Magazine of Civil Engineering

ISSN 2712-8172

journal homepage: http://engstroy.spbstu.ru/

DOI: 10.34910/MCE.108.6

Mechanical properties of slag sand mixture used in road pavements

H. Cherfa*[*a], A. Nechnech[b], N. Saoudi[c], K. Ait Mokhtar[b]

[a]*University of Sciences and Technology Houari Boumediene, Algiers, Algeria*

[b]*Laboratory of Environment, Water Geomechanics and Structures LEEGO / University of Sciences and Technology Houari Boumediene (USTHB)*

[c]*Département of Civil Engineering, Akli Mohand Oulhadj Uviversity Bouira (UAMOB), Bouira, Algeria*

**E-mail: ha_cherfa@yahoo.fr*

Keywords: mechanical properties, local materials, slag, dune sand, pavement, road engineering

Abstract. Today the road has become a necessity and an important factor in the economic and social development of nations. Algeria knows the realization of many grandiose road projects that required large quantities of noble materials such as aggregates and crushed sands and which unfortunately are becoming increasingly rare. The inability of Algerian quarries to supply these materials is a reason for the valorization of industrial waste and local materials that are in abundance. Among these materials, we find granulated slag and dune sand. Our study presents valorization of these two materials through a formulation and characterization of slag sand mixture composed of dune sand treated with different percentages of granulated blast furnace slag, which acts as a hydraulic binder. The results obtained show that this treatment improves the cohesion and mechanical properties of sand dune, which allows its use in road engineering, particularly in the pavement layers.

1. Introduction

The industrials wastes valorization is work that aims on the one hand the protection of the environment and on the other hand the rational and economic use of these materials in the field of civil engineering. Among these wastes we find granulated blast furnace slag (GBFS) which serve to stabilize and improve the mechanical properties of several soils including dune sands (DS) which present local materials without resistance. Algeria has a large iron and steel complex that generates large quantities of granulated slag. For example, the annual production of granulated slag is 430 000 tons [1].

The vast desert area of Algeria contains priceless quantities of dune sands. These sands cover about 60 % the surface of Algeria [2]. Granulated blast furnace slag (GBFS) is a by-product of the manufacture of cast iron in blast furnaces, obtained by rapid cooling, and has been used as a building material since the 17th century [3]. Several research works were carried out for the valorization of (GBFS) and DS in the field of civil engineering.

GBFS are used for soil stabilization [4–7] and for flexible and semi-rigid pavement layers [8–10]. The GBFS is mixed with one or more sands to obtain slag sand (SS) intended especially for the base and foundation road and highway layers. This slag sand can be manufactured in several countries which have steel complexes which produce granulated slag such as India, China, USA, Japan, Russia, UK, Iran, France, Turkey, Brazil,…etc.

In the cement industry, granulated slag is considered as an industrial by product with zero CO_2 emissions because its substitution with clinker allows direct emission reduction of between 65 % and 95 % [11], knowing that CO_2 accounts for 82 % of the total greenhouse gas which is responsible of climate

Cherfa, H., Nechnech, A., Saoudi, N., Ait Mokhtar, K. Mechanical properties of slag sand mixture used in road pavements. Magazine of Civil Engineering. 2021. 108(8). Article No. 10806. DOI: 10.34910/MCE.108.6

change [12]. For the concrete manufacture, Granulated Slag was widely used compared to others wastes [13], it has been used as a basis material to improve the concrete strength [14].Many researchers,in their studies, have shown that the strength of the granulated slag-based concrete is less affected by chemicals product than the conventional concrete when exposed to an aggressive environment [15–20]. Granulated blast furnace slags therefore have many qualities that make them interesting in several application fields.

Dune sands are generally treated and stabilized by cement and lime according to the literature [2]. However, very limited studies have focused on treating and stabilizing these sands with granulated slag for use in road engineering.

This work is concerned with the technique of treating the dune sand by adding different percentages of GBFS as hydraulic binders (GBFS+1 % lime). Initially, the materials used were identified and characterized by conventional geotechnical tests and by mineralogical and chemical analyses. Then in a second step, the study focused on the effect of hydraulic binders on the mechanical behavior in order to determine the optimal mixture which presents the best mechanical properties making it potential candidate for use in pavements layers.

2. Materials and methods

2.1. Materials

2.1.1. Granulated blast furnace slag GBFS

GBFS used in this study is a granulated blast furnace slag of fresh production and 0/5 mm granulometry (Fig. 1) coming from the steel complex of El-Hadjar (Annaba, Algeria), obtained by rapid cooling. It presents the main characteristics given in Table 1. Its reactivity coefficient α is 39. It satisfies the criteria set by the Algerian catalog which specifies a minimum value greater than 20 [21]. Its X-ray diffraction (XRD) analysis and Scanning Electron Microscopy (SEM) image are given in Fig. 2.

Figure 1. Granulated blast furnace slag.

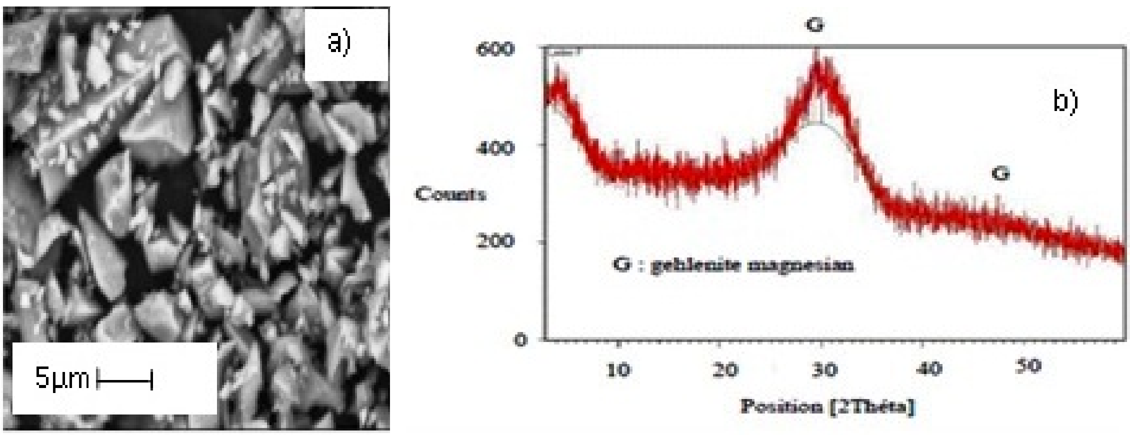


Figure 2. Scanning Electron Microscopy (a) and X-ray diffraction analysis (b) of GBFS

Figure 2 shows that the granulated slag is amorphous and it presents an amorphous halo angle of around 2θ = 30 ° which shows that GBFS is typically glassy. A small quantity of gehlenitemagnesian (G) presents in the glass. This result is consistent with the results found in the literature [22–25]. It was also observed from the SEM picture that the GBFS particles were angular in shape and the surface of slag is rough.

2.1.2. Dune Sand DS

The dune sand used is a fine sand of 0/1 mm granulometry from Boussaâda region (Msila, Algeria). It is siliceous considering its content of silica (SiO_2) which is 97.10 %. According to the GTR 2000 soil classification [26], dune sand belongs to class D1. It is characterized as permeable, incoherent, and poorly graded sand. This suggests that dune sand alone will not be sufficiently compact, and subsequently its immediate bearing index is not adequate [27, 28]. Therefore, a treatment of this sand with hydraulic binders will be essential. The X-ray analysis shown in Fig. 3 reveals its very high quartz content.

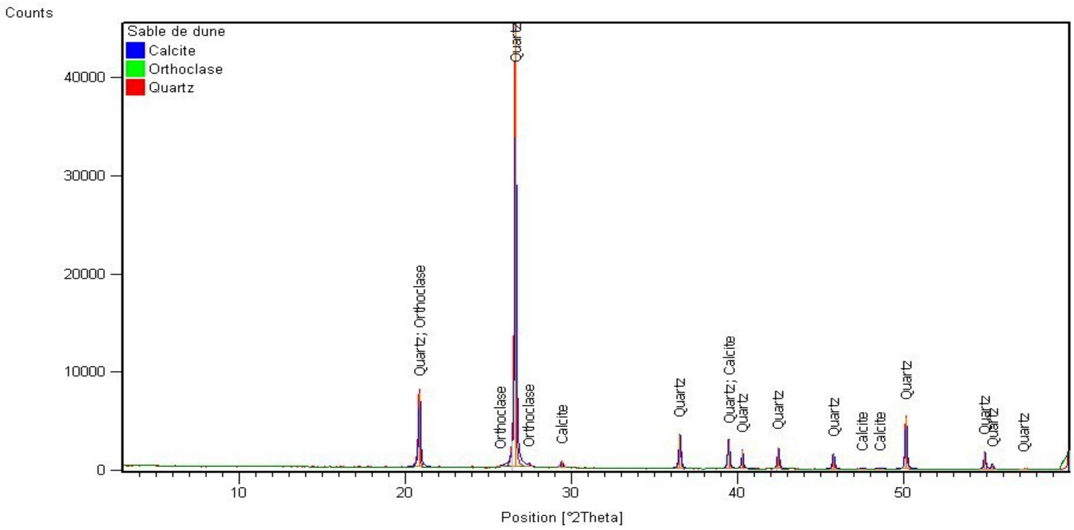


Figure3. DS X-ray analysis.

2.1.3. Crushed Sand CS

CS used is crushed quarry sand with a particle size of 0/6 mm; it is calcareous with carbonate content ($CaCO_3$) of 89 %.

2.1.4. Lime

The lime used in our study is a slaked lime which has a role of basic activator of the slag. It's coming from the region of Ghardaïa, Algeria. Its CaO content is greater than 50 %, it verifies the specifications for its use for roads.

The physic-chemical characteristics of the different study materials are given in Table 1, their particle size curves are represented in Fig. 4.

Table 1.Physico-chemical analysis of the used materials.

Material	GBFS	DS	CS	Lime
Density [g/cm³]	2.8	2.65	2.81	2.58
Friability (%)	19	–	40	–
Blaine specific surface (cm²/g)	2057	–	–	10165
Pistonsandequivalent (%)	–	73.79	94	–
Methylenebluevalues	–	0.4	0.5	–
Basicitymodulus	1.3	–	–	–
Finenessmodulus	3.21	0.88	4.2	–
CoefficientofuniformityCu[1]	3.39	1.97	14.75	–
CoefficientofcurvatureCc[2]	1.17	0.86	1.99	–

[1] $Cu = D_{10} / D_{60}$

[2] $1 \le Cc = (D_{30})^2 / D_{10} \times D_{60} \le 3$,whereD_{10}, D_{30} and D_{60} are diameters (in mm) corresponding respectively to 10, 30 and 60 % passing percentages.

Material	GBFS	DS	CS	Lime
CaO (%)	45.78	0.54	40.61	64.27
SiO_2 (%)	34.99	97.10	5.94	2.85
$CaCO_3$ (%)	–	3.39	89.65	–
Al_2O_3 (%)	9.79	0.71	8.85	0.56
MgO (%)	3.92	0.06	3.56	0.45
Fe_2O_3 (%)	0.67	0.39	3.25	0.27

The methylene blue values of crushed sand and dune sand indicates the absence of noxious clay particles in these sands.

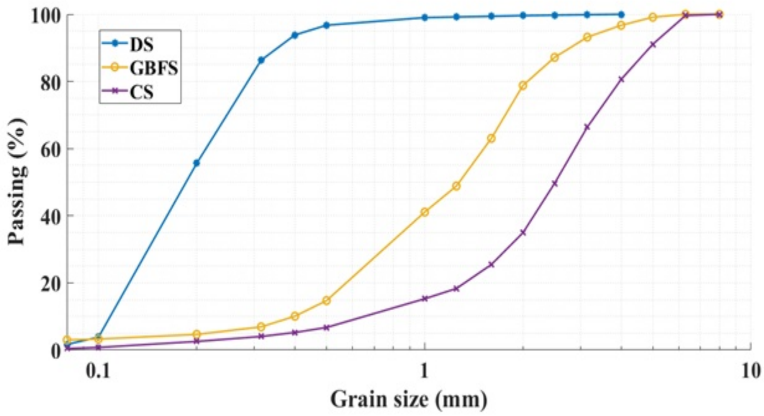


Figure 4. Particle size distribution curves of the used materials.

According to the granulometric curves, we find that our crushed sand is clean, well-graded sand and its grain size curve reflects a continuous dimensional distribution, the uniformity coefficient (Cu> 2) confirms the spread out curve of the granularity. On the other hand, the granulometric curve of dune sand represents a tight granularity which is confirmed by the coefficient of uniformity value (Cu <2), so the dune sand is clean sand as Sm class according to the GTR 2000 Soil Classification [26].

2.2. Methods

The present study deals with the effect of the addition of hydraulic binders (GBFS + 1 % lime) on the mechanical properties of the studied sand. The different mixtures (DS+CS + GBFS + 1 % lime) called slag sands (SS) were formulated, in the laboratory, with percentages of granulated slag (GBFS) ranging from 10 % to 30 %. In order to determine the optimal mixtures, various tests such as; compaction test, CBR test, simple compression test and triaxial shear test were carried out to study the mechanical behavior of the above-mentioned slag sand mixtures.

2.1.5. Slags and mixtures formulation methodology

A slag sand can be defined as the mixture (Fig. 5), carried out in a mixing plant, of one (or more) sand (s), a certain percentage of slag (granulated or pelletized) and a basic activator such as lime at a dosage generally around 1 %. It is mainly used for pavement foundations. The choice of the compositions of the SS mixes is essentially based on the following two criteria:

1. The stability before compaction (immediate stability) of the mixtures is appreciated by their coefficients of uniformity and curvature, the aim of which is to have continuous particle size curves. We must verify that:

$$Cu = D_{10} / D_{60} \geq 6, \quad (1)$$

$$1 \leq Cc = (D_{30})^2 / D_{10} \times D_{60} \leq 3. \quad (2)$$

2. The stability of compacted mixtures is assessed by the immediate bearing test. According to the value of the immediate bearing index (IBI), we can classify the stability of our mixture:

$\mathrm{IBI} \leq 25$, unstable mixture;

$25 \leq \mathrm{IBI} \leq 50$, medium stability;

$\mathrm{IBI} > 50$, stable mixture.

Figure 5. Slag sand mixture.

Table 2 recapitulates the formulations adopted while respecting the conditions of immediate stability.

Table 2.The Cu and Cc values of the different SS mixtures.

Formulation	GBFS (%)	CS (%)	DS (%)	Lime (%)	Cu	Cc
1	0	20	80	0	4.8	1.7
2	10	30	60	1	6	1.7
3	15	37	48	1	6.4	1
4	20	33	47	1	6	1.2
5	25	27	48	1	6	1.12
6	20	22	48	1	8.4	1.15

2.1.6. Compaction test

The compaction is widely used in many geotechnical applications for improving soil compactness [29]. The purpose of compaction is to increase the density of a soil. This consequently reduces its rate of deformation and improves its bearing capacity.

In this respect, the different mixtures that have been formulated by combination of dune sand with different percentages of GBFS were compacted to different water content in order to determine the optimal water content and the maximum dry density by the modified Proctor test according to standard NFP94-093 [30].

2.1.7. Californian Bearing Ratio (CBR) test and simple compression test

The CBR tests were carried out on samples of a mixture of slag sand, compacted in CBR molds, under Proctor conditions, according to standard NF P94-078 [31].The aim of this test is to assess the ability of a soil to support the traffic load. The test consists of punching slag sand mixtures compacted with energy of 56 blows per layer in a CBR mold and at water contents corresponding to the optimum of the Modified Proctor test. The test CBR is carried out in a CBR press (Fig. 6) without overload, to determine the immediate bearing indices (IBI) of the mixtures.

Figure 6. CBR press.

Cylindrical SS samples (Fig. 7) obtained by static compaction, where the mixture is put in a single layer in a cylindrical mold with 50 mm in diameter and 100 mm in height with double piston, then statically compacted at a speed of 1.14 mm/min, according to the standard EN 13286-53 [32]. This method of compaction leads to a homogeneous distribution of compaction stress [33]. The samples were then preserved in bags at a temperature of 20±2 °C until the date of the compression tests according to the standard NF EN 13286-41 [34]. These tests were performed at age of 0, 7, 14, 28, 60 and 90 days.

Figure 7. Cylindrical slag sand samples

The compression test is widely used in pavement and soil stabilization applications [2, 33]. This test is carried out, according to the standard EN 13286-41 [34], on cylindrical slag sand samples.

2.1.8. Unconsolidated undrained triaxial test

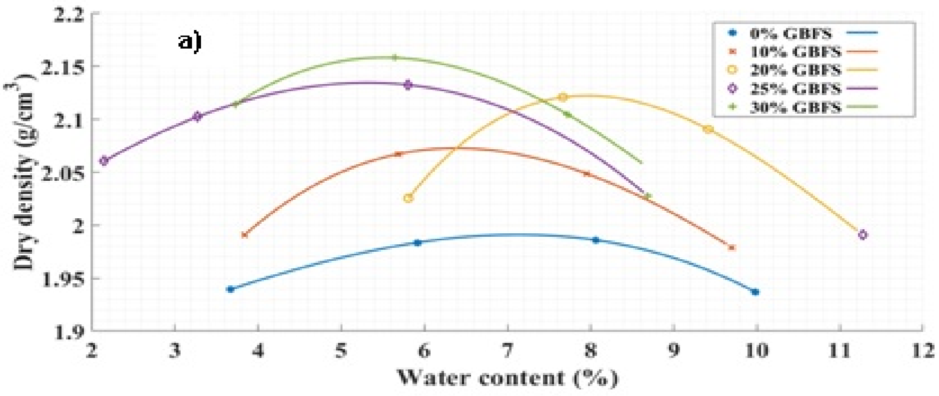
Triaxial shear tests were performed on non-treated sand (0 % GBFS) and slag- treated sand (SS) samples. Triaxial shear tests have been used in most of the experimental programs reported in the literature in order to access the influencing factors on the shear strength of treated soils, which simulated the general construction conditions of a lot of engineering projects [35]. All slag sand mixtures were statically compacted at the Proctor optimum prior their placement in triaxial apparatus (Fig. 8). The test is carried out with a fast speed of 1 mm/min corresponding to an unconsolidated undrained test (UU) according to the standard NF P94-074 [36].The measurement of the axial strain was conducted with a vertical displacement sensor located on the top of pressure cell. The axial deviatoric force was measured by axial load sensor. Three confining pressures σ_3 (100 kPa, 200 kPa, and 300 kPa) were applied.

Figure 8. The triaxial cell.

3. Results and Discussions

3.1. Determination of Proctor characteristics

The results obtained by the modified Proctor test are shown in Fig. 9a. The evolution of the optimum water content and the maximum dry density is shown in Fig. 9b.



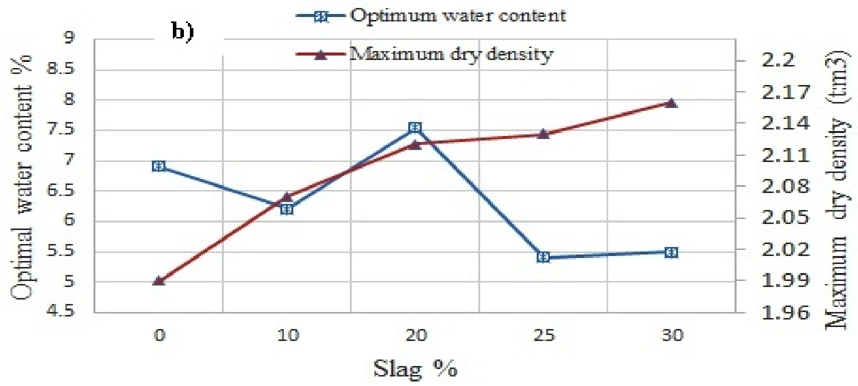


Figure 9. a) Modified Proctor curves according to the percentage of GBFS, b) maximum dry density and optimum water content according to the percentage of slag (GBFS).

From Fig. 9b the density increases while increasing the GBFS content contrary to the optimal water content which reaches it's maximum for 20 % slag and then decreases beyond this value. A similar result was observed by [1].

3.2. Determination of the immediate bearing index (IBI)

Fig. 10 shows the increase of the immediate bearing index (IBI) with increasing of the percentage of GBFS up to the value of 25 % then decreased. According to this result, we can say that our optimal mixture is obtained for 25 % of GBFS added with respect to the bearing capacity of this sand.

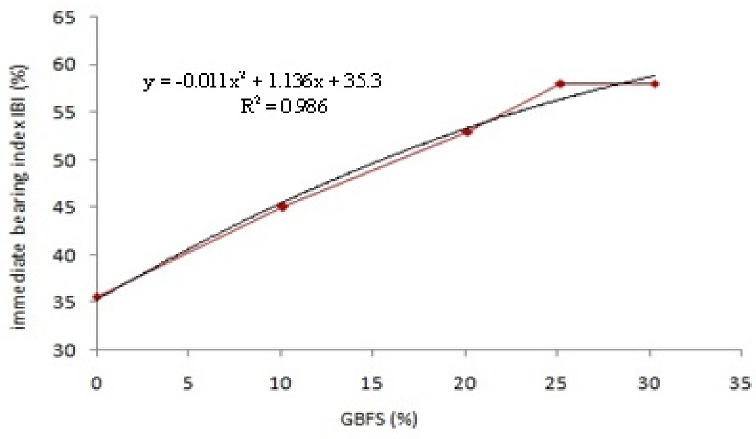


Figure 10. Immediate bearing index (IBI) according to GBFS content.

3.3. Effect of GBFS on the compressive strength of SS

Fig. 11 illustrates the evolution of the compressive strength as a function of the percentages of the binder (GBFS) for different curing times (0, 7, 28, 60 and 90 days).

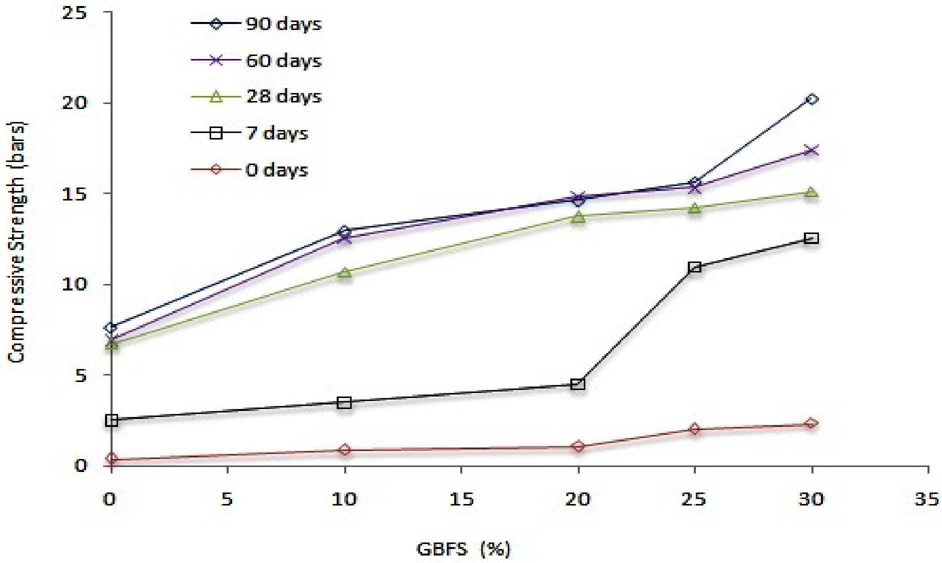


Figure 11. Compressive strength according to GBFS content and curing times.

According to Fig. 11 the compressive strength increases proportionally to the percentages of the added GBFS over time, without reaching a maximum. This result is similar to the result found by smaida and al [2] on the treatment of dune sand with hydraulic binders. These remarkable mechanical performances are due to the chemical role of the slag which consists in improving the microstructure of the SS mixture by fixing the Portlandite ($Ca(OH)_2$) released by the hydration of the slag. This hydraulic reaction gives rise to a second additional calcium silicate hydrate (CSH), the phase responsible for the hardening of slag sand over time.

3.4. The stress- strain behavior of SS

The deviatoric stress ($q = \sigma_1 - \sigma_3$) versus axial strain (ε_1) curves obtained from the triaxial shear tests on sand samples treated with 20 % GBFS are shown in Fig. 12. It was found that SS reveals a peaked stress-strain curves with a peak strength increased with the increase in confining pressure.

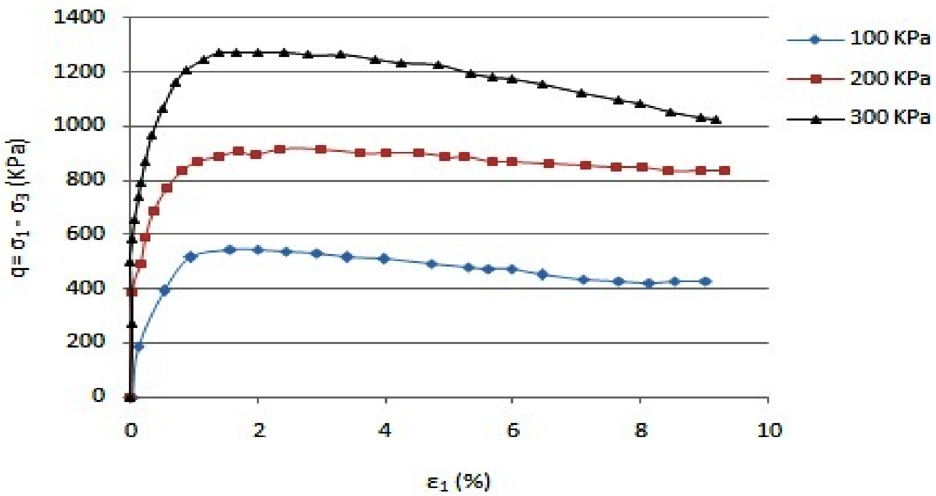


Figure 12. Deviatoric stress versus axial strain curves at 20 % GBFS.

The stress- strain behavior of slag sand can be described as initially rigid, linear up to a well-defined limit point, beyond which the sand undergoes increasingly plastic deformations until failure. The same behavior was observed in the result of Daheur [33].

Fig. 13 shows the maximum deviatoric principal stress (q_{max}) according to GBFS content with various confining pressures 100, 200 and 300 kpa.

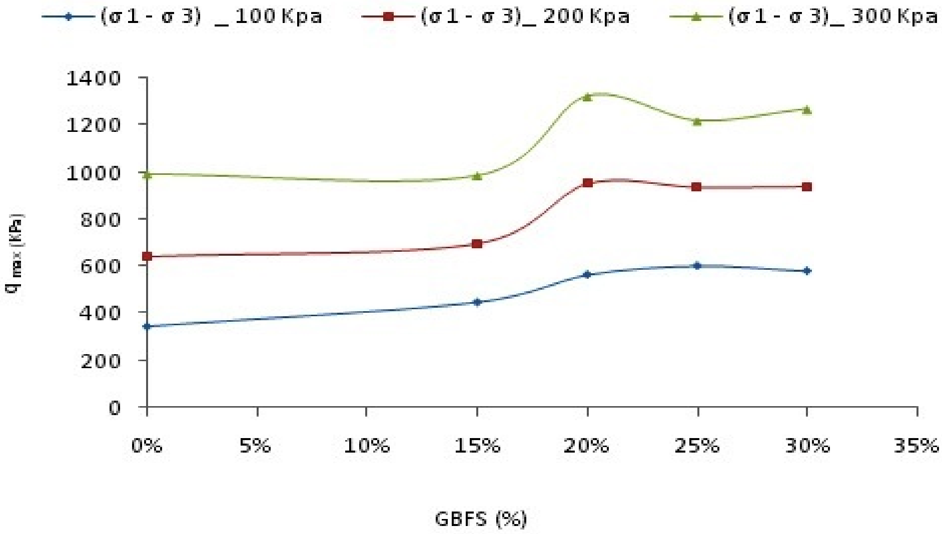


Figure 13. The maximum deviatoric principal stress according to GBFS content with various confining pressures 100, 200 and 300 kpa.

By inspecting the curves presented in Fig. 13, it can be noted that the maximum constraint deviator stress increases with the increase of the dosage in GBFS up to a value of 20 % then decreased.

3.5. Effect of GBFS on the friction angle and the cohesion of SS

Given the cohesive-frictional nature of soils treated with hydraulic binders, the shear strength can be expressed as a function of the internal friction angle and of the cohesion. Table 3 gives the friction angle and the cohesion as a function of the GBFS content. According to this result, the friction angle oscillates between 35.7° and 41.4°. Given the value of the friction angle 38.9° for untreated sand (0 % GBFS) and the value of 38.8° for sand treated with 30 %, we can say that the friction angle is not strongly influenced by the GBFS content. On the other hand the cohesion increases with the increase in percentage of GBFS and reaches a maximum value of 73.5 kpa for 25 % slag added.

Table 3. The cohesion and friction angle values as a function of GBFS.

GBFS (%)	friction angle (°)	Cohesion (kpa)
0	38.9	0
15	35.7	39.9
20	41.4	42.8
25	37.5	73.5
30	38.8	61.4

3.6. Use of slag sand in the foundation layer of a semi-rigid pavement

According to the comparative sizing study carried out on two types of pavement structure, the first with an untreated sand foundation layer and the second with slag sand, we see that by using the slag sand in the foundation layer (Fig. 14), we obtained a gain of 2 cm in thickness at the level of the gravel bitumen base layer. This gain confirms the economic role of our material.

Figure 14. Pavement structure made up of slag sand foundation layer.

4. Conclusion

This article presents a feasibility study on the manufacture of a composite material based on dune sand (DS) treated with granulated blast furnace slag (GBFS). It aims to characterize and to study the mechanical properties of slag sand (SS) mixture prepared in the laboratory. The following conclusions can be drawn from this study:

1. The results of our study allow to conclude that dune sand, which is a local material of low mechanical performance can be improved with treatment with the recycled granulated slag to obtain high resistances while increasing the percentage of slag.

2. Dune sand treatment with GGBF increases the density, bearing capacity, compression strength and shear strength of the slag sand mixture which is suitable for road pavements;the percentages of added GBFS play the role of a hydraulic binder which results in good compactness in the mixtures and subsequently improves mechanical characteristics.

3. With the increase in the percentage of GBFS, the maximum dry density increases. This result is considered to be an indication of the improvement in the compaction characteristics of the sand stabilized with activated slag.

4. The bearing capacity of the sand treated with GBFS is always better than those of untreated sand (0 % of GBFS) and the maximum value of IBI is obtained for 25 % of GBFS which is 58.34 %.

5. The compressive strength of the slag sand mixture increases with increasing GBFS content over time without reaching the maximum; the value of the compressive strength increases from 10.94 bars at 7 days to 15.65 bars at 180 days and it increases from 7.66 bars for untreated sand (0 % of GBFS) to 20.56 bars for 30 % of GBFS at 180 days of cure. Theseresults indicate that sand mixed with GGBS has the potential to be used in road construction, such as in highway and road foundation layer materials.

6. These remarkable mechanical performances are due to the chemical role of the slag which consists in improving the microstructure of the SS mixture by fixing the Portlandite ($Ca(OH)_2$) released by the hydration of the slag. This hydraulic reaction gives rise to a second additional calcium silicate hydrate (CSH), the phase responsible for the hardening of slag sand.

7. According to the triaxial shear test, our material has an elastoplastic behavior with a maximum deviatoric principal stress for 20 % of slag.

8. The friction angle is not strongly influenced by the GBFS content. On the other hand the cohesion increases with the increase in percentage of GBFS and reaches a maximum value of 73.5 kpa for 25 % slag added.

9. Based on the results mentioned above, GBFS activated with hydraulic lime may be the recommended additive for stabilizing the dune sands intended for use in roadways. A percentage of 20 % and 25 % of activated slag are recommended to improve the mechanical properties of dune sand.

10. Finally, two optimal mixtures were determined to improve the characteristics of dune sand in order to adopt it for use in pavement foundations. These mixtures are: (20 % GBFS +1 % lime +33 % CS+47 % DS) and (25 % GBFS +1 % lime +27 % CS+48 % DS). Given the low cost of GBFS which is approximately 3 $ per ton and DS which is in abundance, these mixtures have a double advantage of better performance and lower cost.

5. Acknowledgments

The authors gratefully acknowledge the support of the laboratory CTTP (Technical Inspection of Public Works) which allows us to carry out triaxial tests. They acknowledge the research team of the LEEGO and LBE laboratory of USTHB University for their support to this study as a PhD thesis. Without forgetting the steel complex of El Hadjar (Annaba, Algeria) which provides us with a quantity of granulated slag for our study.

References

1. Zemouli, S., Chelghoum, N. Use of ground granulated blast furnace slag in soils stabilization. Rev. Sci. Technol. 2018. Synthèse. Vol. 36. Pp. 103–114.
2. Smaida, A., Haddadi, S., Nechnech, A. Improvement of the mechanical performance of dune sand for using in flexible pavements. Constr Build Mater. 2019. 208. Pp. 464–471. https://doi.org/10.1016/j.conbuildmat.2019.03.041
3. Tarun Yadav, Jatin Singh, Sandeep Panchal, Md. Mohsin Khan, Shilpa Pal. Analysis of Effect of Ground Granulated Blast Furnace Slag (GGBFS) on the Mechanical Properties of Concrete using Destructive and Non-destructive Tests. J. Mech. cont. & Math. Sci.2019. Vol. 14. No. 1. Pp. 78–90. https://doi.org/10.26782/jmcms.2019.02.00006
4. Ashish, K.P., Pandey, V., Krishna, M., Singh, J.P. Soil Stabilisation Using Ground Granulated Blast Furnace Slag. Int. Journal of Engineering Research and Applications. 2014. Vol. 4. No. 5(Version 2), Pp.164–171.

5. Sharma, A.K., Sivapullaiah, P.V. Ground granulated blast furnace slag amended fly ash as an expansive soil stabilizer. Soils and Foundations. 2016. 56(2). Pp. 205–212. https://doi:10.1016/j.sandf.2016.02.004
6. Jiapei, D., Yuhuan, B., Shenglai, G., Leiju, T., Zhonghou, S. Effects of epoxy resin on ground-granulated blast furnace slag stabilized marine sediments. RSC Adv. 2017. 7. 36460. DOI: 10.1039/c7ra06460h
7. Mohd, A.R., Farhat, H., Lohani, T.K. An experiment on stabilization of soil by using waste product like fly ash, GGBS and CCR. International Journal for Technological Research in Engineering. 2019. Vol. 6.No. 7.
8. Cherfa, H. Stabilisation des sols et des couches de chaussée par des résidus industriels – application au laitier de haut fourneau.Thèse de Magister. Université des Sciences et de technologie Houari Boumediene. Alger, 2010.145 p.
9. Piratheepan, J., Gnanendran, C.T., Lo, S.C.R. Characterization Of Cementitiously Stabilized Granular Materials for Pavement Design Using Unconfined Compression and Idt Testings with Internal Displacement Measurements. Journal of Materials in Civil Engineering. 2010. 22(5). Pp. 495–505. DOI: 10.1061/(ASCE)MT.1943-5533.0000051
10. Du, J., Bu, Y., Guo, S., Tian, L., Shen, Z. Effects of epoxy resin on ground-granulated blast furnace slag stabilized marine sediments. RSC Adv., 2017, 7, 36460–36472. DOI: 10.1039/C7RA06460H
11. Divet, L., Le Roy, R. Étude de la durabilité vis-à-vis de la corrosion des armatures des bétons formulés avec des ciments à forte teneur en laitier de haut fourneau. Bulletin des Laboratoires des Ponts et Chaussées, 2013, pp. 63–84. ⟨hal-00985729⟩
12. Damtoft and al. cited by Adewumi, A.A., Ismail, M., Ariffin, M.A.M., Yusuf, M.O., Maslehuddin, M., Mohamed, H.D. Strength and microstructure of alkali-activated natural pozzolan and limestone powder mortar. 2019. Magazine of Civil Engineering. 92(8). Pp. 36–47. DOI: 10.18720/MCE.92.3
13. Bhavik kumar B. Patel, Jayesh kumar Pitroda,A Review of Geo Polymer Concrete by Using Various Industrial Waste Materials. International Journal of Constructive Research in Civil Engineering (IJCRCE). 2017. Volume 3, Issue 4. Pp.121–131. DOI: http://dx.doi.org/10.20431/2454-8693.0304011
14. Yusuf, M.O.,Johari, M.A.M., Ahmad, Z.A., Maslehuddin, M. Evolution of alkaline activated ground blast furnace slag–ultrafine palm oil fuel ash based concrete. Materials & Design, 2014. 55, Pp. 387–393. http://dx.doi.org/10.1016/j.matdes.2013.09.047
15. Ashish, D.K., Singh, B., Verma, S.K. The effect of attack of chloride and sulphate on ground granulated blast furnace slag concrete. Advances in Concrete Construction. 2016. Vol. 4, No. 2. Pp. 107–121 http://dx.doi.org/10.12989/acc.2016.4.2.107
16. Dave, N., Misra, A.K., Srivastava, A., Sharma,A.K., Kaushik, S.K. Study on quaternary concrete micro-structure, strength, durability Considering the influence of multi-factors. Construction and Building Materials. 2017. 139. Pp. 447–457. http://dx.doi.org/10.1016/j.conbuildmat.2017.02.06
17. Makhloufi, Z., Bouziani, T., Hadjoudja, M., Bederina, M. Durability of limestone mortars based on quaternary binders subjected to sulfuric acid using drying immersion cycles. Const. Build. Mater. 2014. Pp. 579–588. http://dx.doi.org/10.1016/j.conbuild-mat.07.05017
18. Osborne, G.J. Durability of Portland blast-furnace slag cement concrete. Cem Concr Compos. 1999. 21, Pp.11–21. (98) 00032-8Osborne GJ. https://doi.org/10.1016/S0958-9465
19. Yeau, K., Kim, E. An experimental study on Corrosion resistance of concrete with ground granulated blast-furnace slag. Cement Concrete Res.2005. 35. Pp. 1391–1399. https://doi.org/10.1016/j.cemconres.11.010
20. Lurkowski, P., Salih, A. Durability of mortars containing ground granulated blast-furnace slag in acid and sulphate environment. Procedia Engineering. 2015. 108. Pp. 47–54.
21. Catalogue Algérien de dimensionnement des chaussées neuves – Fascicule 1», Ministère des travaux publiques-direction des routes, Novembre (2001).
22. Neto, A.A.M., Cincotto, M.A., Repette, W. Mechanical properties, drying and autogenous shrinkage of blast furnace slag activated with hydrated lime and gypsum.Cement & Concrete Composites. 2010. 32. Pp.312–318. https://doi.org/10.1016/j.cemconcomp.2010.01.004
23. Cao, R., Li, B., You, N., Zhang, Y., Zhang, Z. Properties of alkali-activated ground granulated blast furnace slag blended with ferronickel slag. Construction and Building Materials. 2018. 192. Pp. 123–132. https://doi.org/10.1016/j.conbuildmat.2018.10.112
24. Nguyen, H.-A., Chang, T.-P., Lee, P.-H., Shih, J.-Y. Experimental Investigation of Bond-Slip Performance of Reinforcement in Two Green Concretes. 2020. Journal of Materials in Civil Engineering. 32(3). 04020014.DOI: 10.1061/(asce)mt.19435533.0003029.
25. Nguyen, H.A., Chang, T.P., Chen, C.T., Yang, T.R., Nguyen, T.D. Physical-chemical characteristics of an eco-friendly binder using ternary mixture of industrial wastes. Materiales de Construcción. 2015. Vol. 65. No. 319. http://dx.doi.org/10.3989/mc.2015.07414
26. SETRA-LCPC. GTR. Technical guide for the realization of embankments and layers of form. SETRA-LCPC Editions, Papers I & II. 2000. 98 p. and 102 p.
27. Venkatarama, R.B.V., Ajay, G. Influence of sand grading on the characteristics of mortars and soil–cement block masonry. Constr. Build. Mater. 2008. 22 1614–1623. https://doi.org/10.1016/j.conbuildmat.2007.06.014
28. Haach, V.G., Vasconcelos, G., Lourenço, P.B. Influence of aggregates grading and water/cement ratio in workability and hardened properties of mortars.Constr. Build. Mater. 2011. Vol. 25. Pp.2980–2987. https://doi.org/10.1016/j.conbuild-mat.2010.11.011
29. Ören, A.H. Estimating compaction parameters of clayey soils from sediment volume test.Applied Clay Science. 2014. 101. Pp. 68–72. https://doi.org/10.1016/j.clay.2014.07.019
30. AFNOR NF P94-093: Soils: recognition and tests – Determination of the compaction references of a material – Normal Proctor test – Modified Proctor test. October 2014.
31. AFNOR, NF P94-078. Sols: reconnaissance et essais – Indice CBR après Immersion-Indice CBR immédiat-Indice Portant immediate. (1997).
32. AFNOR NF EN 13286-53. Mélanges traités et mélanges non traités aux liants hydrauliques – Partie 53: méthode de confection par compression axiale des éprouvettes de matériaux traités aux liants hydrauliques. 2005.
33. Daheur, E.G., Goual, I., Taibi, S., Mitiche-Kettab, R. Effect of Dune Sand Incorporation on the Physical and Mechanical Behaviour of Tuff: (Experimental Investigation). Geotech Geol Eng. 2019. 37. Pp.1687–1701 https://doi.org/10.1007/s10706-018-0715-4
34. AFNOR, NF EN 13286-41. Mélanges traités et mélanges non traités aux liants hydrauliques – Partie 41: méthode d’essai pour la détermination de la résistance à la compression des mélanges traités aux liants hydrauliques. 2003.

35. Gueddouda, M.K., Lamara, M., Abou-bekr, N., Taibi, S. Hydraulic behaviour of dune sand bentonite mixtures under confining stress.Geomechanics and Engineering. 2010. 2(3). Pp. 213–227.

36. AFNOR NF P94-074 Sols: Reconnaissance et essais – Essais à l'appareil triaxial de révolution – Essai (UU) non consolidé non drainé – Essai (CU +u) consolidé non drainé avec mesure de pression interstitielle – Essai (CD) consolidé drainé. 1994.

Contacts:

Hayet Cherfa, ha_cherfa@yahoo.fr
Ammar Nechnech, nechnech_a@yahoo.fr
Nacira Saoudi, saoudinacira@qmail.com
Khedidja Ait Mokhtar, k.aitmokhtar@laposte.net