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Effect of various temperatures to liquid limit, plastic limit, and plasticity index of clays

Budijanto Widjaja*, Angela Florencea Nirwanto

Civil Engineering Department, Faculty of Engineering, Universitas Katolik Parahyangan, Bandung, Indonesia

*widjaja@unpar.ac.id

Abstract. This research aims to study the liquid limit, plastic limit, and plasticity index of soil samples treated with elevated temperatures. Liquid limit and plastic limit are physical properties of soils. Bentonite, kaolin, and Pasir Panjang samples were heated in an oven from room temperature up to 100 °C before the test. The liquid limit and plastic limit of soil samples were examined by Casagrande's cup test and fall cone penetrometer test. Results show that the liquid limit and plastic limit of soil samples decrease as temperature increases. Plasticity index varies with the change in liquid limit and plastic limit. The bentonite sample is the most sensitive to temperature change, whereas the kaolin sample is the most insensitive. The sensitivity of the Pasir Panjang sample is in between those of the two other samples.

1. Introduction

Atterberg's limit is used to determine the consistency of cohesive soil, which can be divided into four states: solid, semi-solid, plastic, and viscous liquid. The lowest water content that causes soil to be in solid state is called shrinkage limit. Plastic limit (PL) is the lowest water content with which soil changes its behavior from semi-solid to plastic state, and liquid limit (LL) is the indicator when soil has a transition from plastic to viscous liquid state [1]. Plasticity index (PI) is the difference between PL and LL and is thus dependent on the two. From Atterberg's limit, the other characteristics of soil can be determined, especially soil classification [2], due to that this analysis treats them as physical properties not as mechanical properties.

The soil is often exposed to different temperatures every time. At noon, the soil contacts with sunlight, and the temperature of contacted soil may be the highest one. However, in the evening and morning, the soil contacts with moist air of low temperature. Apart from being influenced by environmental temperature, the adsorption of the ground surface temperature is also affected by the changes in land use. The changes in land use also change the absorption and reflection of solar radiation of soil [3].

To determine the affecting factors of ground surface temperature, this study investigates the effect of different temperatures on LL, PL, and PI. The various temperatures used for testing are from room temperature up to 100 °C following Towhata *et al.* [4]. The soil samples are heated 1 day until 5 days before the test.

2. Materials and Methods

The experiment uses three kinds of soils: two kinds of clay mineral (kaolin and bentonite) and a landslide soil sample from Pasir Panjang Village in Brebes Regency, Central Java, Indonesia. Kaolin and bentonite are chosen because these minerals represent the extreme behavior of clay. The behavior of the other soil sample is between those of the two [5]. Bentonite is more reactive to various treatments than kaolin. The Pasir Panjang sample is chosen as a comparison for the behavior between the two clay minerals.

Soil heating is conducted in three groups: (1) dried soils examined at room temperature (25 °C), (2) dried soils tested by heating in an oven at 100 °C for 1 day, and (3) dry soils tested by heating in the oven at 60 °C and 100 °C for 5 days. Before being heated, the soils must pass through sieve no. 40 (0.4250 mm). Each soil sample is examined using Casagrande's cup test in accordance with ASTM D4318-05 [6] to obtain LL and fall cone penetrometer test in accordance with BS 1377-2 :1990 [7] to obtain the LL and PL of soils.

3. Result and Discussion

3.1 Liquid Limit

The effect of various temperatures on the LL of soil samples by Casagrande's cup test and fall cone penetrometer test is shown in Figure 1 and Table 1. LL is defined as the water content related to 25 times of drops for Casagrande's cup test and at 20 mm penetration for fall cone penetrometer test.

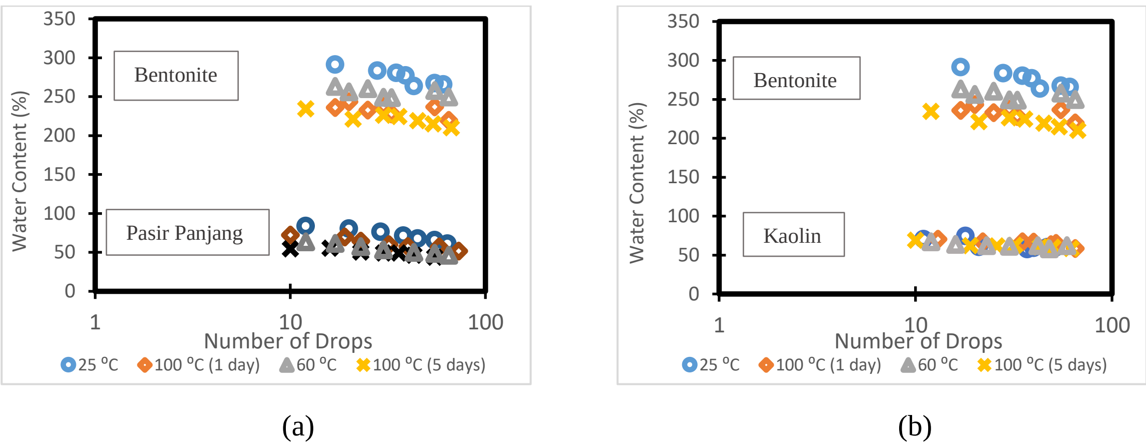

Figure 1. Experimental data at various temperatures using Casagrande's cup test for (a) bentonite and Pasir Panjang samples and (b) bentonite and kaolin samples

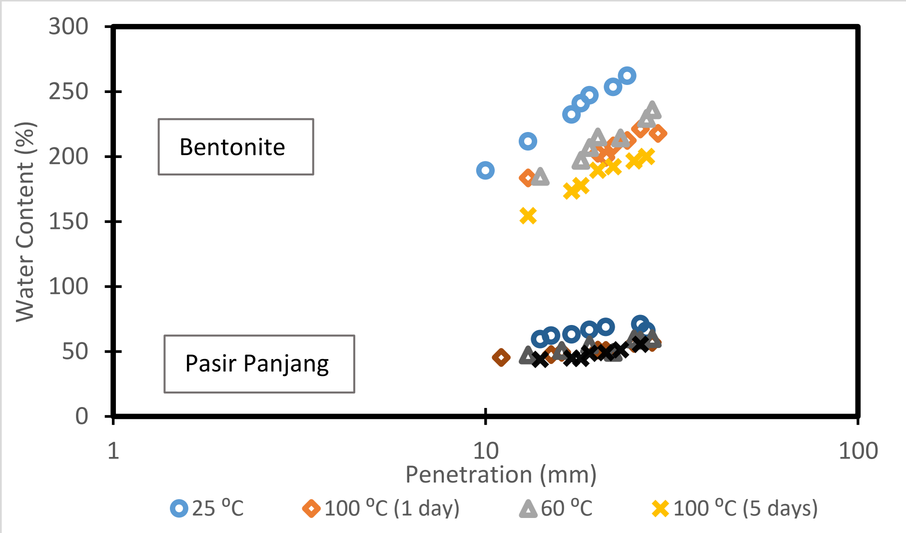

Figure 2. Comparison between bentonite and Pasir Panjang samples with various temperatures using fall cone penetrometer test

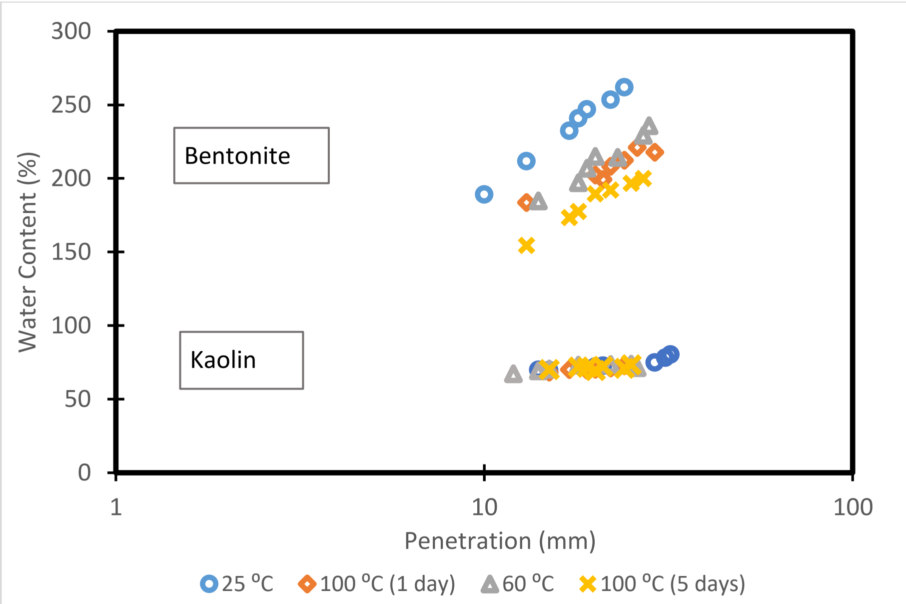

Figure 3. Relationship between water content and cone penetration using fall cone penetration test for bentonite and kaolin samples with the variation in temperature

3.2 Plastic limit
The effect of various temperatures on the PL of soil samples by Casagrande's cup test and fall cone penetrometer test is shown in Table 1. PL is the water content at 2 mm penetration for the latter method.

3.3 Plasticity index
PI is the difference between LL and PL of clay, and its value may not be negative [8]. The effect of various temperatures on the PI of soil samples is shown in Table 1.

Table 1. Results of LL, PL, and PI of soil samples

Temperature	Atterberg's Limit	Soil Samples		
		Bentonite	Kaolin	Pasir Panjang
25 °C	LL^a	284	68	76
	LL^b	250	72	66
	PL	80	50	22
	PI	170	22	44
60 °C (5 days)	LL^a	258	64	56
	LL^b	210	72	56
	PL	80	50	22
	PI	130	22	34
100 °C (5 days)	LL^a	225	64	52
	LL^b	185	72	50
	PL	70	50	21
	PI	115	22	29
100 °C (1 day)	LL^a	239	67	64
	LL^b	202	70	52
	PL	90	52	18
	PI	112	18	34

Note: ^{a} Casagrande's cup test, ^{b} fall cone penetrometer test

3.4 Discussion

The results show that the LL, PL, and PI of bentonite and Pasir Panjang samples treated at various temperatures decrease as temperature increases. However, the decrease rates are low. By contrast, those of the kaolin sample are inconsiderably affected by various temperatures. Overall, the samples require a small amount of water to transform into liquid viscous state even under high temperature. Table 1 presents that the two methods (i.e., Casagrande's cup test and fall cone penetrometer test) obtain similar trends of LL and its reduction rate. The LLs of bentonite and Pasir Panjang samples decrease by approximately ±12% and ±7%, respectively, as temperature increases.

Table 1 shows that the PL of soil samples is slightly affected by various temperatures. Remarkable changes only occur in the bentonite sample. The PL of Pasir Panjang sample is lower than those of the two pure clays. This result is consistent with that reported by Jefferson and Rogers [9]. The decrease rate of PL of soil samples treated at various temperatures is not as large as that of LL. Table 1 also shows that the PI of soil samples decreases as LL and PL decrease. The PI of Pasir Panjang sample is between those of kaolin and bentonite samples. This result is consistent with the statement of Sridharan and Rao [5] that bentonite and kaolin represent the extreme condition of clay and that the behavior of the other clay is between those of the two samples.

The effects of various temperatures on the LL, PL, and PI of soil samples are relatively remarkable. Notably, kaolin and bentonite are produced from volcanic environment. Kaolin is made either by acid leaching of granitic rock or hydrothermal in high volcanic areas [2]. Bentonite originates from weathering of the parent volcanic material [8]. In Pasir Panjang Village, the major type of soil is marl rock, which is claystone [10]. Claystone is a sedimentary rock that is made from sedimentary magma rock.

The sensitivity of the soil samples may be due to the soil classification. In Casagrande's plasticity chart (i.e., USCS), the bentonite and Pasir Panjang samples are classified as soil type CH (clay with high plasticity). On the contrary, the kaolin sample is classified as soil type MH (silt with high plasticity). Thus, the bentonite and Pasir Panjang samples are in the same group, whereas the kaolin sample belongs to a different group. This reason is consistent with that for the PI result.

4. Conclusion

This study shows that various temperatures considerably affect the LL, PL, and PI of soil, especially for the bentonite sample. Casagrande's cup test and fall cone penetrometer test obtain the similar trend of LL. The difference in the results occurs because of the different testing mechanisms used. As temperature increases, the LLs of soil samples decrease (approximately ±12% for the bentonite sample and ±7% for the Pasir Panjang sample). By contrast, the LL of kaolin sample decreases by only nearly ±6% with the increase in temperature. The results of fall cone penetrometer test show that the PL of bentonite sample decreases as temperature increases. The decrease rate of PI of bentonite sample is higher than that of the two other two soil samples because of its decreased LL and constant PL. Therefore, the bentonite sample is the most sensitive to treatment at various temperatures, whereas the kaolin sample is the most insensitive. The sensitivity of the Pasir Panjang sample is between those of bentonite and kaolin samples. The Atterberg's limit may have a different result due to the variation in temperature.

5. References

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