PROPERTIES MEASUREMENT AND APPLICATIONS OF SOME GEOPOLYMERS IN DRY AND WET SAND

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Abstract. The interest in reducing carbon emissions due to the large number of industrial wastes led to the civil engineering sector’s interest in using these products for easy access and for their unique advantages in improving raw materials after mixing them and determining their optimal use ratios. Through experiments and continuous studies, three types of geopolymers were used for this study based on poor sandy soil and mixing it in certain proportions with geopolymers, recording and analysing the results and using it in the practical experiment by using a special model to shed the loads on a square footing and drawing the load - settlement curve that showed the improvement of the sandy soil’s ability to resist shear by increasing the loads and reducing the settlement in the foundations. The laboratory test proved improvement in the shear strength parameters in sandy soil after blending with geopolymers.

Keywords: Foundation, square footing, Geopolymer, Fly Ash, Settlement, Ultimate bearing capacity

1. Introduction

Soil is considered as one of the important components of building system usually, after the tremendous development in the field of civil engineering, its specifications need to be improved to bear the heavy loads of modern buildings, one of the most popular ways to improve engineering soil properties such as bear ability and reduce subsidence is the addition of geopolymer materials.

The design of any foundation for carried out the loading of structures shall be safe support of dead and superimposed loads without exceeding the allowable bearing capacity, permissible settlements and design capability. Soil characteristics play a role in foundation settlement problems have a significant effect on the foundations and other structures, (Patil and Rakarddi, 2015).

Recent environmental statistics indicate a significant increase in carbon dioxide emissions as a result of the massive increase in the production of cement used in the concrete mix, which is very harmful to the environment. To reduce the ill effects of this industrial waste, studies have been conducted on geopolymers. Cement mortar production per ton of absolute cement approximately equal amount of carbon dioxide in the atmosphere. Carbon dioxide emission is one of the main problems that cause global heating. The cement industry is partly responsible for this problem. The increased use of cement can be it is reduced through the use of alternative materials such as fly Ash, subsequent soil, etc. can be used. The researchers concluded that the use of geopolymer mortar has no negative effect on the
The environment is like cement, (Habert, Et.al. 2020). Stabilization of sandy soil with chemical additives has been considered in geotechnical engineering for long time. There are a lack of sufficient research regards to soil stabilization with alkaline activation and geopolymers technology; therefore, it has been given more attention. Cement industries produce 5-8% of total carbon dioxide in the world (Provis, 2018), geopolymer cement emit 62-90% less CO₂ than Portland cement (Schmitz, 2011).

2. Materials
   2.1. Soil

The laboratory tests are carried out at the soil mechanics laboratory of the University of Kufa. Regular soils testing was done to describe soil engineering characterization including the following tests:

- Grain size distribution, see Figure (1) and Table (2).
- Specific gravity.
- Maximum and minimum dry unit weight.
- Direct shear test parameters.
- Chemical, see Table (3).

![Figure (1) Grain size distribution](image-url)
Table (1) physical properties of sandy soil

| Index property                  | Value  | Specification   |
|---------------------------------|--------|-----------------|
| $D_{10}$ (mm)                   | 0.15   |                 |
| $D_{30}$ (mm)                   | 0.3    |                 |
| $D_{50}$ (mm)                   | 0.35   |                 |
| $D_{60}$ (mm)                   | 0.39   |                 |
| Coefficient of uniformity ($C_u$) | 2.6    |                 |
| Coefficient of curvature ($C_c$) | 1.54   |                 |
| Soil classification (USCS)      | SP     |                 |
| Specific gravity ($G_s$)        |        | ASTM D845      |
| Maximum dry unit weight, $\gamma_d$ max (kN/m$^3$) | 18.89  | ASTM D7382-08  |
| Minimum dry unit weight, $\gamma_d$ min (kN/m$^3$) | 15.31  | ASTM D4254-14  |
| Maximum void ratio, $e_{\text{max}}$ | 0.775  |                 |
| Minimum void ratio, $e_{\text{min}}$ | 0.403  |                 |
| Relative density, $D_r$ (%)     | 15% (loose) |          |
| Void ratio, $e$                 | 0.72   |                 |
| Dry unit weight, $\gamma_d$ (kN/m$^3$) |         |                 |
| Optimum water content           |        | ASTM D698      |

Table (2) Chemical properties of sandy soil

| Chemical composition       | Value % |
|----------------------------|---------|
| So$_3$                     | 0.82    |
| Gypsum content             | 1.76    |
| T.D.S                      | 0.54    |
| Organic content            | 0.67    |

The sample of sand was taken from AL-NAJAF city, Iraq with longitude 44° 25' 0'' E and latitude 31° 56' 0'' N. The sample was classified as poorly graded sand (SP) according to USCS.

2.2. Fly Ash
Fly ash class C according to ASTM C618-05 classified as waste from large industries such as thermal power plants and cement production plants. The properties of fly ash are shown in Tables 1.

Pandey and Singh (2010) reported in Figure 1) The relative production and utilization of fly ashes differ clearly from one country to another.

Table 3: chemical properties of Fly Ash

| Particulars | Content (mass%) |
|-------------|-----------------|
| CaO         | 0.67            |
| Al₂O₃       | 22.63           |
| Fe₂O₃       | 5.30            |
| SO₃         | 0.41            |
| MgO         | 0.16            |
| SiO₂        | 66.39           |

Figure (2) worldwide FA production and utilizing in various countries (after Pedey and einghm 2010)

Abmaruzzaman (2010), believes that the get rid of FA will be very costly if not controlled. This can be seen in Denmark, Italy and Netherlands, where all the FA must be exported or utilized since landfill waste is barred (Eijk et al., 2011).

2.3. Metakaolin

After obtaining the result of this trails, researchers can be using metakaolin geopolymer to stabilize soil while another study on the long-term behaviour of geopolymer stabilized soils should be continued by using another raw material (i.e industrial waste by-product) to addressed the costing issues in our thesis we will be used poor sand to stabilize with metakaolin geopolymer [Zhang et al., 2013].

geopolymers is got from the laboratories of the College of Engineering at the University of Kufa have been used in previous scientific experiments by Dr. Mohammed H. S. Shamsa through his study the evaluate the performance of the geopolymer concrete exposed to severe conditions in accordance with the requirements of the ACI 318-14.
2.4. Furnace slag

Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. Ground-granulated blast furnace slag is highly cementitious and high in CSH (calcium silicate hydrates) which is a strength-enhancing compound that improves the strength, durability and appearance of the concrete. Lime and cement are well-known additives for the stabilization of soils. These additives are produced from industrial processes and are associated with the emission of greenhouse gases such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). Industrial by-product materials such as blast furnace slag [Al-Mukhtar et al., 2010, Cokca et al., 2009]. As additives are becoming more popular due to their relatively low cost. Additionally, CO2 emissions can be reduced significantly by the increased use of such supplementary cementing materials currently wasted in lagoons and landfill sites. The most important feature in the stabilization of clayey soils is the ability of the stabilizer to provide a sufficient amount of calcium. Industrial waste, such as fly ash and blast furnace slag can be used as stabilizing agents because they are siliceous and calcareous materials [Wang, 2002].

3. Testing Methodology

The study is summarized to find out the effect of geopolymers on the properties of sandy soil by conducting the test in the case of dry soil and its wet condition. In the dry state, we get through direct shear test the materials will be added at the rate of 1%, 2%, 4%, 6% and 8% and choosing the best improvement percentage shown by the result of the test, then compare those results with the condition of the natural soil.

In the wet case, the standard Proctor test is used to obtain the best water content for each of the three materials after mixing them in the best proportions based on the previous test. Then the direct shear is done and mixed using the optimal water content, and the results of valuable values are recorded and analyzed.

3.1. The direct shear

Testing had been conducted by ASTM D 3080-98. Regular direct shear box test equipment was used for testing the sand of this study, the testing had been conducted within the Soil’s Mechanical Lab of the University of Kufa. The sample dimensions were 6 x 6 x 2.5 cm. This equipment was used for the determination of internal friction angles ($\phi$) of the sand, after the testing carried out gutted the internal friction angles for used sand was 24°. The test was performed with three different normal stresses; 27.24, 54.48 and 108.97 kPa.
3.2. Standard Proctor Test

To get a suitable water content mixing with dry sandy to testing it in wet condition followed the ASTM D-1557, the result of best values of internal friction (ϕ) conducted to estimate the optimum moisture content for each product mixing with natural sand. Then the result used to get the soil strength parameters in wet condition.

4. Result and discussion

4.1. Dry condition

The result obtained from direct shear test showed the variation in the value of internal angle friction (φ) after blinding natural dry sand with used geopolymers products, see table (4)

The direct shear test is carried out following the ASTM D3080. The test was performed with three different normal stresses of 10, 20 and 40 kg which equivalent 27.25, 54.5 and 81.75 kPa, for the sand sample readings of horizontal displacements. It can be observed that the value of internal angle friction (ϕ) increased with the changing the mixing ratio of geopolymers with sand. The first model testing was conducted for natural sand see Figure (1) and find the value of internal angle friction (ϕ) was 29°, these results were used as reference to compare it with another result obtained from mixing sands with three chosen types of geopolymers.

![Natural Sand](image)

**Figure (3):** Shear strength parameters for sand alone

Then, the test was conducted using five samples for each material, the results were as shown in the Figures (2), (3) and (4) The optimum mixing ratio was chosen that led to get the best shear resistance see Table (4.1).
Figure (4) Shear strength parameters for sand with MK
Figure (5) Shear strength parameters for sand with FA
**Figure (6)** Shear strength parameters for sand with GGBS
Based on the results obtained from the direct shear test, we can notice the improvement in the properties of sandy soils after mixing them with geopolymer materials, where an increase in the value of the internal friction angle was about 46% after mixing sandy soils with metakaoline in 4% ratio of mixing.

The above result obtained from direct shear test showed the variation in the value of internal angle friction ($\phi$) after blinding natural dry sand with used geopolymers products.

**Table (4) Direct Shear Result**

| Percent % | 1 | 2 | 4 | 6 | 8 |
|-----------|---|---|---|---|---|
| MK        | C | 4 | 5 | 5 | 3 | 5 |
|           | $\phi$ | 32 | 33 | 35 | 29 | 28 |
| FA        | C | 5 | 6 | 7 | 7 | 6 |
|           | $\phi$ | 30 | 33 | 29 | 27 | 25 |
| GGBS      | C | 2 | 3 | 3 | 4 | 2 |
|           | $\phi$ | 31 | 33 | 34 | 37 | 28 |

Through the results in the Table (5), the best percentage of improvement in soil shear strength parameters when using GGBS is 6%, where the improvement percentage in the internal friction angle was about 54%.

Also, through Table (5) and Figure (5), the appearance of shear strength values was recorded after mixing the geopolymers with sandy soil, which is an additional improvement over the natural state of the soil, which will improve the soil’s ability to withstand shear stresses during loading. This can be explained by changing the chemical content of the soil texture.

**Table (5) Optimum direct shear result with best mixing ratio**

| Test No. | Material | Ratio | Angle Friction | C (kpa) |
|----------|----------|-------|----------------|---------|
| 1        | GGBS     | 6%    | $37^0$         | 4       |
| 2        | MK       | 4%    | $35^0$         | 5       |
| 3        | FA       | 2%    | $33^0$         | 6       |
4.2. Wet condition

From Table (6) and Figure (6) the result of standard proctor test showed the improvement in the dry unit weight of poor sandy soil after mixing with geopolymers in wet condition.

**Table (6) Result of proctor test**

| Material | $\gamma_d$ | O.W.C. % |
|----------|------------|----------|
| FA       | 21.36      | 7.7      |
| MK       | 20.11      | 5.9      |
| GGBS     | 22.01      | 6.5      |
These results indicate an increase in the weight of the dry unit after using geopolymers as an additive for poor sandy soils and thus will improve the bearing capacity of sandy soils when used as a base layer under structures.

![Dry Unit Weight (ρd) (Kg/m3)](image)

**Figure (8):** Improvement in dry unit weight with add geopolymers

Table (7) showed the values of shear strength parameters carried out from direct shear test in wet condition with the optimum water content found out from proctor test, these values used in model to had load – settlement curve for three type of geopolymer.

| Test No. | Material | Angle Friction | C (kpa) |
|----------|----------|----------------|---------|
| 1        | GGBS     | 38°            | 6       |
| 2        | MK       | 39°            | 8       |
| 3        | FA       | 42°            | 12      |

**Table (7):** Shear strength parameters for wet sand with Geopolymers geopolymers

5. Conclusion

In this paper we used the three types of geopolymers as additive with poorly sand loose state soil led to great enhancing in the shear strength parameters. Laboratory tests by direct shear device showed in addition to improving the value of internal angle friction and appearance of the amount of cohesion after adding geopolymers to the sandy soil that is lacking cohesion basically, this is the improvement of
additional and is used to reduce the shear problems in the soil and raise the ability of strength for larger loads and reduce the settlement in the foundations. The occupation of these additives to the voids between the soil particles led to an increase in cohesion and is an important factor in the adoption of geopolymers to improve sandy soil. The improvement shear strength parameters will lead to an increase in the bearing capacity of the soil to weights and a decrease in the settlement of the foundations. In the case of dry soil, the best improvement rate is 6% using with GBBS, but in the wet case, the best additive is FA at 4% ratio.

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