Evaluation of Glass Powder's Impact on the Atterberg Limits of Anbar Soil

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Received: 9 July 2024 | Revised: 1 August 2024 | Accepted: 4 August 2024

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ABSTRACT

Soil stabilization is crucial for the construction industry in regions with clayey expanding soil. Adding certain materials can enhance the geotechnical properties of the soil. Ground glass powder is studied herein as an additive to clay soil, by applying the Atterberg Limit Test (ALT). The use of ALT can give a basic assessment of the suitability of the soil, which also determines the optimal ratio of the glass material that must be added to the mixture. Laboratory experiments were conducted utilizing the Casagrande apparatus by adding 4%, 5%, and 6% of ground glass to clay soil, and the impact of these percentages on soil characteristics was evaluated. The results exhibited a noticeable change in the mixture limits and plasticity. Increasing the percentage of added glass leads to a decrease in all three Atterberg limits improving soil stability and reducing soil plasticity.

Keywords-Atterberg limits; geotechnical properties; Anbar soil; glass powder; clayey soil

I. INTRODUCTION

The use of clayey expanding soil in construction over the region of Anbar, illustrated in Figure 1, raises numerous problems. First and foremost the presence of igneous rocks and their byproducts, such as basic and ultrabasic montmorillonite clay minerals, lead to severe damage and high maintenance costs. Adding ground glass powder can improve clay soil properties [1-4], such as soil stability, leading to increased durability against weather conditions and the support of the applied loads [5]. ALT is deployed to investigate the effect of adding different quantities of glass to enhance soil properties. More specifically, it determines the water content thresholds at which fine-grained soil transitions between different states. These limits are crucial for soil classification as well as for predicting their behavior, particularly their soil consistency, compressibility, and strength, when utilized in the construction field [6]. Several techniques are used to classify expansive soil and its swell ability. The classification mainly relies on the soil's geotechnical features, especially the Atterberg limits, and on factors, such as the clay content, natural water content, and plasticity. For instance, when classifying soils, the Chen method relates the plasticity index to the swelling potential producing the categories seen in Table I.

TABLE I. CATEGORIES OF SWELLING POTENTIAL

Plasticity Index (%)	Swelling Potential (%)
0-15	Low
10-35	Moderate
20-55	High
< 55	Very high

Glass is considered an inert metal, as it can remain in the soil for many years without undergoing decomposition [7]. As an enhancer of soil quality, it is applied in numerous geotechnical engineering operations in the form of glass powder [8-10]. Adding Waste Glass Powder (WGP) to soil improves its strength, durability, and resistance, particularly in heavier-duty infrastructures, such as highways, where foundation integrity is crucial to ensure safe and long-lasting building. [11-13]. A study investigated the effects of increasing WGP in soil highlighting a decrease in the Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI), Linear Shrinkage (LS), and Free Swelling (FS). [14, 15]. Another material suitable for soil treatment is the recycled glass [16-18]. Waste Soda Lime Glass Powder (WSLGP) effects have been tested on both expansive and non-expansive low plasticity soil in various percentages of dry weights. The results suggested that the PI, the Optimum Moisture Content (OMC), and the swell potential decreased, whereas the soil strength increased, as the percentage of the used additive received greater values [19]. Additional studies proposed improvement in stability and durability of the material [20].

The principal objective of this project is to identify the optimum levels of the Atterberg limits when adding glass powder into soil in order to improve its geotechnical properties.

II. METHODOLOGY

As illustrated in Figure 3, clay soil samples were collected from Fallujah in Anbar Governorate and stored in plastic bags. The Atterberg limits were tested on clay soil before and after adding ground glass. This experiment was carried out on soil that included 4%, 5%, and 6% of glass powder. The glass waste was collected from construction material disposal sites and was ground into a powder using an electric crusher. The chemical composition was ascertained, considering that Silicon

Dioxide (SiO_2) and Calcium Oxide (CaO) are its primary constituents. The ALT was conducted to obtain the plastic and liquid limits of the clayey soil, providing insights into its plasticity and compressibility. Employing the Casagrande apparatus, seen in Figure 2, the following steps were taken:

- Soil collection. Debris and large particles were removed. The soil sample was air-dried, crushed into a fine powder, and 10 g of the powder were weighed into a mixing bowl.
- The soil was amended with water that had been distilled and thoroughly mixed to create a paste.
- The LL was determined utilizing a soil cone penetrometer, consisting of a brass cup and a dropped cone. The number of drops needed to close a 3 mm gap was recorded as the LL.
- The PL was determined by rolling a soil sample into a string and bending it into a U-shape. The number of bends without breaking constituted the PL.
- Information on the soil's compressibility and shear strength was received utilizing (1):

$$PI = LL - PL \quad (1)$$

Fig. 1. Anbar Governorate.

III. RESULTS

The study was carried out on clayey soil characterized by a 35% PI. Varying percentages of glass waste were added, specifically 0%, 4%, 5%, and 6% based on the soil's dry weight to estimate the former's effect on the Atterberg limits.

TABLE II. GLASS WASTE EFFECT

Glass Waste (%)	LL (%)	PL (%)	PI (%)
0	65	30	35
4	63	29	34
5	60	28	32
6	58	27	31

Initially, the LL of the soil decreases from 65% to 58% as the percentage of glass waste increases, as evidenced in Figure 4, indicating that the soil is less likely to behave as a liquid at a high moisture content with the addition of glass waste.

Fig. 2. Casagrande apparatus.

Fig. 3. Collected soil sample.

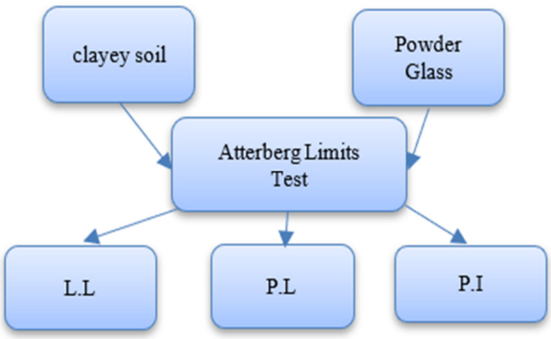

Fig. 4. Illustrative process of the experiment.

Similarly, the PL decreases from 30% to 27% while the percentage of waste glass increases, as observed in Figure 5, demonstrating that as more glass waste is added to the mixture, the plastic to brittle transition on the soil occurs at a lower moisture content. In addition, increasing the glass waste percentage results in the decrease of the PI from 35% to 31%, as illustrated in Figure 6, suggesting less volume changes during moisture conditions. The cumulative results, as presented in Figure 8, highlight the existence of a similar behavior among the three Atterberg limits.

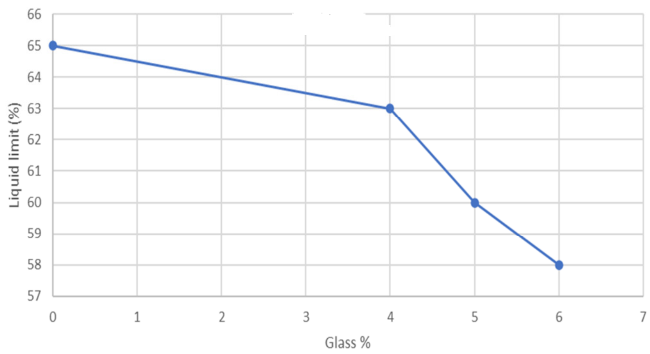

Fig. 5. The efffect of glass powder on LL.

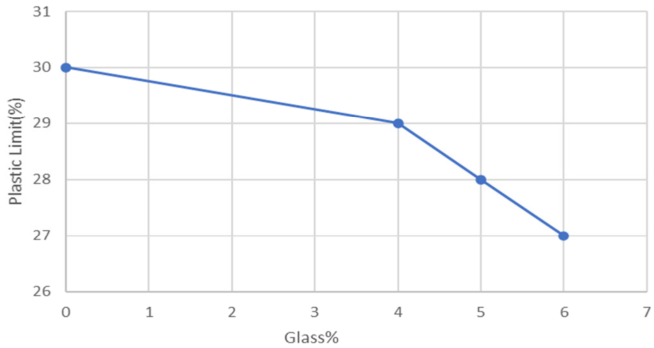

Fig. 6. The effect of glass powder on PL.

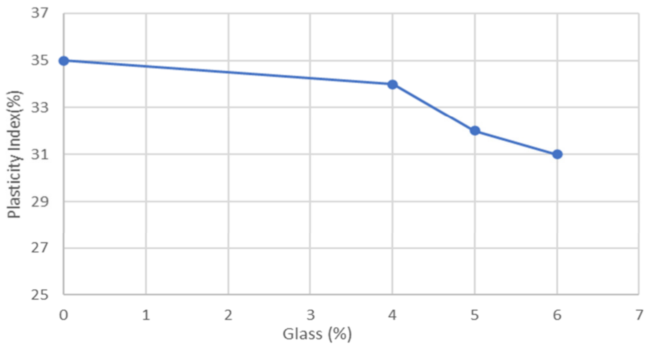

Fig. 7. The effect of glass powder on PI.

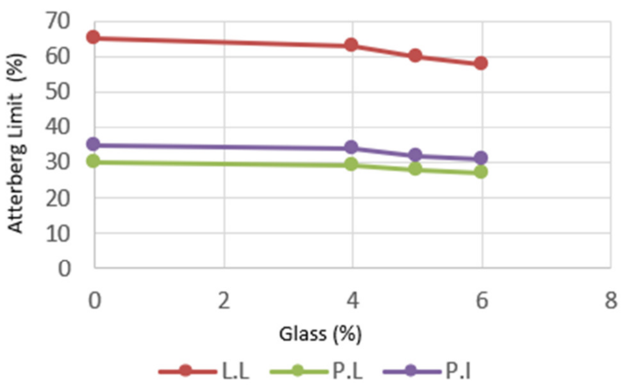

Fig. 8. The impact of glass on Atterberg limits.

IV. DISCUSSION

Clayey soils lead to a significant damage of the structures built on them. Typically, soil improvement methods include the addition of enhancers, such as cement, lime, industrial waste, silicon dioxide dust, etc. The present research explores the application of recycled glass powder to clay soils in the region of Anbar, a relatively unexplored area in geotechnical engineering.

In the conducted experiment, ground glass powder was used to improve the properties of the soil. The Atterberg Limit Test (ALT) was carried out concluding that the addition of glass to the soil leads to a decreasing trend of the Plasticity Index (PI), Liquidity Limit (LL), and Plastic Limit (PL). The addition of glass powder not only improved soil stability and reduced plasticity, but also provided an eco-friendly solution by recycling waste glass.

In conclusion, further experiments are necessary with additional glass proportions and other soil types to fully understand the potential of glass powder in soil stabilization. Swelling tests and California Bearing Ratio (CBR) tests are suggested to determine the broader applicability of these findings. The integration of recycled glass in soil stabilization practices presents a promising avenue for sustainable construction and enhanced soil performance.

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