

Shrinkage and Strength Behavior of Highly Plastic Clay Improved by Brick Dust

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ABSTRACT

Highly plastic soils exhibit unfavorited properties upon saturation, which produce different defects in engineering structures. Attempts were made by researchers to proffer solutions to these defects by experimenting in practical ways. This included various materials that could possibly improve the soil engineering properties and reduce environmental hazards. This paper investigates the strength behavior of highly plastic clay stabilized with brick dust. The brick dust contents were 10%, 20%, and 30% by dry weight of soil. A series of linear shrinkage and unconfined compression tests were carried out to study the effect of brick dust on the quantitative amount of shrinkage experienced by highly plastic clay and the undrained shear strength. The effect of curing on soil shear strength was included in this paper. It was found that the critical behavior of highly plastic soil can be mitigated by mixing with 20% or 30% of brick dust. The undrained shear strength of highly plastic clay mixed with brick dust increased with the increase of brick dust content up to 20%. It was affected by the curing period. The best improvement was achieved when the optimum content of brick dust was 20%. Finally, seven days of curing improved the undrained shear strength with over 100%.

Keywords: Highly plastic clay, brick dust, undrain shear strength, curing, linear shrinkage.

سلوك الانكماش والمقاومة للطين العالي اللدونة المحسن بواسطة غبار الطابوق

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الخلاصة

تظهر التربة العالية اللدونة بعض الخصائص غير المفضلة عند التشبع والتي تنتج عيوبًا مختلفة للمنشآت الهندسية. قام الباحثون بمحاولات لتوفير حلول لهذه العيوب من خلال الفحص المختبري بطرق عملية. تضمنت هذه المحاولات مواد مختلفة يمكن أن تحسن الخصائص الهندسية للتربة وتقلل من المخاطر البيئية. في هذا البحث تمت دراسة سلوك مقاومة القص للطين العالي اللدونة

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المثبت بغيبار الطابوق. كان محتوى غبار الطابوق 10% و 20% و 30% من الوزن الجاف للتربة. أجريت سلسلة من فحوص الانكماش الخطي واختبارات الضغط الحر لدراسة تأثير غبار الطابوق على كمية انكماش الطين العالي اللدونة ومقاومة القص الحر له. تمت دراسة تأثير الانضاج على مقاومة قص للتربة في هذا البحث. وجد أن السلوك الحرج للتربة العالية اللدونة يمكن تقليله بخلطها مع 20% أو 30% من غبار الطابوق. تزداد مقاومة القص غير المبزولة بزيادة نسبة غبار الطابوق المستخدم بنسبة 20%. هذه القيم تأثرت بفترة الانضاج. تم تحقيق أفضل تثبيت عند استخدام المحتوى الأمثل من غبار الطابوق, 20%. أخيرًا، وحد ان انضاج التربة المحسنة بغيبار الطابوق لمدة سبعة أيام حسن مقاومة القص بأكثر من 100%.

الكلمات الرئيسية: الطين العالي اللدونة, غبار الطابوق, مقاومة القص غير المبزولة, الانضاج, الانكماش الخطي.

1. INTRODUCTION

Highly plastic soil is expansive soil, has sensitive engineering properties upon wetting and drying at which its behavior often changed drastically. Such soil would get increased in volume when saturated, and hence would lose its strength, and the shrinkage happens when the soil gets dry, (Jones and Jefferson, 2012), (Al-Busoda and Abbase, 2015a) and (Al-Jeznawi et al., 2019). The loss of strength and volume reduction of this soil can cause negative impact and damage to civil engineering constructions (roads, buildings, pipelines, etc.), which, in some cases, is even more than the damages of hurricanes floods, earthquakes, and tornadoes. Improving the geotechnical properties of these types of soils can help to control the imposed damages to the structures (Khademi and Budiman, 2016).

Numerous amount researches have been carried out to study the possibility of improving these soils. Either by mechanical methods (e.g., soil compaction), (Al-Taie and Al-Shakarchi, 2016) or by adding materials such as cement, lime, sand and adding river mixture soil, (Abdullah and Alsharqi, 2011; Hamad, 2014; Mishra and Mishra, 2015; Ahmed and Hamza, 2015; Al-Busoda and Abbase, 2015b); or these soils treated with chemical additives, (Ismaiel, 2013; Keanawi and Kamel, 2013). In addition to these traditional materials, solid wastes were also used (fly ash, quarry waste, silica fume, cement kiln dust, tire rubber, rice husk, etc.), (Pandian, 2004; Peethamparan and Olek, 2008; Ahmed and Adkel, 2017; Wu et al., 2019; Dutta et al., 2019, Mujtaba et al., 2019).

Recently, efforts have been made to use dust materials from demolition and construction waste material as a stabilizer agent for expansive soils (Al-Baidhani and Al-Taie, 2019). (Mishra and Mishra, 2015) found that the addition of dust waste changes the geotechnical properties of plastic soil. They mentioned that the shear strength of plastic soil increased with the addition of 20% and 30% of stone waste, then it decreased with 40% of dust waste. (Minhas and Devi, 2016) investigated a type of stabilizer such as marble waste powder on alluvial soils at different percentages of composition. Marble waste powder was used in percentages varying from 5 to 15% at an increment of 5% for improving the alluvial soils. It was noticed that the optimum percentage of marble waste powder that required to improve the bearing capacity of the soil is up to 12%. (Zumrawi and Abdalla, 2018) mixed a clayey soil with varying proportions of waste powder (0%, 10%, 15 %, and 20% by dry weight). They found that the addition of waste powder to the clayey soil significantly increased the unconfined compression strength. The shear strength of red tropical soils was improved by 46% due to adding 8% of marble powder (Okagbue and Onyeobi, 1999. Bhavsar and Patel, 2014) studied the stabilization of clayey soil by replacement of 30% of soil with brick dust. The results of the treated soil revealed that brick dust produced a reduction of about 6% in shrinkage with an increase 11.7% in maximum dry density.

This paper reports the results from laboratory tests to investigate the effects of mixing brick dust with highly plastic soil. The shrinkage properties and undrained shear strength were investigated using linear shrinkage and unconfined compression tests. The effect of curing on the undrained shear strength was included in this study.

2. MATERIAL USED

The clayey soil used in this paper was obtained from the west of Iraq. The soil has a liquid limit and plasticity index of 133 and 85, receptively, ASTM D 4318. It has high liquid limit and plasticity index values, and following ASTM D 2487, the soil can be classified as fat clay, CH. The specific gravity of the soil is 2.57, ASTM D854. According to the standard compaction test,

ASTM D698, the soil has a maximum dry unit density of 1.22 t/m³, and optimum moisture content is 35%. The stabilizer material used in this study is brick dust. The brick dust is the waste dust obtained from the construction industry in Baghdad governorate. It was mechanically sieved, and only material passing sieve no. 200 is used. This non-plastic material has a specific gravity of 2.80, **ASTM D854**.

3. SAMPLES PREPARATION AND METHODOLOGY

The standard compaction test of highly plastic clay mixed with brick dust was carried out to obtain the optimum water content and maximum dry density. The content of brick dust was 10%, 20%, and 30%. During all the tests, the highly plastic clay and brick dust were dry mixed, the prespecified required water was added to the dry mixture, and the wet mixture was well mixed to produce homogenous soil-brick dust mixtures. These mixtures were compacted according to **ASTM D854**. The linear shrinkage of the soil-brick dust mixtures was determined as per **BS 1377**. The remolded samples were prepared at high moisture content and placed in a metal mold then placed in an oven to dry at 105 °C to 110 °C. After 24 hours, the length of the soil bar was measured carefully, and the linear shrinkage value was calculated. For unconfined compression test (UCT), samples of soil-brick dust mixtures were compacted to optimum water content and 90% of the maximum dry density. For each soil-brick dust mixture, three samples were extruded from the mold of the standard compaction test. The first sample was tested directly after preparation, while the rest samples were cured for (3 and 7) days before testing. **Fig. 1** shows the cured samples, the test setup, and tested samples. **ASTM D854**. Undrained shear strength of the natural soil and soil-brick dust mixtures were determined from the unconfined compression test. A series of unconfined test was carried out according to **ASTM D2166**.

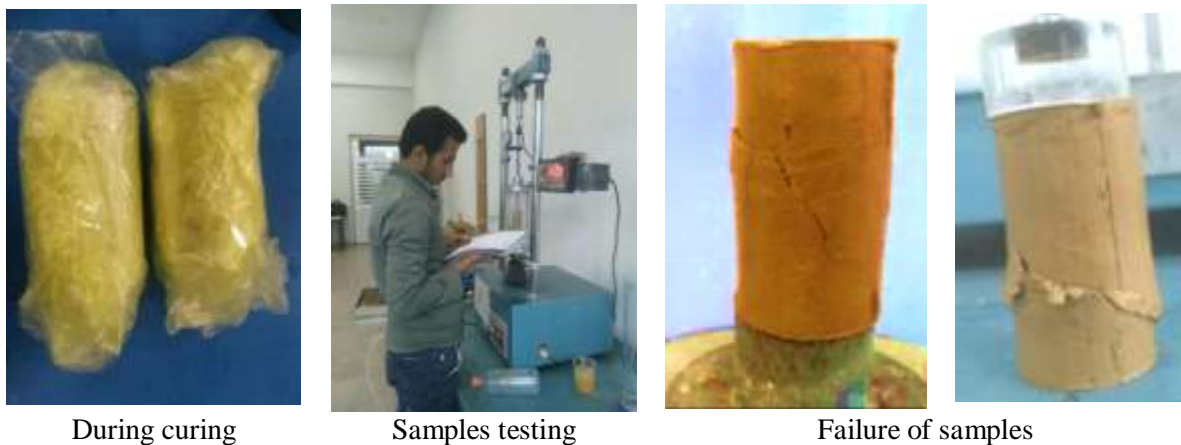


Figure 1. Samples of unconfined compression test.

4. RESULTS AND DISCUSSION

The shrinkage is essential in highly plastic soil. Linear shrinkage is a factor used to provide the quantitative amount of shrinkage experienced by clayey soils, **BS 1377**. It is relevant to converse expansion conditions due to wetting. Linear shrinkage was determined for natural clay, and after mixing the soil with brick dust. **Fig. 2** shows the final stage of drying of soil-brick dust mixtures. As it was calculated from test results, the sample without brick dust revealed a very high linear shrinkage value of 25.6%. According to (**Altmeyer, 1956**), the highly plastic soil of this study has a critical shrinkage behavior. Soil with high shrinkage is expected to give a very high expansive behavior, (**Holtz and Kovacs, 1981**). As an attempt to reduce the effect of this critical behavior of highly plastic soil, the soil was mixed with 10%, 20%, and 30% of brick dust and shrinkage has



been measured, **Fig. 3**. As appears in **Figs. 2 and 3**, the mixing of 10% brick dust has no effect on the value of linear shrinkage, but the number of developed cracks in this mixture looks less than that of natural soil. With increasing dust content, the shrinkage of the soil decrease. The total reduction in linear shrinkage reached 20% at brick dust content 30%. This positive result indicates that the critical behavior of highly plastic soil (high shrink/swell) can be mitigated by mixing with 20% or 30% of brick dust.



0% Brick Dust (natural Soil)



10% Brick Dust



20% Brick Dust



30% Brick Dust

Figure 2. Samples from linear shrinkage for soil-brick dust mixture.

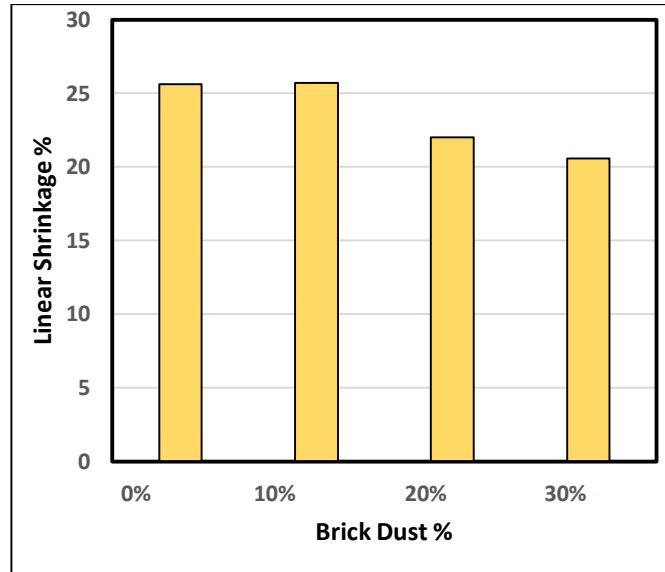


Figure 3. Effect of brick dust on linear shrinkage values.

This paper explored the optimum content of adding brick dust to the shear strength of highly plastic clay. To achieve such purpose, samples with different dosages of brick dust were prepared, and a series of unconfined test was carried out according to **ASTM D2166**. The brick dust content was (0, 10, 20, and 30)%. These samples were tested directly after preparation to obtain the undrained shear strength of soil-brick dust mixtures, **Fig.4**. It is obvious that compacted, and directly tested sample with 20% brick dust possesses a maximum undrained shear strength, c_u . On the other hand, one can be seen that the c_u values for soil with 10% and 30% brick dust are very closed to the c_u value of natural soil. Accordingly, the mentioned percentage (i.e., 20%) was chosen as optimum dust content to improve the undrained shear strength of compacted highly plastic clay.

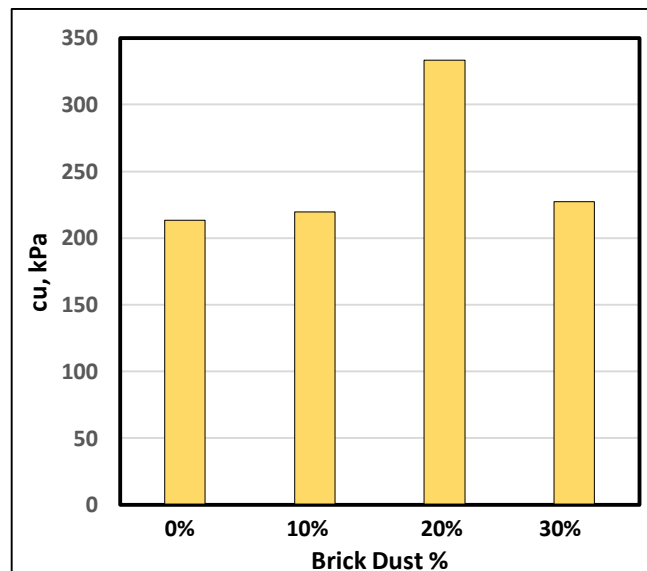


Figure 4. Undrained shear strength of soil-brick dust mixtures.

The effect of curing on undrained shear strength of soil-brick dust mixtures was included in this paper; compacted samples were prepared and kept under preservation humidity and temperature



for three days and seven days. The undrained shear strength of these samples was determined from the unconfined compression test (UCT), as shown in **Fig. 5**. This figure shows that the cu values of treated highly plastic clay are affected by the curing period. In general, an increase in cu values can be observed for different brick dust contents. The curing caused an improvement in cu values for different degrees. The soil samples stabilized with 20% of brick dust are seen more affected by the curing period. **Table 1** presents the improvement ratio (the difference between cu of clay without brick dust and cu of clay with (10% or 20% or 30%) brick dust divided by cu of clay without brick dust) with curing time (3 and 7) days. For each dust content, the improvement ratio is proportioned to the curing period, the best improvement ratio was recorded for dust content of 20%, while the least improvement ratio was recorded for soil samples with 30% brick dust. The seven days improvement ratio's exceeded 100% for soil with 20% dust. Accordingly, the mentioned curing period can be adopted as an optimum curing period with optimum dust content (20%) to improve the undrained shear strength of compacted highly plastic clay.

Table 1. Undrained shear strength improvement ratio with curing time.

Curing Period, days	Brick Dust %		
	10	20	30
0	3.1	56.3	6.6
3	27.8	75.2	12.2
7	42.2	106.6	58.2

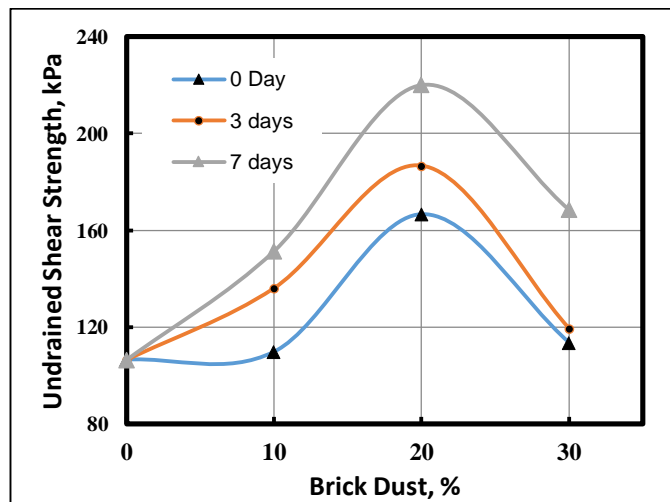


Figure 5. Undrained shear strength of soil-brick dust mixtures

In this study, the stress and strain behavior of soil-brick dust mixtures have been studied. **Figs. 6 to 8** show stress-strain relationships (from unconfined compression test results) for soil mixed with different contents of brick dust and cured for different periods. It can be noted that the relationship for the soil without dust is of ductile behavior. While the pattern of stress and strain relationships for soil-brick dust mixtures are brittle. This behavior is more pronounced in **Figs. 7 and 8**, as the



period of curing increased, higher strength was recorded with less axial strain. With 7 days period, mixtures of soil-brick dust showed the same brittle pattern with higher strength and less strain. **Fig. 9** shows the variation of strain failure with dust contents for different curing periods. A particular effect of curing on the failure strain can be noted, the curing was reducing the failure strain of the mixtures, and with a period of (3 and 7) days, this strain was independent on dust content.

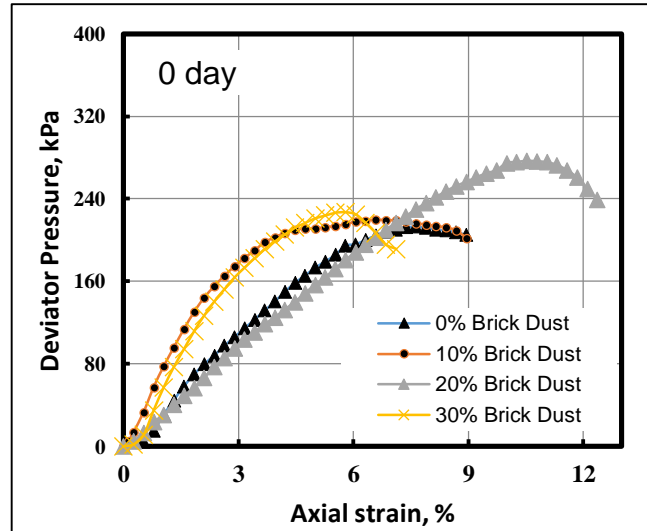


Figure 6. Stress-strain relationships for soil-brick dust mixtures without curing.

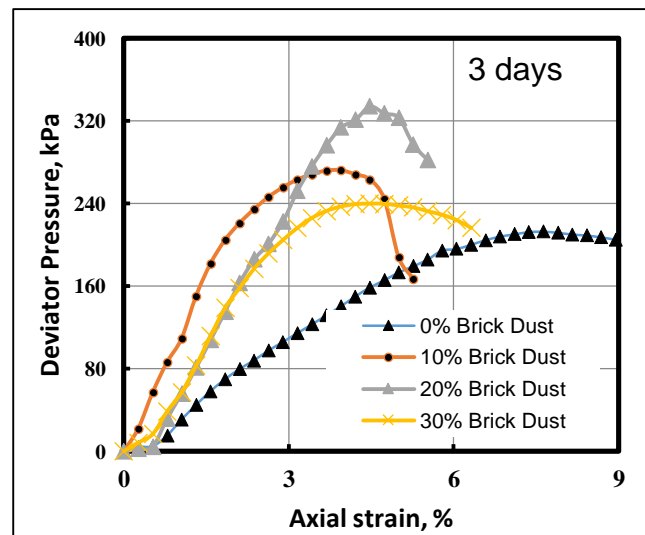


Figure 7. Stress-strain relationships for soil-brick dust mixtures cured for 3 days.

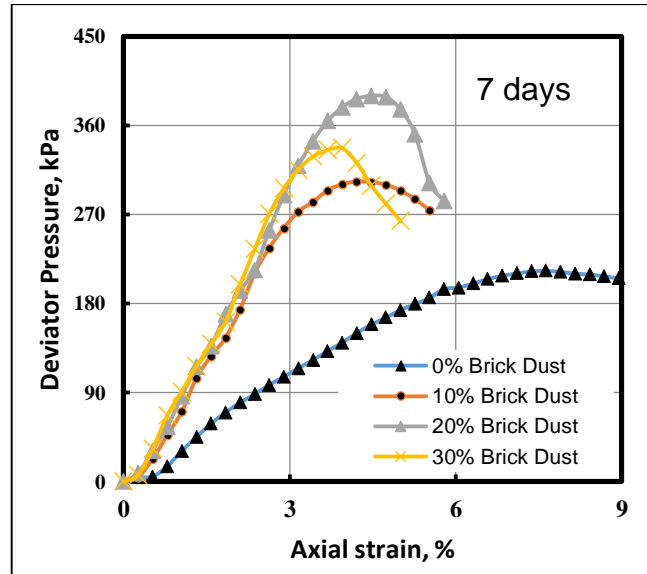


Figure 8. Stress-strain relationships for soil-brick dust mixtures cured for 7 days.

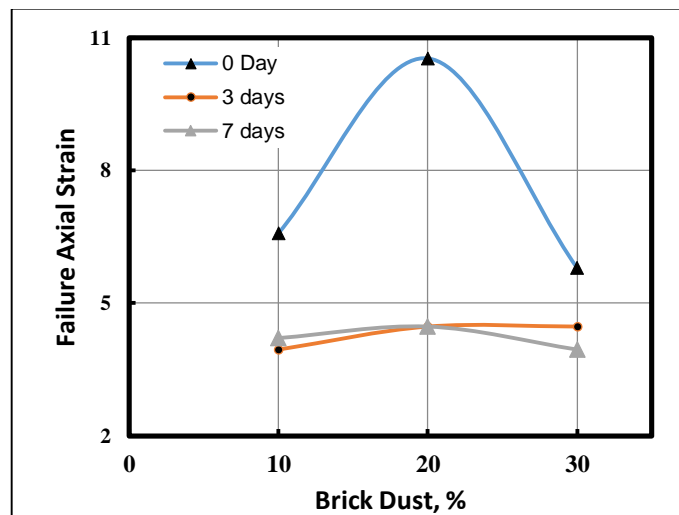


Figure 9. Variation of strain failure with dust contents for different curing periods.

5. CONCLUSIONS

This study presents the results of experimental testing carried out to investigate the effects of brick dust on shrinkage and strength properties and behavior of highly plastic clay. Based on the results, the following can be concluded:

- The critical behavior of highly plastic soil (high shrink/swell) can be mitigated by mixing with 20% or 30% of brick dust.
- The undrained shear strength (c_u) of highly plastic clay mixed with 10% and 30% brick dust is very closed to c_u of natural soil. The dosage 20% of brick dust was chosen as optimum dust content to improve the undrained shear strength of compacted highly plastic clay .



- The c_u values of treated highly plastic clay are affected by the curing period. The soil samples stabilized with 20% of brick dust are seen more affected by the curing period. The 7 days improvement ratio's exceeded 100% for soil with 20% dust .
- The pattern of stress and strain relationships for soil-brick dust mixtures are of brittle nature, while it is of ductile behavior for natural soil. As the period of curing increased, higher strength was recorded with less axial strain.
- The curing was reducing the failure strain of highly plastic soil, with a period of (3 and 7) days, this strain was independent on dust content

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NOMENCLATURE

cu = undrained shear strength, kPa.

UCT = unconfined compression test.