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# Influence of Brick Waste Powder on the Shear Behaviour of Cemented Sandy Soil

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**Abstract**

Many studies have proven that cement can be used effectively to treat unstable soils and improve their performance. This has led to an increased consumption of cement, already excessively used in the construction field. However, the use of cement in soil treatment is environmentally concerning, especially when applied on a large scale due to its significant contribution to $CO_2$ emissions during the production process and its negative effects on the ecosystem and groundwater quality. To reduce the amount of cement consumed in the soil treatment process, its detrimental impact on the environment and its costs, alternative materials such as construction and demolition waste can be used as a complement to cement. This research aims to evaluate the effect of brick waste powder inclusion on the shear behaviour of cemented sandy soil. For this purpose, direct shear tests were carried out on different sand-cement-brick powder mixtures prepared at the dense state ($D_r$ = 80%) with a water content of 10% and cured for 7, 14 and 28 days. The obtained results indicate an enhancement in the shear behaviour of the mixture in terms of maximum shear strength, cohesion and friction angle with increasing brick waste powder content. In addition, the increase of brick waste powder content enhanced the dilative behaviour of the cemented sand. Also, it is speculated through the experimental results that brick waste powder could potentially be used as a partial replacement of cement in soil treatment applications while ensuring similar or better shear strength characteristics.

**Keywords**

cemented sand, brick waste powder, treatment, shear behaviour, shear strength

## 1 Introduction

Due to the rapid population growth, it has become a significant challenge for the construction industry to provide construction sites that comply with the geotechnical performances required for a construction project.

Therefore, soil improvement methods have become widely used over the past decade, as they provide solutions to exploit problematic soils and improve their properties, such as shear strength, permeability, compressibility and stiffness.

Soil improvement methods can be classified into different categories based on defined criteria. Han classified ground improvement methods according to their function into six categories: densification, replacement, drainage and consolidation, chemical stabilization, reinforcement and thermal and biological treatment [1].

Chemical stabilization is a technique that consists of adding reagent materials that amend the mechanical properties of soils to meet the desired qualifications, for instance: cement, lime, and fly ash [2]. Portland cement is a widely used additive for soil treatment. It has been efficient in various applications, such as foundation engineering, pavement construction, and soil improvement [3].

Many previous studies have explored the efficiency of cement stabilization in enhancing the mechanical properties of soils [4–8]

Boutouba et al. found that an increase in cement content up to 10% increased the shear strength, cohesion and friction angle of the sand-cement mixture which became more dilatative [6]. Bayoumy et al. found that adding cement to clayey sand increased maximum dry density, optimum moisture

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content, stiffness and unconfined compression strength. However, specimens with higher cement proportion tend to have a more brittle behaviour and low permeability [7, 9–12]

On the other hand, the cement manufacturing process requires substantial amounts of raw materials and energy. The consumption of raw materials in the construction industry has reached 50% in developing countries [13], which is not considered a cost-efficient or environmentally friendly solution. Moreover, the disposal of increasing construction and demolition (C&D) waste has become a concern due to massive landfill occupation, environmental degradation, as well as shortage of natural resources [14]. Considering these facts, the valorisation of this waste has become necessary and very important.

Waste resulting from construction, demolition and renovation projects is a combination of inert and non-inert materials. It includes a diversity of materials such as plastics, concrete, glass, metal, masonry, and wood [15, 16].

Studies on recycling construction and demolition materials and their valorisation in geotechnical applications recently increased considerably.

Arulrajah et al. studied the geotechnical properties of five recycled construction and demolition materials through an extensive series of geotechnical and geoenvironmental laboratory tests [17]. Regarding usage in pavement subbases, they found that recycled concrete aggregate and waste rock have geotechnical engineering properties equivalent to or superior to those of typical quarry granular subbase materials [17].

The use of recycled construction and demolition waste as a replacement for natural soils in geosynthetic reinforced structures was also evaluated by Cristelo et al. [18]. According to their findings, the mechanical behaviour of recycled construction and demolition waste is consistent with that of natural granular material with a similar particle size distribution in terms of strength envelopes and elastic stiffness values [18].

Sharma and Shrivastava concluded that the incorporation of recycled concrete aggregates and recycled brick aggregates improved the geotechnical properties of sandy soils including shear strength, CBR and compaction characteristics and slightly decreased its hydraulic conductivity [19].

Islam et al. evaluated the efficiency of using recycled waste mortar powder to improve the geotechnical properties of clayey soil [20]. They found that adding the recycled material to the soil enhanced consolidation settlement, increased permeability and pre-consolidation pressure, and reduced settlement time and compression index [20].

Touahamia et al. studied the shear strength of waste materials and their possible utilisation when combined with soil reinforcement. They found that incorporating geosynthetic reinforcement into a recycled material, such as crushed concrete or crushed building debris, significantly enhances the shearing resistance of the material and reduces specimen deformation [21].

Although interest in studying the possibility of using waste materials to improve soil performance has increased recently, research focusing on the mechanical behaviour of cemented soils mixed with waste materials is scarce and limited to a few waste types. Therefore, the objective of this research is to study the shear behaviour of cemented sand mixed with various amounts of brick waste powder.

## 2 Materials

### 2.1 Sand

The soil used in this study is sand collected from the Chlef river banks north of Chlef (Algeria). Once collected and transported to the laboratory, the sand was dried at 105° for 24 h and then sieved to remove particles larger than 2 mm.

The particle size distribution curve of the sand used is illustrated in Fig. 1 and its physical properties are presented in Table 1. It is classified as well-graded sand according to USCS.

### 2.2 Cement

The cement used in this study is Portland cement with limestone (CEM-II/B-L 32.5 N), manufactured by

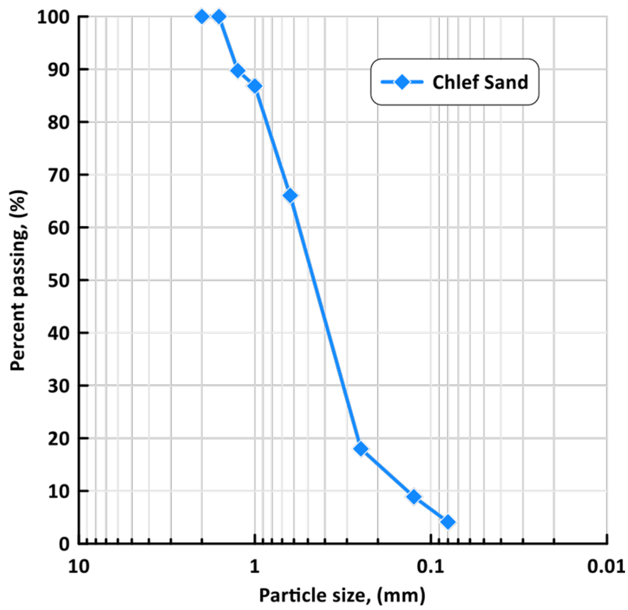


**Fig. 1** Particle size distribution of Chlef sand

**Table 1** Physical properties of Chlef sand

| Properties | Value |
|---|---|
| Uniformity coefficient, $C_u$ (.) | 4.1 |
| Coefficient of curvature, *Cc* (.) | 1.3 |
| Medium size, $D_{50}$ (mm) | 0.46 |
| Maximum diameter, $D_{max}$ (mm) | 2.00 |
| Specific density, $G_s$ (.) | 2.69 |
| Maximum void ratio, $e_{max}$ (.) | 1.05 |
| Minimum void ratio, $e_{min}$ (.) | 0.64 |

LAFARGE company following the Algerian standard (NA 442-2013) [22] and the European standard (EN 197-1:2011) [23]. The chemical and mineralogical, and physical properties of this cement are given in Tables 2 and 3.

### 2.3 Brick waste powder

The brick waste utilized in this study was collected from a building waste dump in Chlef region. The brick waste was first cleaned with water to remove dust residue, then oven-dried at 105° for 24 h. After that, it was crushed using the Micro-Deval machine and then sieved to remove particles larger than 80 microns in diameter to obtain a homogeneous powder. The particle size distribution of brick waste powder (BWP) obtained via a laser scattering particle size distribution analyzer is shown in Fig. 2.

The x-ray diffraction (XRD) patterns of BWP was recorded from 20 to 90 2*θ*°. It is observed that the most dominant crystalline phase belongs to Quartz ($SiO_2$) estimated at 79%, where some peaks could be identified at 20.86, 26.64, 50.14°. The other phases refer to calcium carbonate ($CaCO_3$), Aluminium oxide ($Al_2O_3$), and Ferric oxide ($Fe_2O_3$), estimated at 10%; 8%, and 3% respectively (Fig. 3). Traces of magnesium oxide (MgO) were also found. The main physical properties of BWP are given in Table 4.

This brick powder can be considered as a pozzolanic material (class N) according to the standard ASTM C618-12a since silicon dioxide ($SiO_2$) plus aluminium oxide ($Al_2O_3$) plus iron oxide ($Fe_2O_3$) represents more than 70% of the chemical composition of the brick powder and no trace of sulphur trioxide ($SO_3$) could be observed in it [24].

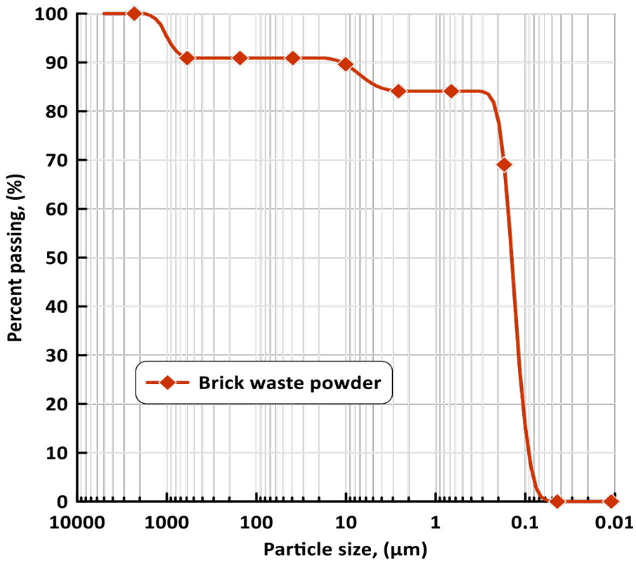


**Fig. 2** Particle size distribution of BWP

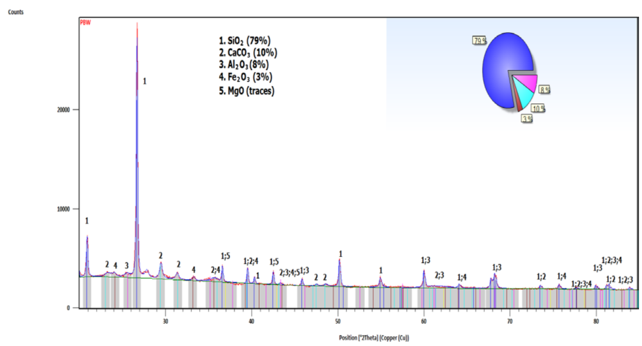


**Fig. 3** X-ray diffraction of BWP

**Table 2** Chemical and mineralogical properties of cement

| Chemical properties | | Mineralogical properties | |
|---|---|---|---|
| Fire loss (%) | 13 ± 0.2 | $C_3S$ (%) | 60 ± 3 |
| $SO_3$ (%) | 2.5 ± 0.5 | $C_3A$ (%) | 7.5 ± 1 |
| MgO (%) | 1.7 ± 0.5 | | |
| Chloride (%) | 0.02 – 0.04 | | |

**Table 3** Physical properties of cement

| Properties | Value |
|---|---|
| Specific density, $G_s$ (.) | 3.1 |
| Average diameter (Microns) | 1.258 |
| Median diameter (Microns) | 0.122 |
| Specific surface ($cm^2/cm^3$) | 4.9733E + 5 |
| $D_{10}$ (Microns) | 0.0787 |
| $D_{60}$ (Microns) | 0.133 |

**Table 4** Physical properties of BWP

| Properties | Value |
|---|---|
| Specific density, $G_s$ (.) | 2.69 |
| Average diameter (Microns) | 95.511 |
| Median diameter (Microns) | 0.142 |
| Specific surface ($cm^2/cm^3$) | 4.025E + 5 |
| $D_{10}$ (Microns) | 0.091 |
| $D_{60}$ (Microns) | 0.156 |

## 3 Experimental program

To achieve the objective of this study, a series of direct shear tests were carried out on sand mixed with different percentages of cement (0, 5, 7.5, and 10%) and BWP (0, 4, 6 and 8%). All samples have a cross-section of 60 × 60 mm$^2$ and a width of 20 mm.

To prepare the samples, the dry mass of the sand-cement-brick powder mixture, equivalent to the proposed initial density, was first determined using the following formulas:

$$M_D = \frac{V_T \times Gs}{1 + e_{\max} - I_D \times \left(e_{\max} - e_{\min}\right)}, \quad (1)$$

where: $M_D$ = dry mass of the mixture; $V_T$ = total volume of the sample; $I_d$ = desired density index; $G_s$ = specific gravity of the mixture; $e_{\max}$ and $e_{\min}$ = maximum and minimum void ratio of the mixture.

The masse of sand, cement, BWP and water of each mixture was then deduced as follows:

$$M_C = C_C\left(\%\right) \times M_D, \quad (2)$$

$$M_{\text{BWP}} = \text{BWP}\left(\%\right) \times M_D, \quad (3)$$

$$M_S = M_D - M_C - M_{\text{BWP}}, \quad (4)$$

$$M_W = w\left(\%\right) \times M_D, \quad (5)$$

where: $M_S$, $M_C$ and $M_{\text{BWP}}$ are the dry mass of sand, cement and BWP respectively; $C_C$, BWP and $w$ are the cement content, the BWP content and the water content respectively.

After weighing the quantities of the components, sand and cement were first mixed, and then brick powder was added. Subsequently, a water content of 10% was incorporated into the mixture, which was then blended manually for 10 min until a homogeneous mixture was obtained (Fig. 4).

The mixture was then placed in a mould of dimensions 60 × 60 × 20 mm$^3$ in three layers. To obtain the dense state, each layer was subjected to 25 strokes. Subsequently, the mixture was allowed to air-dry at room temperature for a predefined curing time (7, 14 and 28 days). At the end of this period, the mixture was ready for testing where it was removed from the mould and placed directly in the shear box.

The mixture was then subjected to normal stress until the vertical displacement stabilised, after which it was sheared at a constant rate of 1 mm/min until a horizontal displacement of approximately 8 mm was reached. Each mixture was tested under three normal stresses 50, 100, and 200 kPa.

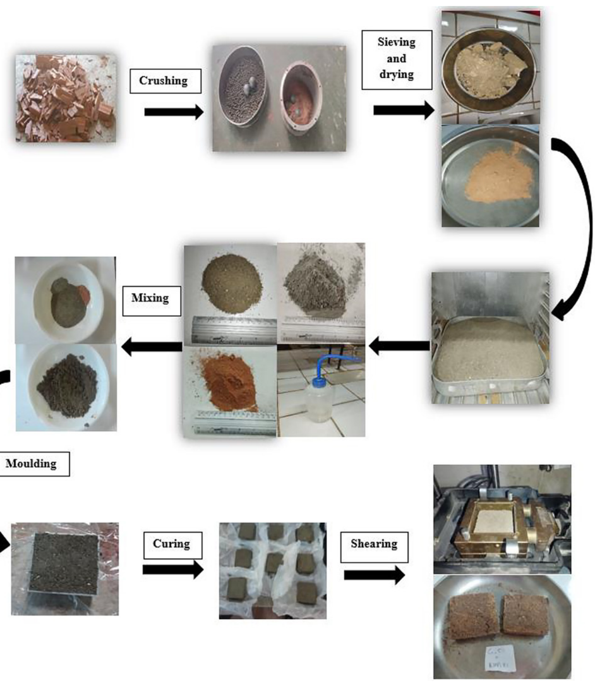


**Fig. 4** Sample preparation

The experimental procedure was conducted at the laboratory of materials science and environment (LMSE) at the University Hassiba Benbouali of Chlef in Algeria. All parameters considered in the testing program are summarised in Table 5.

## 4 Results discussion and analysis

### 4.1 Influence of cement content

The results of direct shear tests conducted on untreated and cement-treated sand are shown in Fig. 5 and Fig. 6. The cemented sand samples were left to cure for 14 days before being sheared. Overall, it is evident that adding cement to sand significantly influences its shear behaviour.

It can be seen from Fig. 5 (a) that the cemented sand samples exhibit a brittle response where the shear strength increases sharply until reaching a maximum value between 1 and 2 mm, after which it decreases considerably, unlike the untreated sand which presents a ductile behaviour. In addition, the maximum ($\tau_{\max}$) and residual shear strength of cemented sand samples are higher than $\tau_{\max}$ of pure sand. For example, the maximum shear strength ($\tau_{\max}$) of the mixture containing 5% cement is 181.08 kPa, representing an increase of approximately 255% compared to untreated sand ($\tau_{\max}$ = 51 kPa).

**Table 5** Parameters considered in the testing program

| Type of samples | Cc (%) | BWP (%) | Designation | Normal stress (kPa) | Relative density (%) | Curing period (days) | Number of tests |
|---|---|---|---|---|---|---|---|
| Untreated sand | 0 | 0 | C0B0 | 50, 100, 200 | 80 | / | 03 |
| Cemented sand | 5 | 0 | C5B0 | 50 | 80 | 07, 14, 28 | 11 |
| | | | | 100, 200 | | 14 | |
| | 7.5 | 0 | C7.5B0 | 50, 100, 200 | | 14 | |
| | 10 | 0 | C10B0 | 50, 100, 200 | | | |
| Sand-cement-brick powder mixtures | 5 | 4 | C5B4 | 50 | 80 | 07, 14, 28 | 15 |
| | | | | 100, 200 | | 14 | |
| | 5 | 6 | C5B6 | 50 | | 07, 14, 28 | |
| | | | | 100, 200 | | 14 | |
| | 5 | 8 | C5B8 | 50 | | 07, 14, 28 | |
| | | | | 100, 200 | | 14 | |

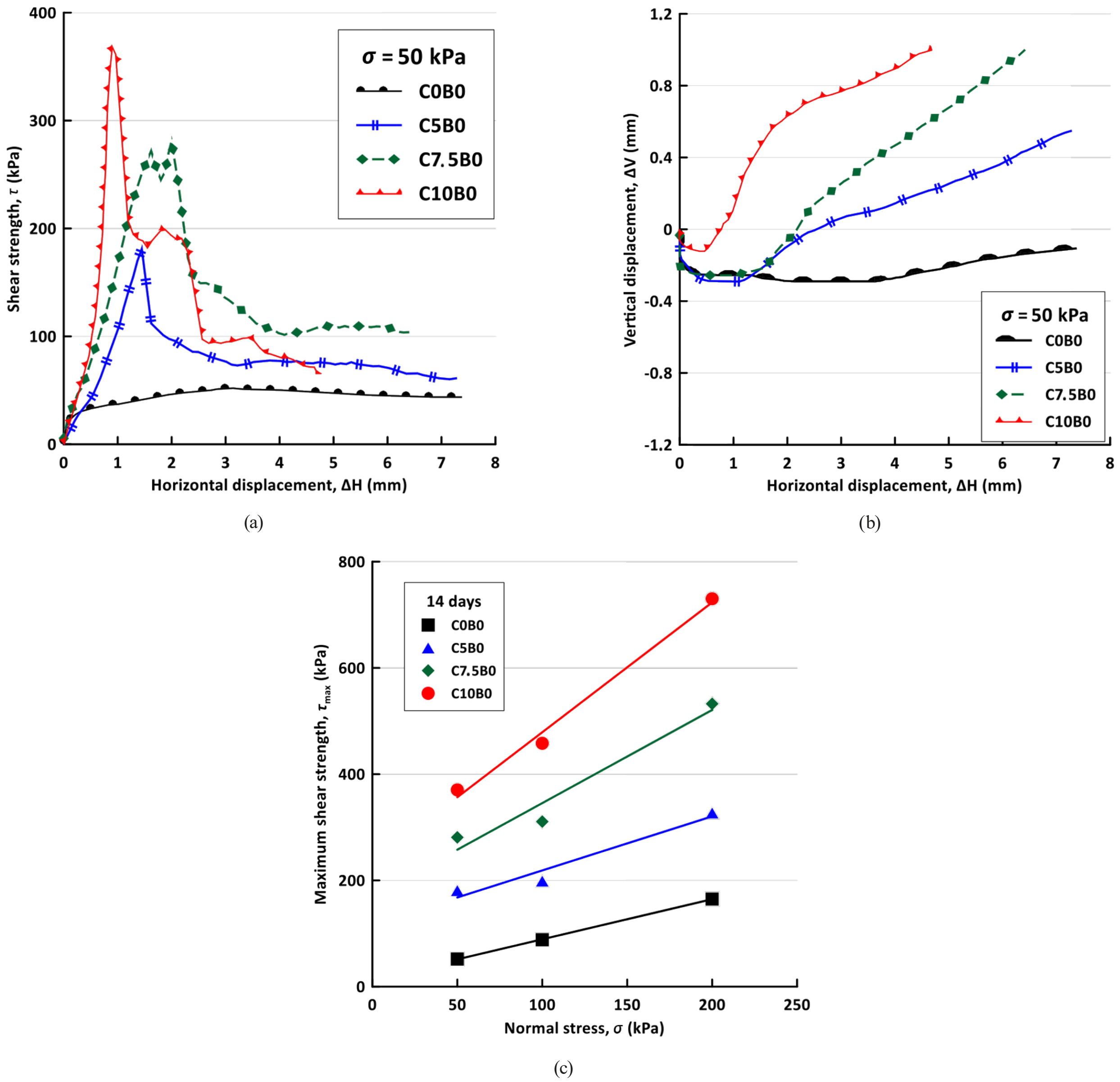


**Fig. 5** Influence of cement content on cemented sand, $D_r$ = 80%, $w$ =10%, curing time = 14 days (a) shear strength versus horizontal displacement, (b) vertical displacement versus horizontal displacement, (c) maximum shear strength versus normal stress (Mohr-Coulomb failure envelopes)

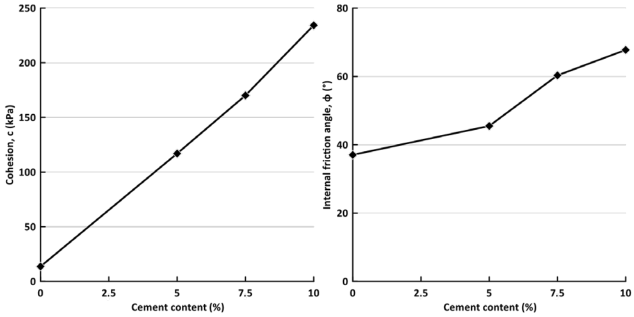


**Fig. 6** Shear strength parameters of uncemented and cemented sand, $D_r$ = 80%, $w$ = 10%, curing time = 14 days

Fig. 5 (b) presents the evolution of the vertical displacement of cemented and uncemented sand samples as a function of the horizontal displacement. The cemented sand specimens exhibit a contractive response at the beginning of shearing followed by a dilative phase that continues until the end of the test. On the other hand, uncemented wet sand shows a contractive behaviour. Moreover, increasing the cement content from 5 to 10% increases the dilative character of cemented sand.

These findings are in good agreement with those concluded by Wang et al.; Boutouba et al.; and Wang et al. Wang et al. found that a more stable and stronger force-chain complex subjected to smaller force concentration is formed in cemented sand, compared with uncemented sand, which gives rise to higher strength. According to Wang et al.; Saxena et al.; and Lade et al. hypothetically attributed the dilative feature to cemented particles forming highly interlocked clusters [6, 25–28]

The Mohr-Coulomb failure envelopes of cemented and uncemented sand samples illustrated in Fig. 5 (c) indicate that the maximum shear strength increases significantly with increasing cement content for all three normal stresses (50; 100; and 200 kPa). In addition, the effect of cement content under 200 kPa is more pronounced compared to other normal stresses.

Fig. 6 presents the variation of shear strength parameters of cemented and uncemented sand, deduced from Fig. 5 (c), as a function of cement content. It is noticed that the increase in cement content from 5 to 10% leads to an increase in the cohesion of cemented sand where values of 116.97, 170.11 and 234.31 kPa are recorded for $Cc$ = 5, 7.5 and 10% respectively (Fig. 6 (a)). Also, the cohesion of sand (13.65 kPa) is insignificant compared to cemented sand where it is approximately eight times lower than the cohesion of treated sand containing 5% of cement. As for the friction angle, it increases considerably with increasing cement content compared to uncemented sand. For instance, the internal friction angle of pure sand is 37.05°, and it reaches 45.5, 60.31, 67.76° for the cemented samples $Cc$ = 5, 7.5, 10% respectively. Similar results were found by Boutouba et al.; and Shooshpasha et al. [6, 29]

### 4.2 Influence of BWP on cemented sand

Figs. 7 and 8 present the results of direct shear tests carried out on cemented sand containing various amounts of BWP (0, 4, 6 and 8%). The cement content was kept constant (5%) for this series of tests and all the samples were sheared after a curing time of 7 and 14 days. The curves of pure wet sand are also presented.

The shear strength of the sand-cement-brick powder composite increases acutely until it reaches a maximum value between 1 and 3 mm, after which a considerable decrease is observed (Fig. 7 (a)). Furthermore, adding BWP to cemented sand improves its shear strength (Fig. 7 (a)). For instance, compared to the reference sample C5B0 ($\tau_{max}$ = 181.08 kPa), the maximum shear strength of the samples containing 4%, 6% and 8% of BWP are 335.89; 356.72; and 390.86 kPa, which represents an increase of approximately 85%, 97% and 116% respectively.

These results seem logical and can be attributed to the pozzolanic reaction of brick powder. According to Resin et al. $SiO_2$ reacts chemically with alkalis in cement and form cementitious product that contributes to the strength development of concrete, due to very fine powder of brick waste [30].

The variation of vertical displacement of sand samples treated with cement and brick powder as a function of horizontal displacement is shown in Fig. 7 (b). It can be observed that the cement-sand samples with and without BWP initially show a contractive phase until a threshold is reached, followed by a dilatancy phase that continues with the development of horizontal displacement until the end of the test. Also, the increase in BWP content leads to an augmentation in the dilative character of the sand-cement-brick mixture. This can be attributed to the role of fine brick powder particles in filling the voids between the cement particles and the sand, leading to an increase in the density of the mixture [30].

The results of the shear strength ratio ($S_r$) of sand-cement-brick powder mixtures as a function of BWP content (0, 4, 6, and 8%) for the three normal stresses (50, 100, and 200 kPa) are presented in Fig. 7 (c). The formula adopted to determine the $S_r$ ratio is similar to that used by Mirzababaei et al. which is as follows:

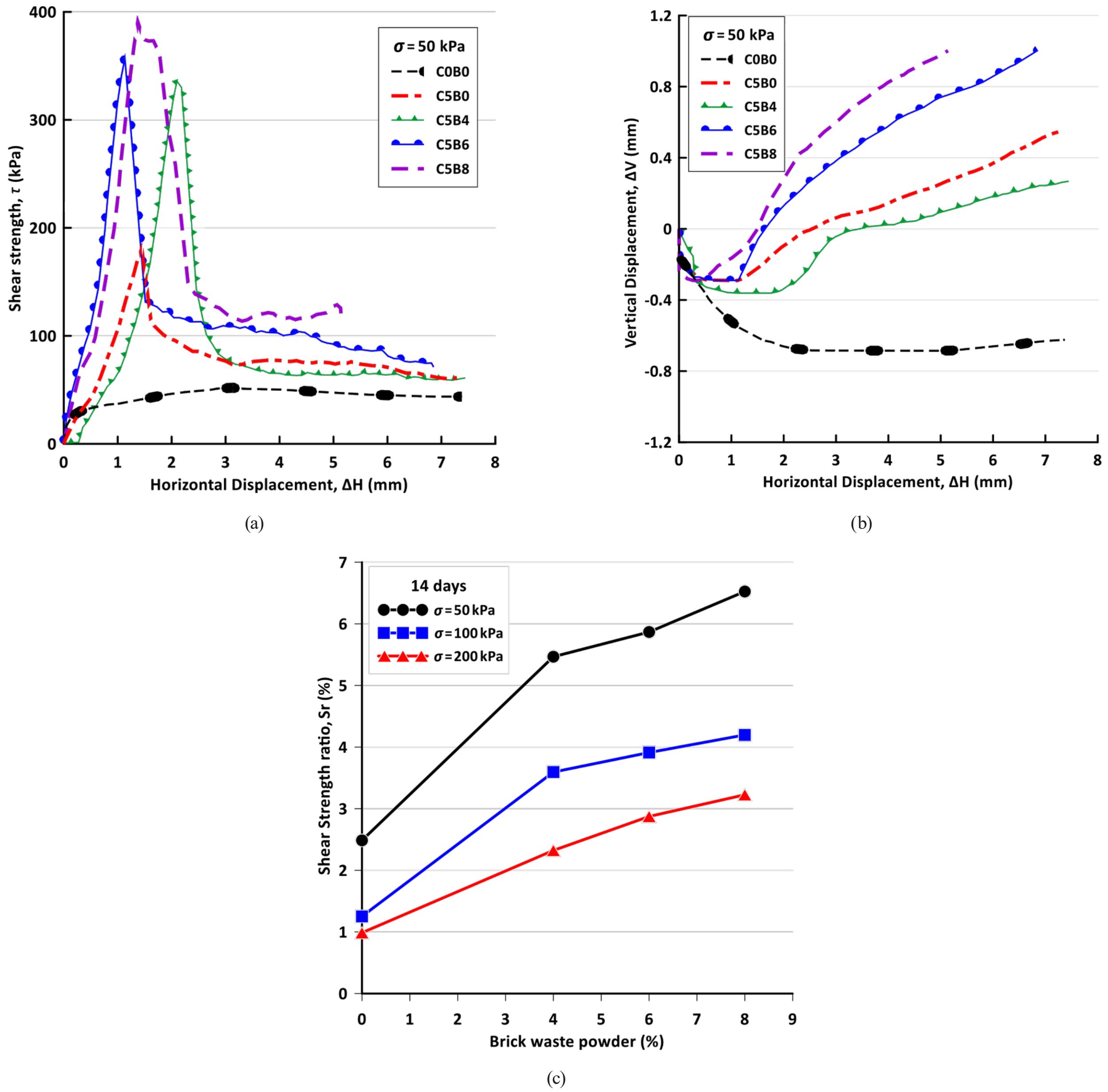


**Fig. 7** Influence of BWP content on shear behaviour of cemented sand, $D_r$ = 80%, $w$ =10%, curing time = 14 days (a) shear strength versus horizontal displacement, (b) vertical displacement versus horizontal displacement, (c) shear strength ratio as a function of brick waste powder content

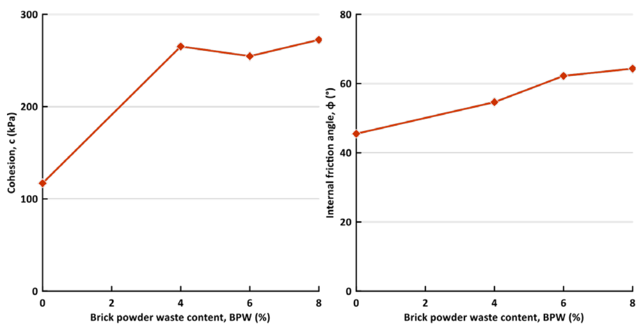


**Fig. 8** Cohesion and internal friction angle of sand-cement-brick powder mixtures

$$S_r = \frac{\tau_{\max M}}{\tau_{\max\ un}}, \quad (6)$$

where $\tau_{\max M}$ represents the maximum shear strength of mixtures containing 5% cement and various brick powder contents, and $\tau_{\max un}$ is the maximum shear strength of untreated wet sand [31].

It is observed that the mixtures containing brick powder (4, 6 and 8%) have a higher strength ratio than cemented sand (0%) for all three normal stresses. Moreover, the increase in brick powder content leads to an increase in the $S_r$ ratio of the sand-cement-brick powder mixture, which means an increase in its shear strength. However, the $S_r$ ratio decreases as the applied normal stress increases.

The shear strength parameters, derived from the data presented in Fig. 7 (c), as a function of BWP content are presented in Fig. 8. It is clear that both parameters of sand samples treated with cement and brick powder increase significantly with increasing BWP content. For example, the cohesion and friction angle values of the cemented sand containing 4% of brick powder ($C$ = 265.22 kPa, $\varphi$ = 54.63°) are about 127% and 20% higher than those of the cemented sand ($C$ = 116.97 kPa, $\varphi$ = 45.5°), respectively. This result may be attributed to the increase in the density of the mixture due to the role of the finer brick powder particles in filling the voids in it. Mansoor et al. also found a slight increase in the dry density of mortar when the cement was replaced by 10 % and 15% brick powder compared to the mortar without brick powder [32].

#### 4.2.1 Influence of curing period on maximum shear strength of sand-cement-BWP mixtures

Fig. 9 shows the maximum shear strength ($\tau_{max}$) values of sand-cement-brick powder mixtures subjected to normal stress of 50 kPa for three different curing times (7, 14, and 28 days). It can be seen that increasing the curing time leads to an improvement in $\tau_{max}$ of the mixture. Mohan et al. also found similar results. Moreover, the effect of increasing brick powder content on $\tau_{max}$ of the mixture is almost the same for the three curing times [33].

#### 4.2.2 Influence of BWP content on the brittleness index of sand-cement-BWP mixtures

As previously stated, all mixtures of sand, cement and brick powder show a significant loss of shear strength after the maximum value compared to pure sand which has ductile behaviour. This loss is attributed to the breakdown of particles bonding created by cementation. The brittleness index is a good measure of such behaviour of materials. In their study, Consoli et al. used the following formula to determine the brittleness index:

$$I_B = \frac{q_f}{q_u} - 1, \tag{7}$$

where $q_f$ and $q_u$ are the failure and ultimate deviatoric stresses respectively [10].

The brittleness index values of the mixtures, summarised in Table 5, were determined using a similar formula where the failure and ultimate deviatoric stresses are replaced by the peak and residual shear strength, respectively.

It is clear from the data in Table 6 that the addition of brick powder to cemented sand results in an increase in its brittleness index. Also, increasing the normal stress from 50 to 200 kPa generally reduces the brittleness index of the mixture. For example, the brittleness index of cemented sand containing 4% brick powder increases by 130% compared to cemented sand under normal stress of 50 kPa, but it decreases by 46% and 73% for 100 and 200 kPa respectively. Haeri et al. also found a decrease in the brittleness index of cemented gravely sand with increasing confining pressure [34].

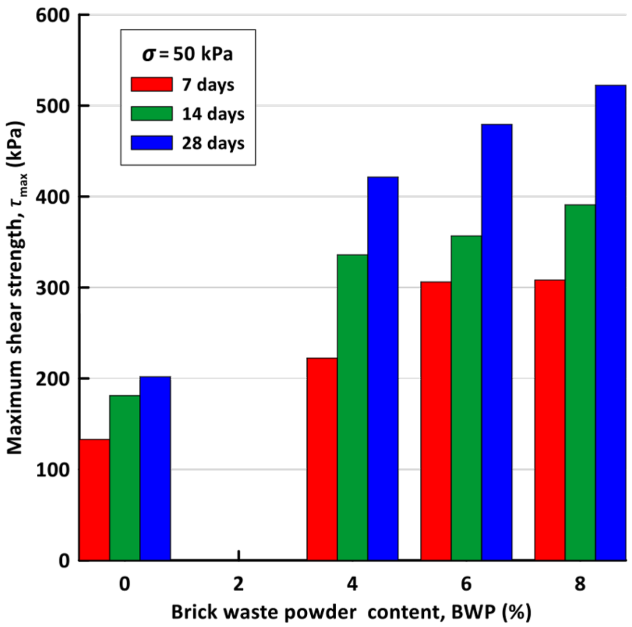


**Fig. 9** Influence of curing time on the maximum shear strength of sand-cement- brick powder mixtures, $Cc$ = 5%, $\sigma$N = 50 kPa

### 4.3 Effectiveness of replacing part of the cement with brick powder in the sand treatment process.

Table 7 provides a comparison between some cemented sand samples with and without brick powder in terms of shear strength, brittleness index and shear parameters. All mixtures were allowed to cure for 14 days. At normal stress equal to or less than 100 kPa, sand treated with 5% cement and 8% brick powder (C5B8) has a higher maximum and residual shear strength than sand containing 10% cement (C10B0). In addition, C5B8 is less brittle than C10B0 under 50 and 100 kPa. Opposite trends are observed under a normal stress of 200 kPa. As for the shear strength parameters, although the friction angle of C10B0 is slightly higher than that of C5B8, the latter has greater cohesion. It can also be noticed that sand treated with 7.5% cement (C7.5B0) has lower maximum shear strength, cohesion and friction angle than sand treated with 5% cement and 6% brick powder (C5B6). However, C5B6 is more brittle than C7.5B0.

The variation of the vertical displacement of the mixtures, mentioned in Table 6, subjected to a normal stress

**Table 6** Brittleness index of sand treated with cement and BWP, $Cc$ = 5%, curing time = 14 days

| Normal stress, $\sigma_N$ (kPa) | BWP (%) | $\tau_{max}$ (kPa) | $\tau_{res}$ (kPa) | $I_B$ |
|---|---|---|---|---|
| 50 | 0 | 181.08 | 61.22 | 1.96 |
| | 4 | 335.89 | 60.97 | 4.51 |
| | 6 | 356.72 | 71.14 | 4.01 |
| | 8 | 390.86 | 120.89 | 2.23 |
| 100 | 0 | 198.89 | 109.86 | 0.81 |
| | 4 | 405.72 | 118.69 | 2.42 |
| | 6 | 433.72 | 98.11 | 3.42 |
| | 8 | 458.94 | 177.03 | 1.59 |
| 200 | 0 | 327.11 | 212.55 | 0.54 |
| | 4 | 547.05 | 246.44 | 1.22 |
| | 6 | 637.80 | 215.86 | 1.95 |
| | 8 | 695.72 | 163.86 | 3.24 |

**Table 7** Comparison between some cemented sand samples with and without brick powder in terms of shear performance, curing time = 14 days

| Parameter | $\sigma_N$ (kPa) | C10B0 | C5B8 | C7.5B0 | C5B6 |
|---|---|---|---|---|---|
| $\tau_{max}$ (kPa) | 50 | 370.39 | 390.86 | 281 | 356.72 |
| | 100 | 458.08 | 458.94 | 310.67 | 433.72 |
| | 200 | 730.25 | 695.72 | 532.44 | 637.81 |
| $\tau_{res}$ (kPa) | 50 | 65.14 | 120.89 | 96.67 | 71.14 |
| | 100 | 128.33 | 177.03 | 162.53 | 98.11 |
| | 200 | 193.22 | 163.86 | 201.25 | 215.86 |
| $I_B$ (%) | 50 | 4.68 | 2.23 | 1.91 | 4.01 |
| | 100 | 2.57 | 1.59 | 0.91 | 3.42 |
| | 200 | 2.78 | 3.25 | 1.64 | 1.95 |
| $C$ (kPa) (at failure) | / | 234.31 | 272.47 | 170.12 | 254.68 |
| $\varphi$ (°) (at failure) | / | 67.76 | 64.33 | 60.31 | 62.21 |

of 50 kPa, as a function of the horizontal displacement is presented in Fig. 10. It clearly shows that the C10B0 sample is a little more dilative than the C5B8 sample at large horizontal displacement. Moreover, the C5B6 and C7.5B0 samples exhibit quite similar behaviour.

In summary, it can be concluded that the C5B8 sample has a comparable shear behaviour to the C10B0 sample while the C5B6 sample has a better shear performance than the C7.5B0 sample. These findings prove that it is possible to replace part of the cement with BWP in the sand treatment process while ensuring a similar or better shear behaviour by increasing the brick powder content. This will reduce the consumption of cement used in some sand treatment operations and the price of the latter, and also provide a solution to the problem of accumulation of brick waste and its negative impact on the environment.

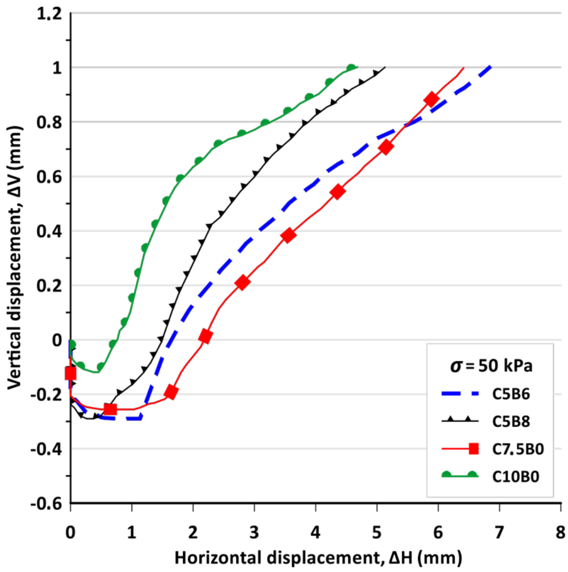


**Fig. 10** Vertical displacement versus horizontal displacement: comparison between cemented sand with and without brick powder, σN = 50 kPa, curing time = 14 days

## 5 Conclusions

This paper presents the results of direct shear tests carried out to evaluate the effect of adding BWP at different proportions on the shear behaviour of cemented sand. The following main conclusions can be drawn:

- All cemented sand samples show a brittle behaviour and a dilative character compared to pure wet sand which exhibits a ductile and contractive response. The increase in cement content significantly increases the shear strength, cohesion and internal friction angle of the cemented sand and promotes its dilative character.
- The addition of BWP to cemented sand improves its shear behaviour. The maximum shear strength and friction angle of the sand-cement-brick powder mixture increase with increasing BWP content. This is mainly attributed to an enhanced chemical reaction, which leads to the formation of supplementary cementitious products that contributes to the improvement of the overall mechanical properties of the sand (Resin et al.). In addition, the mixtures become more resistant by extending their curing time.
- The increase in the brick powder content also enhances the cohesion and dilative character of the sand-cement-brick mixture. This is most likely due to the role of fine brick powder particles in filling the voids between the cement and sand particles, which leads to an increase in the density of the mixture (Resin et al.).
- Despite the good trends observed when adding brick powder to cemented sand in terms of improving its shear strength. It was noted that the brittleness index of the samples generally rises with increasing brick powder content. Further studies should be conducted on the mechanical behaviour of sand treated with cement and brick waste focusing on reducing its brittleness by adding fibres.
- The main benefit that can be derived from this study is that BWP could be used as a potential partial replacement to cement in the sand treatment process while ensuring similar or better shear behaviour simultaneously reducing the treatment process costs in some geotechnical applications and the negative impact of cement and brick waste on the environment.

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## References

[1] Han, J. "Principles and practices of ground improvement", [e-book] John Wiley and Sons, 2015. ISBN 978-1-118-25991-7

[2] Erken, A., Feizollahzadeh, H., Hotz, C. "Stress strain behavior of a cement-fiber treated sands", In: Proceedings of the 19th International Conference on Soil Mechanics and Geotechnical Engineering, Seoul, South Korea, 2017, pp. 357–360. ISBN 978-89-952197-5-1 [online] Available at: https://www.issmge.org/publications/publication/stress-strain-behavior-of-a-cement-fiber-treated-sands

[3] El-Hanafy, A. M., Abdelaziz, M. H. "Effect of using cemented sand as a replacement layer beneath a strip footing", Housing and Building National Research Center (HBRC) Journal, 17(1), pp. 1–17, 2021. https://doi.org/10.1080/16874048.2020.1863050

[4] Consoli, N. C., Viana da Fonseca, A., Cruz, R. C., Heineck, K. S. "Fundamental parameters for the stiffness and strength control of artificially cemented sand", Journal of Geotechnical and Geoenvironmental Engineering, 135(9), pp. 1347–1353, 2009. https://doi.org/10.1061/(ASCE)GT.1943-5606.0000008

[5] Amini, Y., Hamidi, A. "Triaxial shear behavior of a cement-treated sand gravel mixture", Journal of Rock Mechanics and Geotechnical Engineering, 6(5), pp. 455–465, 2014. http://doi.org/10.1016/j.jrmge.2014.07.006

[6] Boutouba, K., Benessalah, I., Arab, A., Djafar Henni, A. "Shear strength enhancement of cemented reinforced sand: Role of cement content on the macro-mechanical behavior", Studia Geotechnica et Mechanica, 41(4), pp. 200–211, 2019. https://doi.org/10.2478/sgem-2019-0020

[7] Bayoumy, M. H., Alsawwaf, M., Nasr, A. M. "Shear strength characteristics of cemented clayey sand soil", Journal of Engineering Research, 5(2), pp. 26–30, 2021. https://doi.org/10.21608/erjeng.2021.78189.1015

[8] Bittar Marin, E. J., Quiñónez Samaniego, R. A., Neto, A. T., Consoli, N. C. "Cement stabilized soil field samples: Quality control for bases and sub-bases", Geotechnical and Geological Engineering, 41, pp. 4169–4184, 2023. https://doi.org/10.1007/s10706-023-02514-5

[9] Consoli, N. C., Prietto, P. D. M., Ulbrich, L. A. "Influence of fiber and cement addition on behavior of sandy soil", Journal of Geotechnical and Geoenvironmental Engineering, 124(12), pp. 1211–1214, 1998. https://doi.org/10.1061/(ASCE)1090-0241(1998)124:12(1211)

[10] Consoli, N. C., Vendruscolo, M. A., Fonini, A., Dalla Rosa, F. "Fiber reinforcement effects on sand considering a wide cementation range", Geotextiles and Geomembranes, 27(3), pp. 196–203, 2009. https://doi.org/10.1016/j.geotexmem.2008.11.005

[11] Janalizadeh Choobbasti, A., Soleimani Kutanaei, S. "Effect of fiber reinforcement on deformability properties of cemented sand", Journal of Adhesion Science and Technology, 31(14), pp. 1576–1590, 2016.
https://doi.org/10.1080/01694243.2016.1264681

[12] Yu, J., Mao, Z., Zhou, J., Yu, Z., Liu, X., Gong, X. "Experimental study on engineering properties of cemented soil with high water content", Applied Sciences, 13(2), 937, 2023.
https://doi.org/10.3390/app13020937

[13] Najafpoor, A. A., Zarei, A., Jamali-Behnam, F., Vahedian-Shahroudi, M., Zarei, A. "A study identifying causes of construction waste production and applying safety management on construction site", Iranian Journal of Health Sciences, 2(3), pp. 49–54, 2014.
https://doi.org/10.18869/acadpub.jhs.2.3.49

[14] Vieira, C. S., Pereira, P. M. "Use of recycled construction and demolition materials in geotechnical applications: A review", Resources, Conservation and Recycling, 103, pp. 192–204, 2015.
http://doi.org/10.1016/j.resconrec.2015.07.023

[15] Tihomirovs, P., Kara De Maeijer,P., Korjakins, A. "Demolition waste glass usage in the construction industry", Infrastructures, 8(12), 182, 2023.
https://doi.org/10.3390/infrastructures8120182

[16] Zhang, L., Wu, H., Wang, X., Wu, F., Ding, Z., Song, L., Rong, X., Wen, X., Liu, J., Zhong, P. "Investigation of rates of demolition waste generated in decoration and renovation projects: An empirical study", Buildings, 14(4), 908, 2024.
https://doi.org/10.3390/buildings14040908

[17] Arulrajah, A., Piratheepan, J., Disfani, M. M., Bo, M. W. "Geotechnical and geoenvironmental properties of recycled construction and demolition materials in pavement subbase applications", Journal of Materials in Civil Engineering, 25(8), pp. 1077–1088, 2013.
https://doi.org/10.1061/(ASCE)MT.1943-5533.0000652

[18] Cristelo, N., Silva Vieira, C., de Lurdes Lopes, M. "Geotechnical and geoenvironmental assessment of recycled construction and demolition waste for road embankments", Procedia Engineering, 143, pp. 51–58, 2016.
https://doi.org/10.1016/j.proeng.2016.06.007

[19] Sharma, A., Shrivastava, N. "Geotechnical characterization of construction and demolition waste material blended with sandy soil", International Journal of Geosynthetics and Ground Engineering, 9, 43, 2023.
https://doi.org/10.1007/s40891-023-00458-7

[20] Islam, S., Islam, J., Hoque, N. M. R. "Improvement of consolidation properties of clay soil using fine-grained construction and demolition waste", Heliyon, 8(10), e11029, 2022.
https://doi.org/10.1016/j.heliyon.2022.e11029

[21] Touahamia, M., Sivakumar, V., McKelvey, D. "Shear strength of reinforced-recycled material", Construction and Building Materials, 16(6), pp. 331–339, 2002.
https://doi.org/10.1016/S0950-0618(02)00029-6

[22] IANOR "NA 442-2013: Cement-composition, specifications and conformity criteria for common cements", IANOR, Algiers, Algeria, 2013. [online] Available at: https://www.calameo.com/read/001496329437503a35a15

[23] European committee for standardization "EN 197-1:2011 Cement-part 1: Composition, specifications and conformity criteria for common cements", AFNOR, Brussels, Belgium, 2011. [online] Available at: https://www.intertekinform.com/en-gb/standards/i-s-en-197-1-2011-868797_saig_nsai_nsai_2066037/

[24] ASTM International "ASTM C618-12a: Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete", ASTM International, West Conshohocken, PA, USA, 2012.
https://doi.org/10.1520/C0618-12A

[25] Wang, Y.-H., Leung, S.-C, "A particulate-scale investigation of cemented sand behavior", Canadian Geotechnical Journal, 45(1), pp. 29–44, 2008.
https://doi.org/10.1139/T07-070

[26] Wang, L., Chu, J., Wu, S., Wang, H. "Stress-dilatancy behavior of cemented sand: comparison between bonding provided by cement and biocement", Acta Geotechnica, 16(5), pp. 1441–1456, 2021.
https://doi.org/10.1007/s11440-021-01146-4

[27] Saxena, S. K., Avramidis, A. S., Reddy, K. R. "Dynamic moduli and damping ratios for cemented sands at low strains", Canadian Geotechnical Journal, 25(2), pp. 353–368, 1988.
https://doi.org/10.1139/t88-036

[28] Lade, P. V., Overton, D. D. "Cementation effects in frictional materials", Journal of Geotechnical Engineering, 115(10), pp. 1373–1387, 1989.
https://doi.org/10.1061/(ASCE)0733-9410(1989)115:10(1373)

[29] Shooshpasha, I., Shirvani, R. A. "Effect of cement stabilization on geotechnical properties of sandy soils", Geomechanics and Engineering, 8(1), pp. 17–31, 2015.
http://doi.org/10.12989/gae.2015.8.1.017

[30] Resin, R., Alwared, A., Al-Hubboubi, S. "Utilization of brick waste as pozzolanic material in concrete mix", In: MATEC Web of Conferences, Sharm el-Shiekh, Egypt, 2018, pp. 1–8.
https://doi.org/10.1051/matecconf/201816202006

[31] Mirzababaei, M., Arulrajah, A., Horpibulsuk, S., Soltani, A., Khayat, N. "Stabilization of soft clay using short fibers and poly vinyl alcohol", Geotextiles and Geomembranes, 46(5), pp. 646–655, 2018.
https://doi.org/10.1016/j.geotexmem.2018.05.001

[32] Mansoor, S. S., Hama, S. M., Hamdullah, D. N. "Effectiveness of replacing cement partially with waste brick powder in mortar", Journal of King Saud University – Engineering Sciences, 36(7), pp 524–532, 2024.
https://doi.org/10.1016/j.jksues.2022.01.004

[33] Mohan, M., Apurva, A., Kumar, N., Ojha, A. "A review on use of crushed brick powder as a supplementary cementitious material", In: International Conference on Materials, Mechanics and Structures, Kerala, India, 2020, pp. 1–15. ISBN 9781713847724
https://doi.org/10.1088/1757-899X/936/1/012001

[34] Haeri, S. M., Hamidi, A., Hosseini, S. M., Asghari, E., Toll, D. G. "Effect of cement type on the mechanical behavior of a gravely sand", Geotechnical and Geological Engineering, 24(2), pp. 335–360, 2006.
https://doi.org/10.1007/s10706-004-7793-1