DETERMINATION OF CLAY PROPERTIES FOR FORMATION OF CERAMIC LINERS-ICS INSULATION

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ABSTRACT

The study was carried out to determine the properties of clay samples used in ceramic liner production to insulate improved cookstoves (ICS) against heat losses. Two samples were collected from Laikipia County. The soils were subjected to Atterberg's test due to soils exhibiting significant differences in strength, consistency, and behaviour in their states. Moisture variations in clay and silts usually show four distinct states of consistency. They include solid, semi-solid, plastic, and liquid. Atterberg limit tests usually define the boundaries between states based on moisture contents at different points where the physical changes occur. These values in ICS are used to predict potentially expansive soils, stronger shear strength in soils, and shrinkage values. It was found that of the two samples tested out, sample 1 was of less linear shrinkage and had a low swell potential overall. A soil sample with less swell potential and linear shrinkage better withstands cracking and volumetric changes. This ensures greater margins of quality control from the initial stages of preparations to finished clay ceramic liners for cookstoves.

Keywords: ICS, Ceramic liners, Atterberg limits

1.0 INTRODUCTION

With charcoal remaining the standard cooking fuel in East Africa, improved cookstoves provide efficient and safer cooking alternatives [1]. An improved cookstove comprises three fundamental parts: a metal frame, ceramic liners, and a fuel source. Ceramic liners have a more significant influence on the efficiency of any ICS [1]. Ceramic liners are used between the metal frame of the cookstove to control the fire source. The ceramic liners also protect the frame from heat deterioration while safely providing the user portability[2]. With the better design of ceramic liners, better energy efficiency numbers are achieved throughout utilisation.

Ceramic liners provide a much cheaper production solution making improved cookstoves affordable for most domestic homes [3]. One of the significant advantages of using ceramic liners in production is that they can produce large numbers with a few tools. The material used is also available naturally in the required state and requires little input to prepare it for moulding. Ceramic liners have been used for a long time due to their strength in handling high temperatures over a more extended period without cracking or breaking down [1]. The liners are also flexible to be shaped for any metal frame they are intended for.

These, however, do not go without some shortcomings. Clay soils contain high levels of bentonite, a mineral capable of swelling up to eighteen times their dry volume when wet. Using sandy soils can provide a low permeability liner, especially in areas lacking natural clay soil [2]. Soils portray swelling and shrinkage properties primarily due to fine grain particles smaller than *425μm.* Clay is said to have matured for clay liners once it has achieved the maximum density and is as hard as possible. The Atterberg limit is used to study these soils' physical behaviour. This clearly outlines four consistency states and the limits marking boundaries between them. By understanding the limits, the right amount of water content can be used in the preparation of clay liners with efficiency in production and utilization of improved cookstoves.

Variations in different types of clay are expressed in this range of properties. Clay, being of fine particle sizes, has most properties defined in the Atterberg limits.

Atterberg suggested four states of consistency namely:

i. Solid state: where no change of volume with an increase in soil moisture
ii. Liquid state: mass behaves like a liquid with less shear strength.
iii. Plastic limit: where the soil mass can be deformed without cracking
iv. Semi-solid state: where soil mass cannot be deformed without cracking

This paper investigates two soil samples from Laikipia county and tries to discern which sample is best prepped for use in the making of clay liners for Improved Cookstoves.

2.0 METHODOLOGY

2.1 Liquid Limit (LL)

The soil was first passed through *sieve NO 40 or 425µm or 0.425mm* to obtain soil samples usually affected by Atterberg limits. The soil was then mixed with water, and a uniform paste was produced using a spatula and a glass table. The soil was placed in a Casagrande cup, and a groove was made at the centre using a grooving tool. The limit was determined when the gap closed by 0.5 inches along the bottom. The number of blows was recorded for soil content producing between 15 blows to 35 blows. The moisture was determined by using a dry oven over a night to obtain the percentage of water content for every blow count. The data was analysed using a graphical method to get the correlating moisture content for the 25-blow mark. This was then termed the liquid limit for the specific soil sample.

2.2 Plastic Limit (PL)

The limit was tested using soil samples passing through sieve NO 40 or 425µm or 0.425mm. The percentage moisture content was increased by adding water to the soil sample and mixing it using a spatula and a glass table. The uniform paste was then repeatedly rolled into strands of about 3mm diameter soil mass. They were rolled up to a point where the strands crumbled; otherwise, they were considered too wet or too dry compared to the plastic limit. After the preparation of the strands, they were oven dried, and their change in mass was noted to obtain the moisture content value. This was then labelled as the plastic limit for the soil sample.

2.3 Shrinkage limit (SL)

The soil was prepared by obtaining soil mass by grains passing through a *sieve NO 40 or 425µm or 0.425mm.* The sample closest to the liquid limit (25 blow mark to close Casagrande groove by 5 inches) was used. The samples were prepared into an oil-coated linear shrinkage mould, air-dried for the night, and oven-dried for 24 hours. The change in linear length after drying was recorded; thus, the shrinkage was expressed as a percentage change of soil length to that of initial mould length.

3.0 RESULTS AND DISCUSSION

3.1 Plastic Limit and Liquid Limit

The plastic limit and liquid limit results are summarised in Table 1. The average plastic limit in sample 1 was lower than in sample 2. The average liquid limit was lower in sample 1 than in sample 2. Margins between the plastic and liquid limits were used to find the plasticity index, which helped grade each soil sample with a swell potential.

The soil potential in sample 1 from Laikipia was also found to be lower than that of sample 2 from Laikipia. Clay soils are usually sensitive to soil moisture due to the grain particles being active in soaking up water content and losing it to dry up [2].

Table 1: Data collected

Sample 1				**Sample 2**			
Average Plastic limit	Liquid limit	Plasticity index	Swell potential	Average Plastic limit	Liquid limit	Plasticity index	Swell potential
15.23%	31.92%	16.69%	low	46%	96.04%	50.04%	Very High

By obtaining the values of plastic and liquid limit, the swell potential could be deduced from their difference, helping determine the swell potential of soil.

3.2 Linear Shrinkage

The linear shrinkage of both sample 1 and sample 2 collected in Laikipia County have been summarised in Table 2 below in percentage. The more a soil sample absorbs water to become of physical structure, the more the soil sample is likely to have a higher linear shrinkage due to loss of its composition under normal or heated conditions [8]. Using a soil sample with the least shrinkage ensures less cracking of the clay liners when the moulded sample is air and oven dried in preparation for metal structure fitting. A less shrinking soil specimen would provide less volume change in clay liners through the preparation process, ensuring that quality control is regulated and ICS production is increased with minimal modifications [9].

Table 2: Linear shrinkage

Location	Linear shrinkage
Sample 1	10.0%
Sample 2	16.43%

Sample 1 had a minimal linear shrinkage value as compared to sample 2. This would express the likelihood of sample 1 being less likely to crack and maintain the required dimensions once undertaking the brisque firing stage, as observed in laboratory tests.

Sample 2 maintained a relatively continuous and less volume change during the linear shrinkage firing stage to remove mechanical water from the soil. A soil sample that changes volume less usually avoids cracking better than a sample with higher shrinkage [8].

4.0 CONCLUSION AND RECOMMENDATION

For the tests carried out, sample 1 was determined as the most favourable sample to use in clay liner making of the two samples tested out. The sample showed less linear shrinkage and low swell potential overall. This meant less cracking would occur when the sample is dried and subjected to high temperatures compared to sample 2.

Clay liner would depend on various parameters such as the availability of material and the material's physical properties. For clay liners production, the following is asserted:

I. Clay mixing with moisture content below the liquid limit reduces the risk of cracking because the mould maintains an equal volume after drying.

II. Due to clay liners using a significant thickness of the clay, air drying the moulds ensures uniform expulsion of water content in the early stages before it can be subjected to oven drying.

III. Airtight clay liners help ensure thermal efficiency and thus require to be heated to extreme temperatures hence none or minimal presence of organic soluble is preferred.

Steps such as these helps ensure no water bubbles are created inside the clay moulds, leading to cracking in later stages of the preparation.

REFERENCES

[1] Romana. Manpreet, "Improved Clean Cookstoves," *Project Drawdown*, Feb. 2020, Accessed: Oct. 31, 2022. [Online]. Available: https://drawdown.org/solutions/improved-clean-cookstoves

[2] T. A. Egloffstein, K. V. Maubeuge, and E. Reuter, "Efficiency and Field Performance of Geosynthetic Clay Liners and Compacted Clay liners." [Online]. Available: https://www.issmge.org/publications/online-library

[3] Wikipedia, "Improved cookstove - Wikipedia." https://en.wikipedia.org/wiki/Improved_cookstove (accessed Oct. 31, 2022).

[4] *ASTM D4318 - 10 Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*. ASTM, 2010. Accessed: Oct. 28, 2022. [Online]. Available: http://www.astm.org/Standards/D4318.htm

[5] H. Jamal, "Atterberg's Limits," *AboutCivil.Org*, Accessed: Oct. 28, 2022. [Online]. Available: https://www.aboutcivil.org/atterberg-limits.html

[6] H. Jamal, "Atterberg Limits Soil Classification - Liquid Limit, Plastic Limit, Shrinkage," *www.aboutcivil.org*, Accessed: Oct. 28, 2022. [Online]. Available: https://www.aboutcivil.org/atterberg-limits.html

[7] H. B. Seed, R. J. Woodward, and R. Lundgren, "Fundamental Aspects of the Atterberg Limits," *Journal of Soil Mechanics and Foundations Div*, vol. 92, no. SM4, pp. 63–64, Nov. 1967, doi: 10.1061/JSFEAQ.0000685.

[8] "Shrinkage Limit Test," *United States Army Corps of Engineers*, Accessed: Oct. 28, 2022. [Online]. Available: http://www.usace.army.mil/publications////eng-manuals/em1110-2-1906/a-IIIB.pdf

[9] M. Suliman and A. Alkherret, "Using Fine Silica Sand and Granite Powder Waste to Control Free Swelling Behavior of High Expansive Soil," *Mod Appl Sci*, vol. 15, pp. 53–62, Jun. 2020, doi: 10.5539/mas.v15n1p53.