah pengeringan oven tidak boleh digunakan dalam penyediaan tanah liat untuk ujian keplastikan dan ujian pengecutan.

Kata kunci: Pengeringan udara; pengeringan ketuhar; tanah liat; sifat-sifat indek

1.0 INTRODUCTION

All soils consist of three different components that are solid particles, water and air. The inter-relationship of the different components is important to define the condition or the physical properties of the soil. Generally, index properties of soils are determined by laboratory testing on soil samples obtained from the site. Most of the testing parameters determined from the laboratory testing are linked for correlation with descriptive data acquired from in-situ testing (field testing) by geotechnical engineers. The data obtained is used to study the subsurface investigation of a particular site for preliminary design, to verify the validity of design assumptions made based on engineering judgment and as additional data to enable engineering properties of the soils to be analyzed in numerical term for failure analysis.

According to Yong *et al*. [1] the nature of a soil is greatly determined by its composition which is influenced by its natural formation, environment, and anthropogenic activities. Commonly the soil constitutes of three phases that is solid phase, water phase and gas phase. The solid phase is built up by numerous types of particles such as carbonates, clay minerals, oxides and many others. The interaction of the various soil solid which also known soil fraction with water phase and gas phase construct the element of soil composition, influencing the ratio of the each phases in soil. Hence, the soil composition is essentially fundamental feature that directly affect the development of various soil structure, physical and chemical properties.

Clay soil exhibits a structure that is greatly influenced by chemical environment existed during deposition and by it stress history. The clays are typically complex aluminum silicates composed of silica tetrahedron and alumina octahedron of distinct structural units with unique relationships to one another. The silica tetrahedron consists of four oxygen ions and one silicon ion with the orientation while the alumina octahedron consists of six oxygen ions and one aluminum ion with the orientation. As for the alumina octahedron, some of the oxygen ion may carry a hydrogen ion in order to obtain valence balance.

The clay minerals are secondary minerals formed from the chemical weathering of primary mineral in parent rocks. The mineral formed depends on the composition of the molar ratios of chemical elements in solution and ions that lost during leaching in the dissolution process. The chemical combinations of minerals in the fine soil fraction can be principally divided into 3 groups: *montmorillonite*, *illite* and *kaolinite*. A numbers of studies have been carried out worldwide to investigate the effect of soil sample pre-drying on soil index properties and also engineering properties as well. Previous research showed that drying soil sample at 110°C will remove all of the free water (gravitational water which moves in, through and out of the soil by gravity) and most of the clay attached water while drying at 60°C removed part of the clay attached water. Conversely, air drying caused a minimal loss of attached water [2-3]. It is due to loss of free water and clay attached water resulted in a destruction of the soil structure and consequently affecting the soil properties. It was noted that drying at 110°C and 60°C would cause soil aggregation and thus resulted in an obvious reduction in liquid limit, plasticity index, and clay content (fine grained soil). Even though the drying temperature did not change soil classification, it was observed that higher temperatures caused the soil to behave in a less plastic manner. The experimental results indicated that both swell potential and swell pressure were reduced with drying temperature while the compression index and coefficient of compressibility increased. In addition, the unconfined compressive strength was also found to decrease with increasing drying temperature.

In addition, drying at lower temperature and even partial air-drying at room temperature can also cause significant changes [3]. If the soil used for the determination of Atterberg limits was first dried, then its value becomes smaller than the Atterberg limits that run on natural conditions. This is because, the drying of the soil sample will affect generally all tropical residual soils [3],[4].

Atterberg limits determination is also facing the same problem just as the problem of determining the moisture content, as indicated by Moh and Mazhar [5], when water is added to the soil, it tends to disperse the soil particles into smaller size and this will increase the surface area of the particles. By increasing the surface area of the soil, it resulted in high water absorption which will changes the liquid limit of the soil [5]. According to Townsend [6], the effect of drying before testing may lead to decrease of adhesions caused by oxidation of iron and aluminum and cause dehydration especially for *halloysite* and *allophane* [6].

In addition, Murthy [7] stated that drying of soil sample produces an irreversible change in the colloidal characteristics of the organic matter in a soil. A soil may be classified as organic soil if the liquid limit of the oven-dried sample is less than about 75% that for the air-dried sample [7]. He also stated that oven-drying lowers the plastic limits of organic soils, but the deviation in plastic limit is less than the liquid limit. This is further explained by Bujang *et al*. [8] that alteration of clay minerals and aggregation of fine particles to become larger particles that remain bonded even on re-wetting could be happened for partial drying of soil sample at moderate temperatures [8]. Any disturbance or alteration to the soil sample original conditions may distort the real properties values of the soil and provide a misleading data for safe and cost effective engineering design. It is due to the presence of bonding between soil particles by cementation or interlocking of the tropical residual soil. He suggested that if drying is necessary, only minimal drying should be applied to natural soil in preparation of classification testing.

The effect of air drying and oven drying method on soil plasticity could not be used to replace the air drying method in preparation works for Atterberg Limit test [9]. Studies revealed that the finer the size of the soil, the greater the effect of oven dried on the soil plasticity where he found the percentage of plasticity index between air drying and oven drying are 4%, 6% and 13% for coarse, medium and fine grain soil respectively. Later, a detailed investigation on index properties of Lateritic Soils in different pre-drying conditions was carried out by Gidigisa [9] from Addis Ababa University. The Atterberg Limit tests were carried out for as received condition, air drying at 50°C for 24 hours and oven drying at 105°C for 24 hours indicates there is significant difference between the values of plasticity index determined for as received condition compared to the oven dried [10]. The results revealed that oven dried soil have more significant impact on the clay content of soil compared to air dried and the increase in drying temperature reduces the specific gravity value of the lateritic soil. In this study, the pre-drying condition is the main factor to influence the results of the soil index properties testing especially plasticity and shrinkage testing. As discussed, the temperature applied during soil sample drying having significant impact on the soil plasticity as high temperature may alter the soil physical properties permanently. However, lower temperature applied will not able to eliminate the water content sufficiently or it may take longer time to achieve the dry condition. Longer duration used for dying the soil sample prior to testing would be non-cost effective. Besides pre-drying condition, there are various factors affect the soil index properties testing results included soil sample mass, soil grain size, water content, chemical contamination, relative humidity in the laboratory, testing apparatus and tester reliability. The above factors are disregarded to make sure the variation of result is due to the temperature and duration. Therefore this study is carried out to compare the soil index properties values obtained from five different pre-drying conditions with regards to the temperature effect and duration of pre-drying.

2.0 MATERIALS & SPECIMEN PREPARATION

The material to be used for this study was clayey soil so that plasticity testing could be performed on the soil samples. The soil samples selected varied in particle size distribution to compare the effect of drying on the fine soil particle content. The approximate weight of each soil sample is 5 kg. A total of three disturbed clayey soil samples were taken from two different locations in Peninsular Malaysia. A sandy clay sample was collected from a hill site in Kajang, Selangor and two marine clay samples were retrieved from the sea bed at offshore of Kerteh, Terengganu by third party driller. All the soil samples are used with consent of the third party driller. The soil samples marking and details are presented in Table 1. Figure 1 shows the physical appearance of the soil samples used for the laboratory testing. The soil samples were prepared by referring to the guideline in the British Standard BS 1377:1990- Part 1. Before testing, each of the collected soil samples will be divided into five (5) sections for different pre-drying condition [11][12]. At the same drying process, a small portion of soil sample from each section is put into the oven together for moisture content measurement at different temperature and duration. The determination and pre-dried in five different conditions as the followings.

(i) Oven drying at 50°C for 12 hours before testing
(ii) Oven drying at 50°C for 24 hours before testing
(iii) Oven drying at 50°C for 48 hours before testing
(iv) Oven drying at 105°C for 12 hours before testing
(v) Oven drying at 105°C for 24 hours before testing

The index property testings were performed after the pre-drying of the five sections of soil samples. All the laboratory testings were carried out referring to a standard procedure British Standard BS 1377:1990- Part 2 so that the outcomes of the testings are reliable, eliminating other factors other than pre-drying conditions.

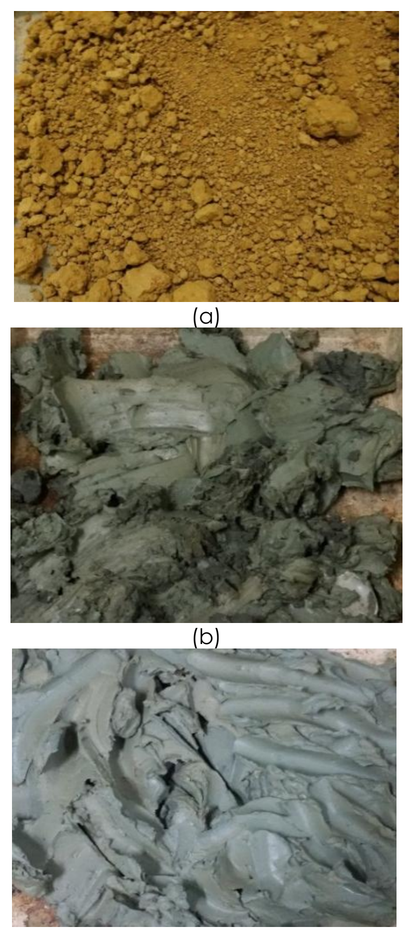


Figure 1 Soil samples used for laboratory testing (a) Sample A – Sandy Clay (0.5 to 1.0 m), (b) Sample B – Marine Clay (0.9 to 1.8 m), and (c) Sample C – Marine Clay (3.0 to 3.8 m)

Table 1 Details of soil samples collected for testing

Sample marking	Soil Sample A	Soil Sample B	Soil Sample C
Sample condition	Disturbed sample	Disturbed sample	Disturbed sample
Soil origin	Hill side	Sea bed	Sea bed
Depth of soil collected	0.5 m to 1.0 m	0.9 m to 1.8 m	3.0 m to 3.8 m
Location	Kajang, Selangor	Kerteh, Terengganu	Kerteh, Terengganu

3.0 RESULTS & DISCUSSIONS

The comparison of the index properties testing at various different pre-drying conditions that are 50°C for 12 hours, 24 hours and 48 hours and 105°C for 12 hours and 24 hours is discussed individually for each type of testing to study the effect of pre-drying temperature and duration.

3.1 Effect on Moisture Content

Figure 2 present the graph showing variation of moisture content corresponding to the five drying conditions for all the soil specimens. From the graph, it is observed that the moisture content of soil specimen A exhibit insignificant variation due to temperatures and duration during drying while specimen B and C exhibit significant increase 15% to 48% in moisture content from 50°C to 105°C for both 12 hours and 24 hours of pre-drying. When the duration of drying increased during pre-drying at 105°C, the moisture content increase at slower rate as most of the water in the soil particles is being release at that temperature. Agreement is achieved with study done by Fourie [13], stating that water content increased gradually with temperature of drying more than 40°C [13]. It is explained by Bujang etal. [8] that the existing crystallised water within soil mineral structure in soil would be released during sample drying between 105°C and 110°C and these changes are more significant in clayey soils containing minerals of *halloysite* and *allophone* [21].

3.2 Effect on Atterberg Limit

Generally, plasticity is the most outstanding characteristic of clayey soil which gives a good overall indication of the soils engineering properties. Any factor that affects the soil plasticity will also likely to affect its other properties of interest. Pre-drying of clayey soil is one of the factors that will have pronounced effect on the soil plasticity [2],[3].

The variation of the liquid limit for all the testing is presented in a graph as shown in Figure 3. Sample A and B exhibit lower variation in liquid limit that are 5% and 7% respectively as the temperatures of pre-drying increased from 50°C to 105°C at drying duration of 12 hours compared to 10% observed for sample C. Meanwhile, at pre-drying duration of 24 hours, the liquid limit marked a larger decrease that are 4%, 6% and 13% for sample A, B and C when the pre-drying temperature increase from 50°C to 105°C. The rapid decrease of liquid limit sample C may cause by the oxidation of clay minerals and hydration in the soil particles [14-25].

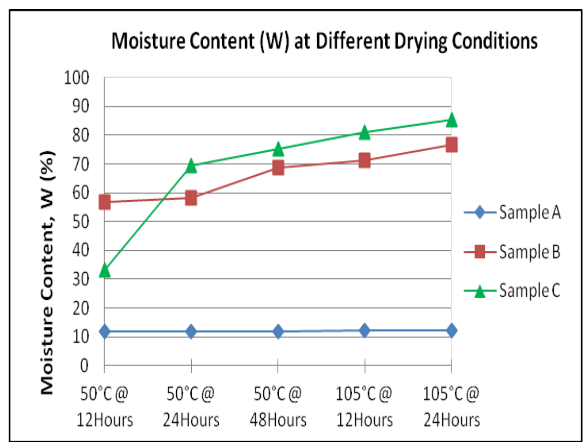
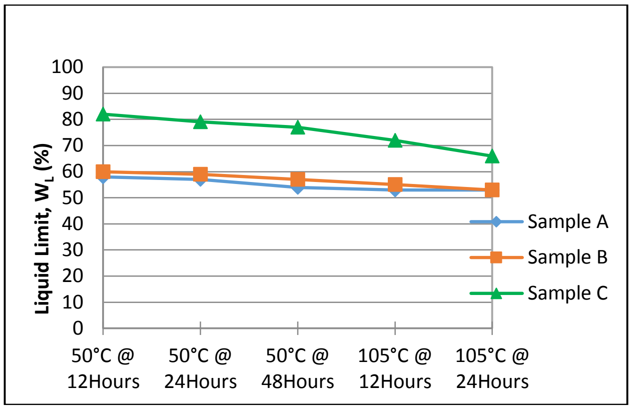


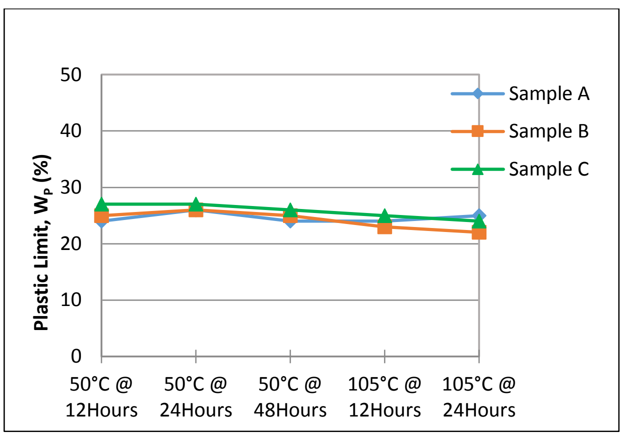
Figure 2 Moisture Content at Different Pre-Drying Conditions for the three soil samples

At the pre-drying temperature of 50°C, the liquid limit for soil sample A, B and C decreased 4%, 3% and 5% respectively from 12 hours to 48 hours. At the pre-drying temperatures of 105°C, the liquid limit for sample B and C decreased 2% and 6% respectively from 12 hours to 24 hours while the change in liquid limit for sample A at this temperature is constant even the pre-drying duration was extended from 12 hours to 24 hours at both pre-drying temperature of 50°C and 105°C. The deviation of plastic limit obtained from the three soil samples at the five pre-drying conditions is shown in Figure 3. The plastic limit for both soil sample B and C decreased 2% at pre-drying duration of 12 hours when the pre-drying temperature was increased from 50°C to 105°C while no change is observed in sample A. At 24 hours of pre-drying duration, sample

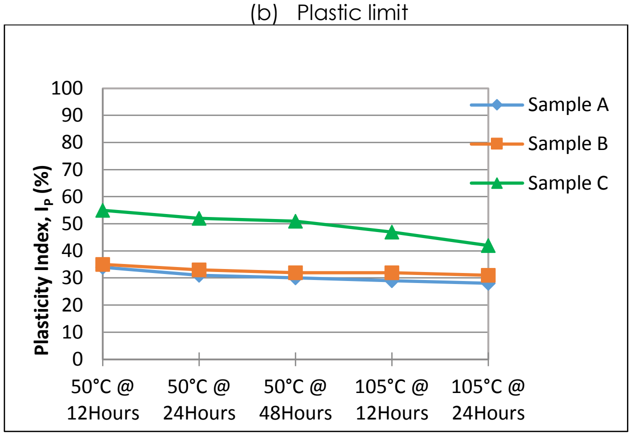
A exhibit plastic limit change of 1% compared to sample B and C which exhibit change of 4% and 3% at the same conditions. The changes of plastic limit for all the three soil samples are less than liquid limit due to the deviation in plastic limit is less than the liquid limit [7]. As for pre-drying temperature of 50°C and 105°C, the plastic limit of the three soil samples also shows insignificant difference even the pre-drying duration was increased from 12 hours to 24 hours and 48 hours.



(a) Liquid limit



(b) Plastic limit



(c) Plasticity index

Figure 3 Different Pre-Drying Conditions for the three soil samples (a) Liquid Limit, (b) Plastic Limit and (c) Plasticity Index

The variation of plasticity index due to the five pre-drying conditions for all the three soil samples. It is observed that the trend of change in plasticity index is almost identical to the change observed in liquid limit as both parameters have a strong relationship. Soil sample C exhibit the widest range of decrease of plasticity index among the three soil samples that are 8% and 10% of decrease due to temperature increase of 50°C to 105°C at 12hours and 24 hours pre-drying prior to testing. However, the effect of pre-drying duration is lesser, that are 4% and 5% at 50°C and 105°C respectively when pre-drying duration increase from 12 hours to 48 hours.

The decrease in plasticity index in this study shows agreement with study done by Dibisa (2008) who indicated there is significant difference between the values of plasticity index determined for as received condition compared to the oven dried [10]. It also achieves agreement with Lee (2006) studies revealed that the finer the size of the soil, the greater the effect of oven dried on the soil plasticity [9]. Soil sample C has higher percentage of fine soil particles compared to sample A and B. This phenomenon could be further explained by Bujang *et al*. [8] that alteration of clay minerals and aggregation of fine particles to become larger particles that remain bonded even on re-wetting could be happened for partial drying of soil sample at moderate temperatures. It is due to the presence of bonding between soil particles by cementation or interlocking of the soil.

The soil sample A which has higher amount of coarse grain particles (sand) is not affected by the pre-drying conditions. The pre-drying effect is more pronounced in soils containing more fine grain particles which contain clay minerals, in this case sample B and C (marine clay) were affected. Still, the effect of temperature and duration of pre-drying is affecting plasticity of sample C the more significantly due to the increasing depth compared to sample B as soil at increasing depth is less disturbed and chemical reaction by other agent is minimal.

Greatest effect is observed on soil sample C which contains highest percentage of fine particle (silt and clay) and lowest content of sand. The plasticity index decrease 8% and 10% when pre-drying temperature increase from 50°C to 105°C at duration of 12 hours and 24 hours respectively. This change of plasticity index associated well with liquid limit and linear shrinkage which also exhibit depreciation due to temperature increment. Nevertheless, plastic limit do not exhibit pronounced decrease due to the pre-drying effect.

3.2.1 Classification Of Fine Grained Soil

The relationship between the plasticity index and the liquid limit is used in the British Soil Classification System to establish the sub-groups of fine soil. Plasticity chart shown in Figure 4 is used to classify the three soil samples tested pre-dried at five different conditions. Generally, the A-line in the plasticity chart provides an arbitrary division between silts and clays, and vertical divisions (of percentage liquid limit) to define five different degree of plasticity. Figure 4 shows that all the three soil samples are clay which is the target material of this study. Sample A and B are classified as Clay of high plasticity (CH) with liquid limit ranged from 53% to 60% and plasticity index ranged from 28% to 35% at five different pre-drying conditions as discussed earlier. Conversely, the sample C is classified as Clay of very high plasticity (CV) for those specimens pre-dried for 50°C at 12 hours, 24 hours & 48 hours and 105°C for 12 hours. However, at the maximum temperature of 105°C and pre-drying duration of 24 hours, Sample C is classified as same as Sample A and Sample B. In this case, the high temperature and duration of pre-drying has lower the plasticity of the clay which the minerals in the clay may be altered and aggregation of fine particles happened due to the pre-drying condition. In addition, the reduction of limit liquid and plasticity index caused by the pre-drying at high temperature (105°C) and long duration (24 hours) classify of sample C as Clay of high plasticity (CH) instead of Clay of very high plasticity (CV). At this pre-drying condition, the liquid limit value of 66% and plasticity index of 42% is categorised at CH while liquid limits and plasticity index values at lower temperature (50°C) and shorter duration (12 hours) marked classification category as CV. This results come to the agreement with a research done by Basma et.al (1994) explaining that loss of free water and clay attached water resulted in a destruction of the soil structure and consequently affecting the soil properties due to drying at 110°C and 60°C would cause soil aggregation and thus resulted in an obvious reduction in liquid limit, plasticity index even though the drying temperature did not change soil classification, it was observed that higher temperatures caused the soil to behave in a less plastic manner [2].

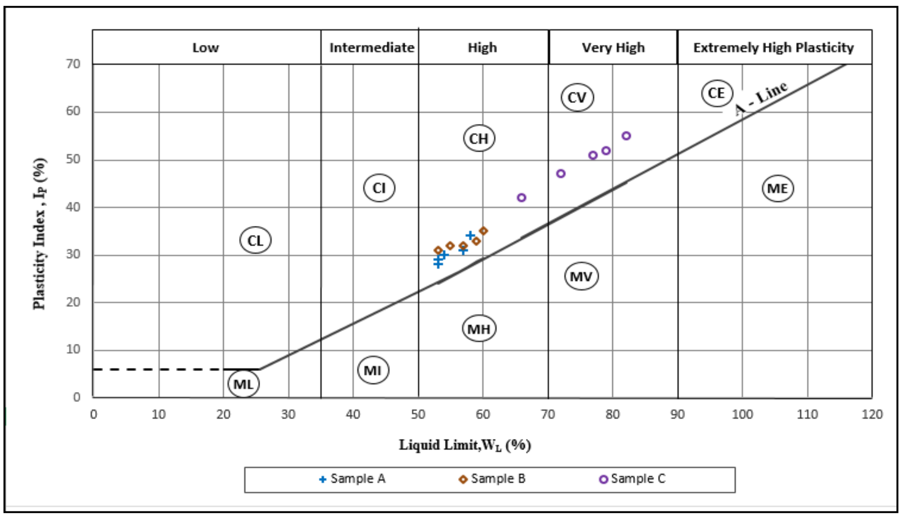


Figure 4 USCS plasticity chart for classification of the soil samples.

3.3 Effect on Linear Shrinkage

Figure 5 illustrates the change of linear shrinkage due to the five different pre-drying conditions. Sample A and B exhibit marginal decrease of shrinkage limit which are within 2% as the temperature of pre-drying increase from 50°C to 105°C at pre-drying duration of 12 hours & 24 hours. Meanwhile, sample C exhibits slightly higher variation, 4% at the same condition.

As for the effect of duration of pre-drying, the variations of shrinkage limit for all the three soil samples are nearly constant at both pre-drying temperature. A minor variation of less than 2 % for pre-drying at 50°C and less than 1% for pre-drying at 105°C were observed for all the three soil samples. It shows that duration of pre-drying have a minimal effect on shrinkage of clayey soil compared to temperature of pre-drying. Both swell potential and swell pressure were reduced with drying temperature while the compression index and coefficient of compressibility increased. In addition, the unconfined compressive strength was also found to decrease with increasing drying temperature [2].

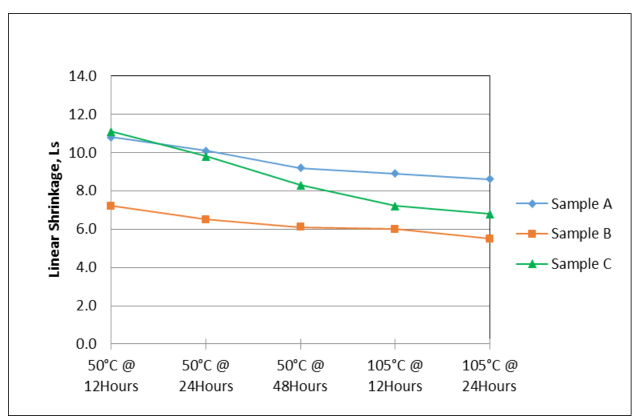


Figure 5 Linear Shrinkage at Different Pre-Drying Conditions for the three soil samples

4.0 CONCLUSION

A total of 3 soil samples from different nature (hill side and sea bed) and depths (0.5m to 1.0m, 0.9m to 1.8m and 3.0m to 3.8m) were tested at different pre-drying conditions to investigate the effect of temperature and duration of pre-drying on the soil index properties. From all the findings and discussion, we could conclude that pre-drying of soil prior to testing basically has effect on the index properties values, depending on the type of soil tested. Based on the laboratory testing performed, the following conclusion can be drawn:

1. The moisture content increase significantly as the temperature and duration of drying increased. Moisture content is mainly influenced by water-holding capacity in the soil which is controlled primarily by soil texture and organic matter. Soils with smaller particles (silt and clay) have a larger surface area than those with larger sand particles, and a large surface area allows a soil to hold more water. In other words, a soil with a high percentage of fine particles and organic matter, has a higher water-holding capacity which need higher temperature and duration for drying the soil.
2. Pre-drying of soil samples has enormous effect on the plasticity behavior of all the clayey soil tested. The entire three soil samples exhibit pronounced decrease of liquid limit (5% to 16%) and plasticity index (6% to 13%) due to increment of temperature and duration of pre-drying. Greatest effect is observed in soil sample C which is marine clay at depth of 3.0m to 3.8m. Decrease of 8% and 10% of plasticity index for soil sample C due to temperature increase of 50°C to 105°C at 12 hours and 24 hours pre-drying is revealed from this study. This behavior possibly attributable to the characteristic of the soil sample itself as it is a pure marine clay with very least sand content and less disturbed at the depth of 3.0m below sea bed.. At high temperature, the clay mineral may lost the water held in the clay mineral structure, therefore cause irreversible change in the colloidal characteristics of the organic matter in a soil. Hence, it is proven that pre-drying is not suitable for Atterberg Limit test for high fine particle content soils especially on clay of *montmorillonite, halloysite* and *allophane*.
3. It is also reveals that particle sizes of the soil also affect the plasticity of the clayey soil. The more sand content, the lower value of plasticity index was observed where plasticity index for soil sample A (ranged 28 % to 34 %) is lower than sample C (ranged 42 % to 55 %) as sand content in soil sample A is about 40 % higher than soil sample C (not more than 2 % of sand content). This may due to decrease of the inter-molecular attraction force in the soil. As the inter-molecular attraction force decrease, it caused the liquid limit decrease and hence the plasticity index depreciates as well. Besides, it is also observed that the finer the size of the soil, the greater the effect of pre-drying temperature and duration on the soil plasticity. Not only that, soil samples with the higher percentage of sand tend to be having lower moisture content value as most of the water content is soil has already been drained at its natural state.
4. The linear shrinkage associates well with plasticity index which also show decrease as the pre-drying temperature and duration increased. Conversely, particle density or specific gravity of the three soil samples is not greatly affected (less than 3 %) by the pre-drying temperatures and duration especially on soil sample A which have higher content of sand (40%). The effect is found stronger on finer soil particles practically on soil sample B and C.

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