Behaviour of Consistency Limit on Stabilized Soil in Effect to Temperature Changes

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Abstract. Soil engineering properties are usually determined in a laboratory setting at room temperature of 270C. Seasonal changes, which is mainly the alteration in thermal condition in surrounding soil, causes reasonable concern about the nature and magnitude of temperature changes which influences soil engineering properties. The particle size distribution, consistency limit, strength, mineralogy, and permeability of the soil are all accompanied by rise in temperature. In clayey soils, as the temperature rises, the average particle size increases as a result of agglomeration and cementation of the clay particles. In this paper, an attempt is made to study the change in temperature which directly influences the consistency limit of clayey soil stabilized with Lime and Rice husk ash at different proportions.

Key words: Temperature, Consistency limit, Atterberg limit, RHA, Lime, Clayey soil.

1 Introduction

Clay minerals are a specific category of layer silicates formed through the chemical weathering of other silicate minerals on the Earth's surface. They consist of planes of cations (positively charged ions) that are arranged in sheets, with coordination to oxygen atoms in either tetrahedral or octahedral fashion. These sheets are further organized into layers, often referred to as having a 2:1 ratio. There is one tetrahedral sheet and one octahedral sheet present in the fundamental structural unit of minerals with a 1:1 layer arrangement. The most common mineral in clay group is montmorillonite which is also known as the Smectite group. This mineral structure is made up of two Si tetrahedral sheets and one Al octahedral sheet in the middle. The units are stacked in such a way that their oxygen layers are adjacent to one another, leading to weak force of attraction and excellent cleavage between them. As a result, water can easily move between the sheets, breaking the bonds and causing substantial swelling.

Atterberg's limits are a set of tests used to assess the consistency of clayey soils. These limits divide the soil behavior into four distinct phases: solid, semi-solid, liquid, and plastic states. The liquid limit represents the point at which the soil transitions from its plastic state to a more fluid, liquid-like state. On the other hand, the plastic limit refers to the minimum moisture content at which the soil changes from a semi-solid to a plastic condition, indicating its ability to be molded and shaped. These limits provide valuable information about the engineering properties and behavior of clayey soils.

The lowest water content at which the soil becomes firm is referred to as the shrinkage limit. The plasticity index (PI), which is mostly determined by water content, is calculated using the difference between the PL and LL values. Because of particle movement, the average particle size in sandy soils tends to get smaller when the temperature gets higher. This could be because temperature has an effect on the bond that holds fines and sand grains together. Clayey soils noticed an increase in their average particle size as the temperature rises because the clay component tends to aggregate and cemented as the temperature rises.

The temperature of the earth is subjected to a wide range of extremes on a regular basis. At midday, the soil is in direct contact with the sun, which means that the temperature of the part of the soil that is being heated is most likely to be at its peak. On the other side, the soil is brought into touch with cold, wet air during the night and the early morning hours. Alterations in land usage, in addition to the temperature of the surrounding environment, have an impact on the rate at which the ground

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surface absorbs heat. Alterations in land usage have an effect on the amount of solar radiation that is absorbed and reflected by the soil.

2 Literature Survey

Widjaja et al. (2019) investigated the effect of high temperatures on the Atterberg limits of soil samples. The researchers selected bentonite, kaolin, and Pasir Panjang as the samples and subjected them to gradual heating in an oven, ranging from room temperature to 100°C. To assess the liquid-holding capacity of the soil samples, they employed the Casagrande cup test and fall cone penetrometer test. The findings of the study revealed that temperature variations had a notable impact on the liquid limit (LL), plastic limit (PL), and plasticity index (PI) of the soil samples, particularly in the case of the bentonite sample. Among the different soil types, the bentonite sample was the most sensitive to temperature changes, while the kaolin sample exhibited the least sensitivity. Both the Casagrande cup test and fall cone penetrometer test exhibited similar trends in relation to the liquid limit. On average, the liquid limit of the soil samples decreased by approximately 7% with increasing temperature. Specifically, the liquid limit of the bentonite sample experienced a reduction of around 12% as the temperature increased, while the decrease in the liquid limit of the kaolin sample was less than 6%. These findings suggest that high temperatures can significantly influence the Atterberg limits of soil samples, with the bentonite sample being particularly susceptible to temperature changes. The Casagrande cup test and fall cone penetrometer test yielded consistent results regarding the liquid limit.

Shao et al. (2012) focused on investigating the effects of temperature on various properties of soil, including Atterberg limit, swelling, shear strength, and permeability. They specifically examined how these properties changed as the temperature increased from 5 to 50°C. The research findings revealed several important insights. Firstly, as the temperature increased, there was a reduction in the liquid limit of the soil. This means that the soil became less susceptible to undergoing plastic deformation as it transitioned from a solid to a liquid state. Additionally, the swelling of the soil increased with higher temperatures, indicating an expansion in volume due to the absorption of water. The permeability of the soil also increased as the temperature rose. This means that the soil became more permeable to the movement of water. The researchers attributed these changes in permeability and swelling to alterations in the total volume of water absorbed by the soil. They found that minerals with high water adsorption, particularly hydrophilic minerals, played a significant role in mediating the effects of temperature. The presence of more hydrophilic minerals intensified the influence of temperature on the liquid limit of the soil, while reducing its effect on the swelling ratio. Furthermore, the increase in temperature led to a significant rise in the soil's permeability. This increase in permeability facilitated the release of adsorbed water from the soil into the surrounding environment. The study also noted a strong and proportional relationship between temperature and cohesive force. As the temperature increased, the cohesive force within the soil also increased, affecting its shear strength. Overall, the findings of Shao et al. (2012) demonstrate that temperature variations have significant effects on the Atterberg limit, swelling, shear strength, and permeability properties of soil. These effects can be attributed to changes in water absorption and the presence of hydrophilic minerals.

Jefferson et al. (1998) developed an experimental methodology to establish the relationship between temperature and consistency limit. The method allowed for more reliable results over a broader temperature range of 10–80°C. The study discussed the findings for kaolinite, smectite, and mixtures of these clays with varying proportions. Smectites showed higher sensitivity to temperature changes compared to kaolinites. Temperature caused the liquid limit of smectitic clay to rise, while the liquid limit of kaolinite experienced a slight decrease. The variation in liquid limit was influenced by the specific surface area of clayey soil and the type of inter-particle contacts occurring within it. Gadzama et al. (2017) investigated the effect of temperature on selected tropical black clays in Northeastern Nigeria. Soil samples were heated to temperatures of 25, 50, 75, 100, and 150°C, and various tests were conducted, including Atterberg limits, free swell, compaction, and California bearing ratio. The results indicated a decrease in both liquid and plastic limits, an increase in maximum dry density, and a reduction in California bearing ratio. The plasticity index and optimum moisture content did not exhibit a clear pattern. Statistical analysis confirmed the significant influence of temperature on the engineering properties of the soil samples, suggesting a positive effect on their qualities. A temperature of 100°C was identified as optimal for soil remediation and improvement of geotechnical properties. Yilmaz (2010) assessed the impact of temperature on the properties of kaolinite and bentonite, including particle size, water content, specific gravity, plasticity, activity index, swelling, compression index, and strength. The samples were subjected to temperatures ranging from 100 to 600°C. Kaolinite lost its plasticity at 400°C, while bentonite did so at 500°C. The swelling of both kaolinite and bent its significantly decreased after thermal treatment at 400°C. The mineralogical, physical, and mechanical properties of the kaolinite and bentonite specimens underwent significant changes as a result of the thermal treatment.

In summary, Widjaja et al. (2019) examined the Atterberg limit of soil samples at high temperatures and found that temperature affected the liquid limit, plastic limit, and plasticity index, with bentonite being the most affected. Shao et al.

(2012) observed that temperature influenced the liquid limit, swelling, and permeability of soil, primarily due to changes in water volume and the presence of hydrophilic minerals. Jefferson et al. (1998) investigated the relationship between temperature and consistency limit, noting variations in liquid limit based on clay type and surface area. Gadzama et al. (2017) studied the engineering properties of soil at different temperatures, observing changes in liquid and plastic limits, maximum dry density, and California bearing ratio. Yilmaz (2010) evaluated the effects of temperature on various properties of kaolinite and bentonite, noting transformations in mineralogical, physical, and mechanical characteristics after thermal treatment.

3 Effect of temperature on Consistency limit of Clay Materials

The soil from Siruseri, which is located in Chennai, was selected for this study. According to the plasticity chart by Arthur Casagrande, the soil's classification as high plastic, clayey soil (CH) describes it best. The location of soil on the plasticity chart is depicted in figure 1. It is important that the materials that will be utilized in this investigation be analyzed in order to identify their consistency limit. This will allow the researcher to predict how the materials will behave when applied to soil throughout the investigation. Determining the qualities of raw materials in accordance with the IS standard requires characterization, which is a vital step. In order to improve the clay soils physical characteristics, lime (L), either in the form of quicklime (CaO) or hydrated lime (Ca (OH)2), has been applied to them. The removal of the bran and germ from rice results in the generation of an agricultural waste known as rice husk. Ash was produced by burning rice husk that had been collected from a nearby agricultural area at a temperature of 400 degrees Celsius. Lime (L) and Rice Husk Ash (RHA) were utilized in this investigation by combining these components with soil at three distinct temperatures of 27, 60, and 100 degrees Celsius prior to the heating process. Table 1 provides a tabular breakdown of the many oxides that make up raw materials and their respective compositions.

Table 1. Composition of Lime & Rice Husk Ash

Constituent	Silica (%)	Alumina (%)	CaO (%)	$CaCO_3$ (%)	Carbon (%)	MgO (%)	K_2O (%)	Fe_2O_3 (%)	LOI (%)
Lime	0.36	0.04	97.88	–	–	0.23	–	0.03	–
Rice Husk Ash	67.3	4.9	1.36	–	2.23	1.81	0.39	0.95	17.78

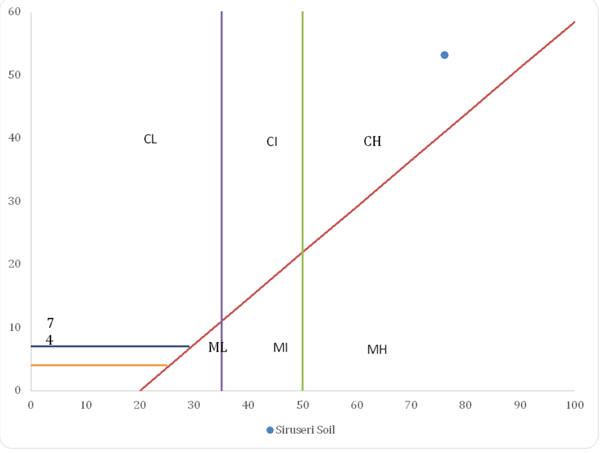

Fig.1. Plasticity Chart of Siruseri Soil.

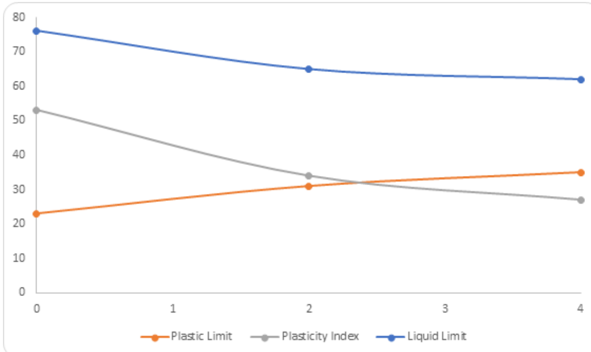

Fig. 2. Effect of Lime at various proportions on Siruseri Soil at 27^{0}C.

It is seen from the above curve (Fig 2) that blending of lime with virgin soil shows a decreasing trend in liquid limit as percentage of lime increases at 27^{0}C. The minimum water content in which change of state occurs from semi solid to plastic state shows a rising trend on increasing the content of lime to virgin soil from Siruseri. According to Soundarya (2022), the plasticity index, which measures the difference between the liquid limit and plastic limit, decreases as the liquid limit and plastic limit values decrease. In the case of Siruseri soil, the liquid limit values for different compositions were as follows: 76.16% for Siruseri soil alone, 65% for soil with 2% lime, 62% for soil with 4% lime, and 58% for soil with 8% lime. The plastic limit values were not explicitly mentioned, but based on the statement that the 8% lime with soil composition is considered non-plastic because a thread of 3mm cannot be rolled out, we can infer that the plastic limit for that composition is higher than 58%. Calculating the plasticity index for each composition by subtracting the plastic limit from the liquid limit, we get the following values: Siruseri soil: 76.16% - Plastic Limit = Plasticity Index (not provided) Soil with 2% lime: 65% - Plastic Limit = 34% Soil with 4% lime: 62% - Plastic Limit = 27% Unfortunately, the plasticity index for Siruseri soil alone was not provided in the given information.

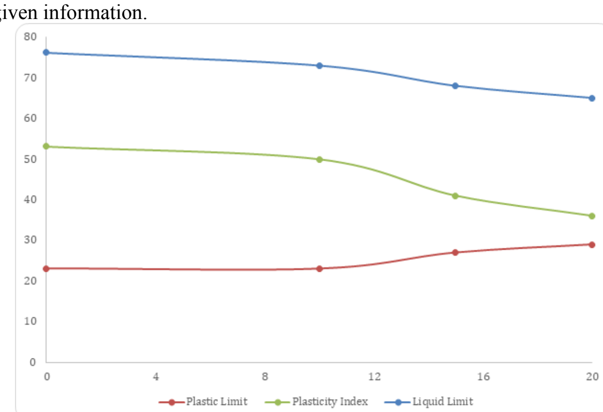

Fig. 3. Effect of RHA at various proportions on Siruseri Soil at 27^{0}C.

The study conducted by Prakash (2009) investigated the effect of Rice Husk Ash (RHA) on the soil consistency limits, which play a significant role in soil cohesion. The liquid limit (LL) was determined using Cassagrande's method, and the results showed that soil samples blended with 10% RHA, 15% RHA, and 20% RHA had liquid limits of 73%, 68%, and 65% respectively, as shown in Figure 3. The plastic limit (PL) of the clay soil mixed with 10% RHA, 15% RHA, and 20% RHA was measured using the traditional thread rolling method, yielding values of 23%, 27%, and 29% respectively. The addition of RHA to Siruseri soil resulted in a decrease in the plasticity index, as evidenced by the decreasing trend in the liquid limit (LL) and plastic limit (PL) values. The plastic limit is a significant indicator of soil moldability and is closely associated with soil cohesion. While the conventional method of determining the plastic limit using thread rolling, which relies on soil cohesion, was employed, there is a need to explore alternative approaches that explicitly consider soil cohesion before considering other methods.

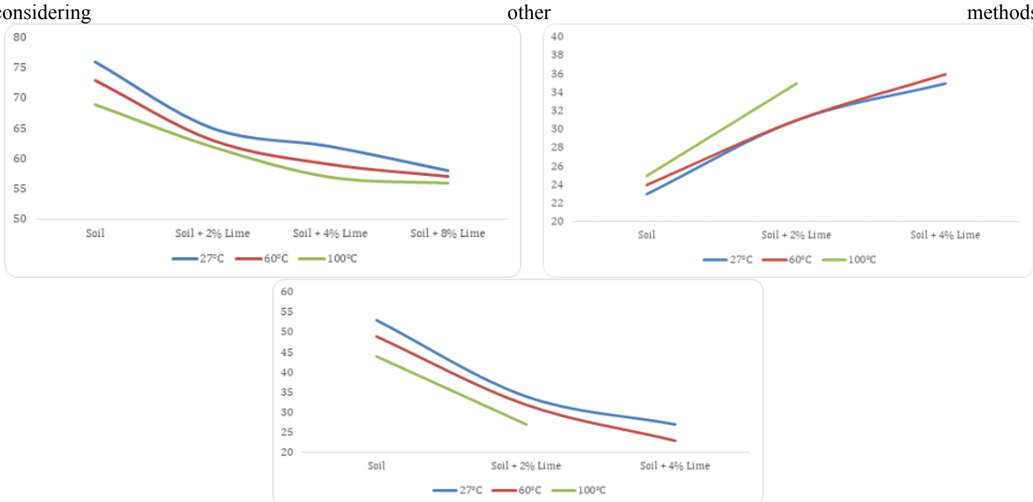

Fig. 4. Effect of Temperature on Atterburg Limit on addition of Lime with soil

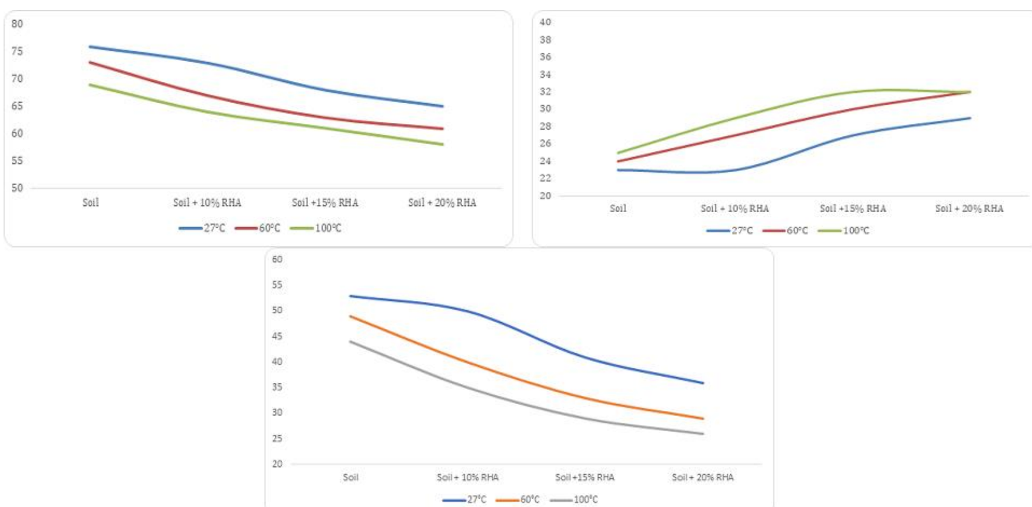

Fig. 5. Effect of Temperature on Atterburg Limit on addition of RHA with soil

All four soil sample curves lie within a confined zone that defines all three temperature crossing lines. All additive-added soil's liquid limit decreased with temperature. Unlike virgin soil, soil added with RHA showed a modest drop, which, given the test, shows a trend rather than a significant decrease. (Soundarya et.al., 2019) Except for virgin soil, which may reflect a trend rather than a rise, the plasticity index values. Figure 4 shows a temperature-dependent decrease. Environmental temperature and land usage affect ground surface temperature absorption. Land usage affects soil solar radiation absorption and reflection. Lime (L) and Rice Husk Ash (RHA) were mixed with soil and subjected to the thermal effect at 27, 60, and 100 °C. The results of particular temperature influence on Atterburg limits were shown in Figure 4 and Figure 5 respectively. Moisture affects clay engineering on a large scale. Clays lose their adsorbed water and hydrate at temperatures beyond dehydration but below dehydroxylation. The pore space and interlayer gaps diminish, affecting the acidity of clay mineral surfaces and interlayers. Clay material porosity and plasticity change when absorbed water evaporates. Thermal treatment induces changes in water viscosity, thereby impacting the liquid and plastic limits of clay soils. Fang and Daniels (2006) conducted research that demonstrated a decrease in the liquid and plastic limits of kaolinitic and montmorillonitic clays with increasing temperature. Thermal treatment has an impact on the consistency limits and unit weight of clay soils. Additionally, Chandrasekhran et al. (1969) observed significant variations in Atterberg limits among different soil types. Determining Atterberg limits can be challenging due to the non-plastic behavior exhibited by clays at different temperatures. Heat treatment enhances the cohesion between clay particles, resulting in improved shear resistance and compressive strength, particularly in clay-based soils with high plasticity.

4 Conclusion

Thermal treatment has a significant influence on the behavior of clay due to its impact on both free and adsorbed water. Changes in the forces of adsorbed water and the expansion of free water within clay formations are the primary causes of temperature-induced stress. The thermo-mechanical deformation of the solid skeleton alters the hydraulic gradient and transient flow of pore water. The plasticity index in Rice Husk Ash (RHA) can decrease by up to 100% under the influence of temperature, which is particularly important in clay-rich areas that exhibit rapid clay-water reactions. The extent of thermal changes in clay soil depends not only on the temperature and duration of exposure but also on the mechanical and mineralogical compositions of the clayey soil. In this context, the addition of RHA to the soil modifies the Atterberg limit, with a gradual decrease in the Plasticity Index observed for soil with 20% RHA compared to the original soil.

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