Effect of Phosphogypsum As a Waste Material in Soil Stabilization of Pavement Layers

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ABSTRACT

The aim of this research is to use phosphogypsum (PG) waste produced from phosphoric acid plants as a stabilization material to improve the properties of non-plastic soil, such as Aqaba soil in Jordan. The mixture formula of the material was optimized and the PG dosages 0%, 5%, 10%, 20% and 25% by weight of the soil sample were tested. The sieving and grading of the soil, Atterberg limit, dry unit weight, moisture content, Proctor and Califorina Bearing Ratio (CBR) were tested. It was concluded that 21% represented the optimum percentage of PG in all soil specimens, especially in Proctor and CBR tests for the red silty sand and gravel (A-2-4). This result also could influence the base, sub-base and sub-grade pavement layers to one pavement layer with less depth of its stabilization.

KEYWORDS: Phosphogypsum, Soil stabilization, Proctor, Califorina Bearing Ratio (CBR), Pavement.

INTRODUCTION

Phosphogypsum is a waste by-product from processing of phosphate rock by wet acid method for phosphoric acid production. About 3.2 tons of PG were generated for one ton of phosphoric acid produced (Becker, 1989).

Shen et al. (2009) prepared a new type of steel slag–fly ash–PG solidified material composed of solid wastes to be utilized as pavement material. PG dosage of 2.5% results in highest strength. The development of strength for resilience modulus and splitting strength of this material were studied compared with some typical pavement materials. In term of long-term strength, it was much higher than that for cement stabilized granular materials. The solidified material had best water stability among those pavement materials.

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Shweikani et al. (2013) studied the radiation dose measurement due to the presence of PG in cement. The measurement was performed using an appropriate radiation exposure model based on radiation capacity (gamma spectroscopy and solid state nuclear track detector CR-39). Radium equivalent and activity intensity index safety criteria were calculated. It was found that the extra dose to the public due to this addition was within the acceptable levels. Results showed that using PG is safe in construction materials.

Degirmenci et al. (2007) described soil stabilization with the use of PG with cement and fly ash. Unconfined compressive strength, standard proctor compaction and Atterberg limit tests were carried out on the soil samples. Conclusions indicated that the addition of cement, fly ash and PG reduces the plasticity index of the soil, while the maximum dry unit weight increases as the contents of cement and PG increase and decreases with fly ash content. It was also found that the optimum moisture contents of the stabilized soil samples decrease with the addition of cement, fly ash and PG. This resulted in an increase of unconfined compressive strength of the soil. Therefore, the waste by-products; PG and fly ash may provide inexpensive and advantageous construction products.

Shen et al. (2007) studied a new type of lime–fly ash–PG binder to improve the performance of lime–fly ash binder which was a typical semi-rigid road base material binder in China. Modified lime powder had much higher activity than ordinary quick lime or slaked lime powder; it was the best alkali activator to prepare lime–fly ash–PG binder. The optimum of the binder consisted of 8–12% modified lime, 18–23% PG and 65–74% fly ash. It has been shown that lime–fly ash–PG binder had higher strength than ordinary lime, cement and lime–fly ash stabilized soils road base materials. Granular soils stabilized with this binder had higher later strength than that of lime–fly ash or cement stabilizing granular soil; it had higher early strength and steady strength development.

The objective of this research is to use waste PG produced from phosphoric acid plants as a stabilization pavement material to improve the properties of non-plastic soils such as those in Aqaba- Jordan.

METHODOLOGY

PG materials may have varying degrees of harmful effect on the environment, especially when piled in rural areas like Aqaba region. In this research, six soil specimens containing different concentrations of PG material; namely: 0%, 5%, 10%, 15%, 20% and 25%, were mixed with red silty sand gravel Aqaba soil.

The classification of soil and PG was related to AASHTO Designation: M 145-91 (Ministry of Public Works and Housing, 2003) as shown in Table 1. The material classification of the results from Table 1, indicated as A-2-4 is related to AASHTO M-145 (AASHTO, 1995).

The maximum dry density and optimum moisture content related to standard Proctor test are according to AASHTO T-180-D (AASHTO, 2002), and CBR test load is according to AASHTO T-193 (AASHTO, 2002).

Table 1. Classification of soil and phosphogypsum

Sieve Size	% Passing of Soil	%Passing of PG
3" (76.2mm)	100	100
No.4 (4.75mm)	99.8	100
No.10 (2.00mm)	98.5	95.3
No.40 (0.425mm)	48.6	87.3
No.200 (0.075mm)	12.2	71.0
Liquid Limit (LL) (%)	N.P.	
Plastic Limit (PL) (%)	N.P.	
Plasticity Index (PI)	N.P	

Table 2. Variation of optimum dry density (ODD) and optimum moisture content (OMC) with PG content in soil

PG content, %	ODD, gm/cm^3	OMC, %
0	1.69	6
5	1.7	6.25
10	1.74	6.5
15	1.85	6.8
20	1.92	7
25	1.87	7.5

RESULTS AND DISCUSSION

Moisture density in soils using a 4.5kg rammer and 457mm drop distance, as indicated by AASHTO Designation: T 180-97, showed that non-plastic soil used does not have a liquid limit (LL), a plastic limit (PL) and a plasticity index (PI). Additionally, according to sieving, the classification of soil was silty or clayey gravel and sand (A-2-4). PG used in this research was a raw material and was classified as filler mineral.

Figure 1 shows the variation of moisture content (MC) and dry density (DD) at different contents of PG as obtained from Proctor test. Optimum dry density

(ODD) and optimum moisture content (OMC) values at different contents of PG are summarized in Table 2.

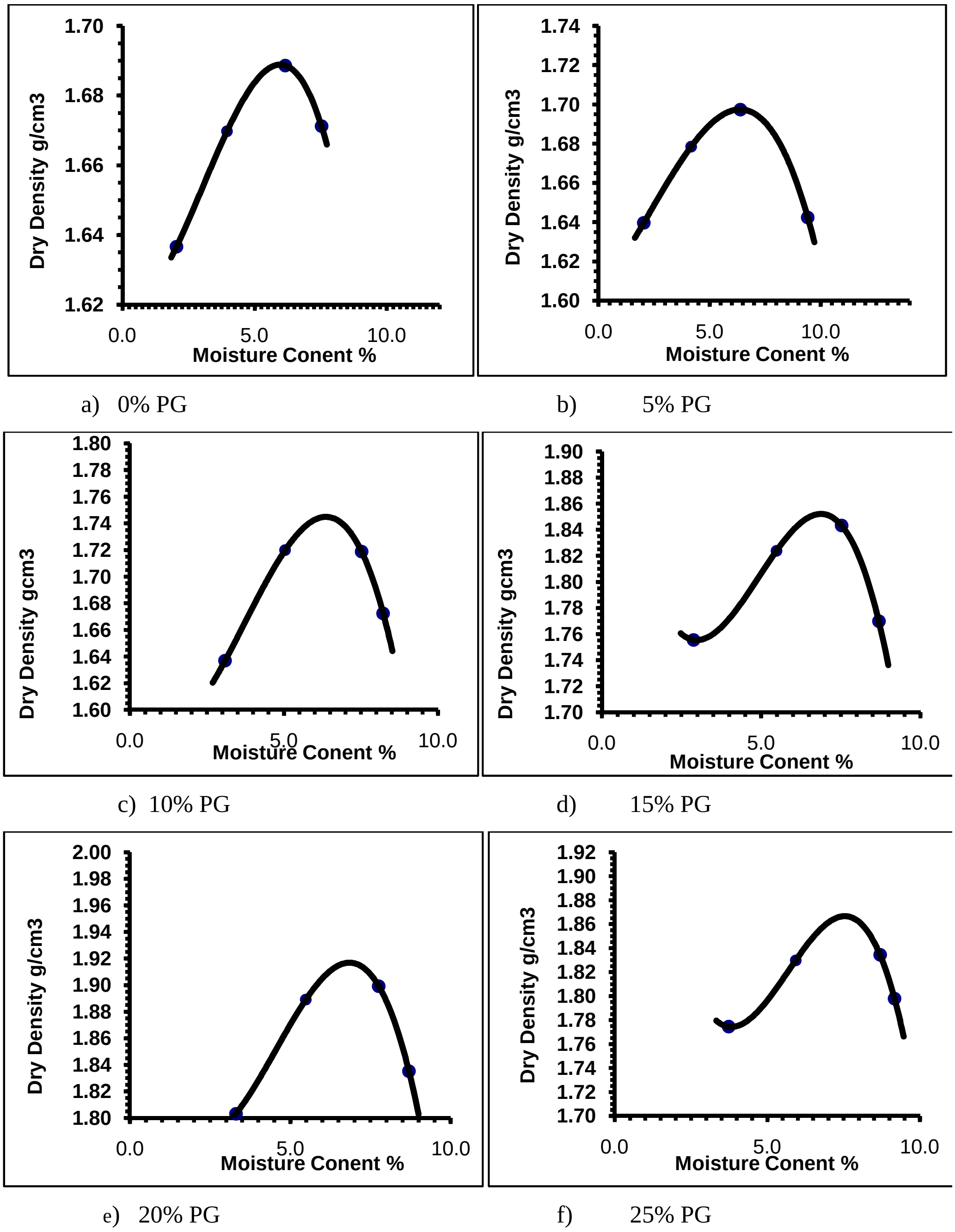


Figure (1): Standard Proctor test on soil with a) 0%PG, b) 5% PG, c) 10% PG, d) 15% PG, e) 20% PG, f) 25% PG

From Figure 1 and Table 2, it is shown that as the percentages of PG increases in soil the dry density increases and the moisture content increases. It is also shown that until the 20% addition of PG to the soil, the optimum dry density increases and the optimum moisture content increases.

Figure 2 represents the percentages of PG and moisture dry density (MDD); it indicates that MDD=1.93 gm/cm^{3}at PG=21.4% is the optimum percentage that could be added to silty or clayey gravel soil as a perfect percentage. This result of the Proctor test indicates a limit for the value of MDD which should not be less than 1.7gm/cm^3 as indicated in AASHTO-T-180D (AASHTO, 2002).

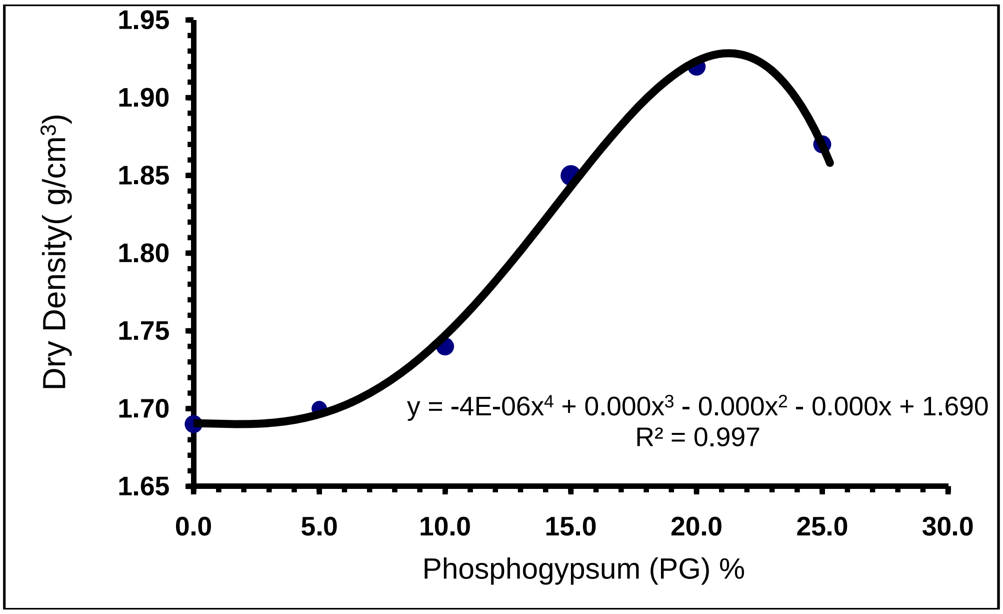


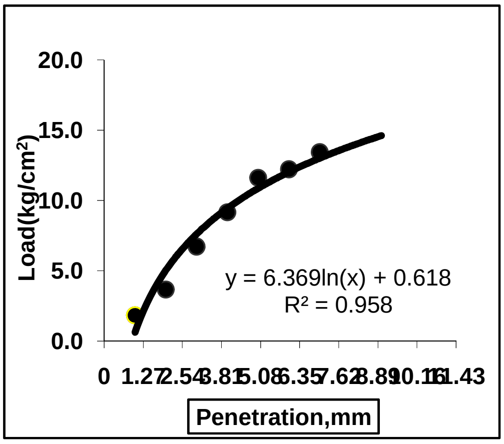
Figure (2): Relationship between dry density and percentage of PG in soil

CBR test gives the potential strength of the pavement layers by comparing CBR percentage for 2.54 mm and 5.08 mm penetration. If 5.08 mm penetration gives a greater value, this value will be used. According to Figure 3-a the 0%PG sample has been tested with a standard penetration value associated with recording the load values, then CBR % values were calculated for specified standard penetration of 2.54 mm and 5.08 mm to determine the greater value, which was between 9.6% and 11.1% as shown in Figure 3-a, noting that the relation between load and penetration is proportional with a maximum load value of the standard penetration of 7.62 mm equal to 13.4kg/cm^2, and so on.

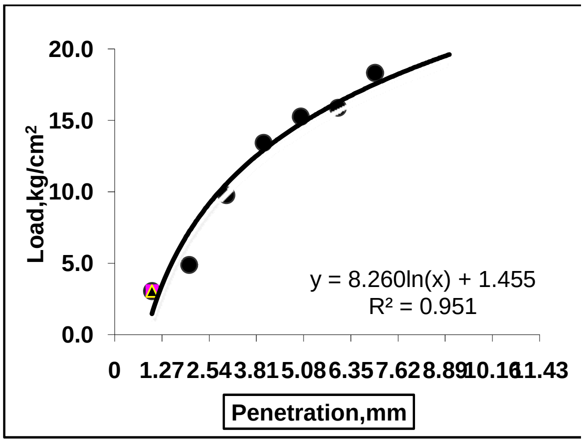
Figure 3-b shows that, with 5% PG, the values of CBR% in the standard penetration of 2.54 mm and 5.08 mm are 14.0% and 14.5%, respectively, which indicates that the maximum load value at 7.62 mm is equal to 18.4kg/cm^2. Figure 3-c shows that, with 10% PG, the CBR% values were 24.4% and 32.6% at standard penetration, and the greater value was used. Figure 3-d, with 15% PG, shows that the values of CBR% as related to standard penetration were 27.9% and 34.9%, where the greater value was used. Figure 3-e, with 20% PG, shows that CBR% values at standard penetration were 26.6% and 45.4%, and again the greater value was used. Figure 3-f, with 25%PG, shows that the CBR% values were 36.6% and 43.0%, and again the greater one was used.

Figure 4, showing CBR% with good correlation coefficients (R^2=96.1%), indicates that as the percentage of PG in the soil increases the load increases up to 20% PG, then it decreases at 25% PG.

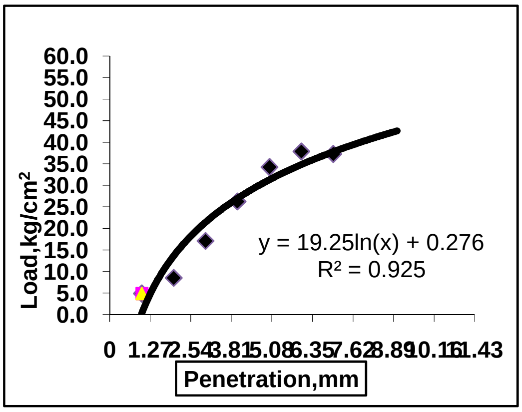
California Bearing Ratio (CBR) test is related to AASHTO Designation: T-193-99 (AASHTO, 2002)



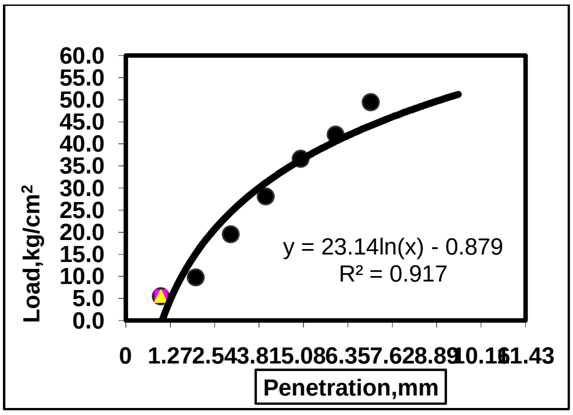
a) 0%PG



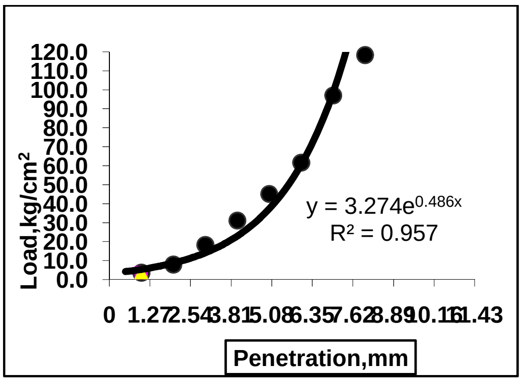
b) 5%PG



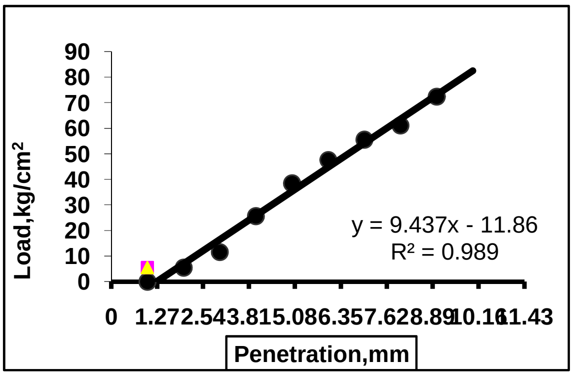
c)10%PG



d)15%PG



e) 20%PG



f) 25%PG

Figure (3): Relationship between load and penetration at a) 0% PG b) 5% PG c) 10%PG d) 15% PG e) 20% PG and f) 25%PG

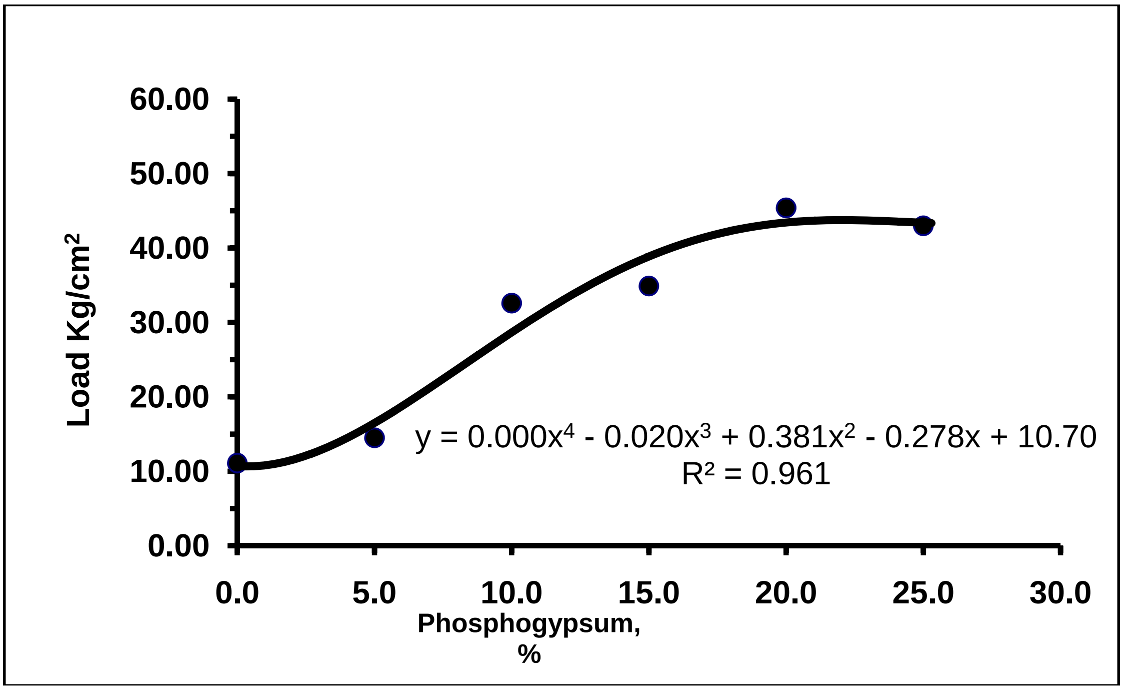


Figure (4): Relationship between load and percentage of PG in soil

CONCLUSIONS

Depending on the test results, it can be concluded that:

- The optimum value of the percentage of PG to be added to the silty or clayey gravel and sand soil is 21.4%.
- The potential strength of the soil increased with the increase in the PG content up to 20% as indicated in the CBR test.
- In pavement construction, the use of PG as a soil stabilizer could reduce the depth of the pavement layer on the expense of the sub-base layer, while giving the same properties to all of the layers.
- Correlation coefficient related to all the data in the test experiments indicated the best fit.
- The use of PG as a soil stabilizer could solve the negative environmental impact on Aqaba region as well as put an end to stacking huge quantities of PG resulting from the phosphoric acid plant at Aqaba.

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REFERENCES

AASHTO DESIGNATION: M145-91. (1995). "Classification of soil and soil aggregate mixture for highway construction purposes".

AASHTO DESIGNATION: M180-97. (2002). "Moisture-density relations of soil using a 4.54-kg (10 lb) Rammer and a 457-mm (18in) Drop".

AASHTO Designation: T 193-99. (2002). "The California Bearing Ratio (CBR)".

Becker, P. (1989). Phosphates and phosphoric acid: raw materials, technology and economics of the wet process. Fertilizer Science and Technology Series. New York, Marcel Dekker, Inc., Vol. 5, 752p.

Ministry of Public Works and Housing, Jordan. (2003). "Specification for Highway and Bridge Construction". Directorate of Planning and Development, 2 (2, 3), 2-7; 3-5; 3-17.

Nurhayat Degirmenci, Arzu Okucu, and Ayse Turbi. (2007). "Application of phosphogypsum in soil stabilization". Building and Environment, 42 (9), 3393-3398.

Shweikani, R., Kousa, M., and Mizban, F. (2013)." The use of phosphogypsum in Syrian cement industry: radiation dose to public". Annals of Nuclear Energy, 54, 197-201.

Weiguo Shen, Mingkai Zhou, and Qinglin Zhao. (2007). "Study on lime-flay ash-phosphogypsum binder". Construction and Building Materials, 21 (7), 1480-1485.

Weiguo Shen, Mingkai Zhou,Wei Ma, Jinqiang Hu, and Zhi Cai. (2009). "Investigation on the application of steel slag–fly ash–phosphogypsum solidified material as road base material". Journal of Hazardous Materials, 164, 99-104.