ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/342941174

Resilient modulus and deviatoric stress of cemented soils treated with crushed waste ceramics (CWC) for pavement subgrade construction

Article · June 2020

DOI: 10.14382/epitoanyag-jsbcm.2020.14

CITATIONS
0

READS
32

11 authors, including:

Kennedy Onyelowe
Makerere University
115 PUBLICATIONS **704** CITATIONS
SEE PROFILE

Duc Bui Van
Hanoi University of Mining and Geology
41 PUBLICATIONS **203** CITATIONS
SEE PROFILE

Chidozie Ikpa
Federal University Ndufu Alike Ikwo
12 PUBLICATIONS **28** CITATIONS
SEE PROFILE

Adrian. Oshioname Eberemu
Ahmadu Bello University
113 PUBLICATIONS **832** CITATIONS
SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project Renewable Energy Application Successes in Geotechnics View project

Project Influence of Geological Formation on Subsurface Exploration and Geotechnics of Lateritic Soils View project

All content following this page was uploaded by Kennedy Onyelowe on 24 July 2020.

The user has requested enhancement of the downloaded file.

creative commons Attribution BY NC

Resilient modulus and deviatoric stress of cemented soils treated with crushed waste ceramics (CWC) for pavement subgrade construction

Útalapozás készítéséhez alkalmazott zúzott hulladékkerámiával (CWC) kezelt cementált talajok rugalmassági mudulusa és deviátoros feszültsége

Kennedy Chibuzor ONYELOWE ▪ Department of Civil Engineering, Michael Okpara University of Agriculture, Nigeria ▪ konyelowe@mouau.edu.ng

Duc BUI VAN ▪ Faculty of Civil Engineering and Member, Research Group of Geotechnical Engineering, Construction Materials and Sustainability, Hanoi University of Mining and Geology, Vietnam

Chidozie IKPA, Department of Civil Engineering, Faculty of Engineering, Alex Ekwueme Federal University, Nigeria

Kolawole OSINUBI ▪ Faculty of Engineering, Ahmadu Bello University, Nigeria

Adrian EBEREMU ▪ Faculty of Engineering, Ahmadu Bello University, Nigeria

A. Bunyamin SALAHUDEEN ▪ Department of Civil Engineering, Faculty of Engineering, University of Jos, Nigeria

Oscar C. NNADI ▪ Department of Civil Engineering, College of Engineering & Engineering Technology, Michael Okpara University of Agriculture, Nigeria

Moses C. CHIMA ▪ Department of Civil Engineering, College of Engineering & Engineering Technology, Michael Okpara University of Agriculture, Nigeria

Jesuborn OBIMBA-WOGU ▪ Department of Civil Engineering, College of Engineering & Engineering Technology, Michael Okpara University of Agriculture, Nigeria

Kizito IBE ▪ Department of Civil Engineering, College of Engineering & Engineering Technology, Michael Okpara University of Agriculture, Nigeria

Benjamin UGORJI ▪ Department of Civil Engineering, College of Engineering & Engineering Technology, Michael Okpara University of Agriculture, Nigeria

Érkezett: 2019. 12. 12. ▪ Received: 12. 12. 2019. ▪ https://doi.org/10.14382/epitoanyag-jsbcm.2020.14

Abstract

The behavior of resilient modulus of cemented lateritic soils treated with crushed waste ceramics and utilized as pavement underlain has been investigated under laboratory conditions. This is the measure of the rigidity of soils used as foundation materials. The rampant failures of pavements due to undesirable characteristics exhibited by the foundations has spurred this research work to enable a better understanding of the behavior of soils used as foundation materials and how best they can be handled or treated to ensure stability and durability of the structures. The soils were first characterized and found to belong to A-2-7, A-2-6, A-7 and A-7-5 group of soils according to the AASHTO classification method. Also, they were found, from basic experiments, to be highly plastic soils with high clay contents. The soils were treated with crushed waste ceramics in the proportion of 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, 110% and 120% by weight of solid with a constant addition of 2.5% by weight ordinary cement. The results of the examination showed that the resilient modulus increased substantially with increased rate of crushed waste ceramics. This showed that crushed ceramic waste is a good pozzolanic material for soils stabilization in the construction of pavement foundations.

Keywords: resilient modulus, deviatoric stress, cemented soils, crushed waste ceramics, solid wastes, geomaterials, pavement foundation

Kulcsszavak: rugalmassági modulus, deviátoros feszültség, cementált talajok, zúzott hulladékkerámiák, szilárd hulladék, geoanyagok, útburkolat alapozás

Kennedy Chibuzor ONYELOWE
is a senior lecturer and researcher at the department of civil engineering, Michael Okpara University of Agriculture, Umudike, Nigeria, an adjunct senior lecturer at the department of civil engineering, Alex Ekwueme Federal University, Ndufu Alike Ikwo, Abakaliki, Nigeria.

Duc BUI VAN
is a lecturer at the Hanoi University of Mining and Geology, Hanoi, Vietnam and member of the research group of Geotechnical engineering, Construction Materials and sustainability, HUMG, Vietnam.

Chidozie IKPA
is currently a technologist in the department of civil engineering laboratory of the Alex Ekwueme University, Ndufu Alike Ikwo, Nigeria.

Kolawole J. OSINUBI
is an astute professor of geoenvironmental engineering at the Ahmadu Bello University, Zaria, Nigeria.

Adrian O. EBEREMU
is an Associate Professor at the Ahmadu Bello University, Zaria, Nigeria with research experience in geotechnical and geoenvironmental engineering.

A. Bunyamin SALAHUDEEN
is senior lecturer and researcher at the University of Jos, Nigeria.

Oscar C. NNADI
is a graduate of civil engineering from the Michael Okpara University of Agriculture, Umudike, Nigeria with research interest in soil stabilization and construction materials.

Moses C. CHIMA
is a graduate of civil engineering from the Michael Okpara University of Agriculture, Umudike, Nigeria with research interest in soil stabilization and construction materials.

Jesuborn OBIMBA-WOGU
is a graduate assistant at the department of civil engineering, Michael Okpara University of Agriculture, Umudike, Nigeria with research interest in geotechnical engineering.

Kizito IBE
is a graduate assistant at the Michael Okpara University of Agriculture, Umudike, Nigeria with interests in structural engineering.

Benjamin UGORJI
is a graduate assistant at the Michael Okpara University of Agriculture, Umudike, Nigeria with interests in geotechnical engineering.

1. Introduction

The unbounded aggregate layer and unsaturated state upon which pavement foundations are constructed play an important role in the performance of pavements more especially with the hydraulically bound conditions where rise and fall of moisture due to suction plays another role [1, 2, 3, 4, 5]. It is wrong to assume that pavement layers are under steady saturated conditions and this assumption affects the design and eventually the stiffness and stability of the pavement foundations [6, 7]. According to Ba *et al.* [8] it is noted that moisture migration and percolation into the pavement layers either through suction and surface water seepage affects the resilient modulus and stability of subgrade materials, which commonly are constructed with compacted lateritic soils. It has been proven through research that moisture affects the carrying capacity and strength of clayey soils due to the loss of strength on immersion [7, 9]. The behavior of soils under suction is directly corresponding with the resilient modulus of such soils especially when subjected to the effect of moisture [10, 11]. This behavior brings about the failure of pavements when they are underlain with unsuitable and expansive soils, which behave in undesirable pattern under the influence of matric suction [2, 12]. Due to the fluctuations in the water conditions of the subgrade, the pavement foundations are designed for the most critical exposure conditions [13, 14, 15]. Soils stabilization has been adopted to improve on the inadequate properties of the soils utilized as subgrade materials [2-5, 10]. This is achieved through the use of chemical compounds like the ordinary Portland cement or biobased or lignocellulose materials, which are environmentally friendly geomaterials [10, 16, 17, 18]. The biobased or lignocellulose materials are derived through controlled direct combustion to have ash or through crushing to achieve powder with good gradation. In this work, crushed waste ceramics is derived by crushing waste ceramic materials collected from dumpsites. This material is used as a geomaterial in the stabilization of soils for use as subgrade materials because of its pozzolanic properties [18]. Due to the high content of aluminosilicates in the CWC, its blend with soft lateritic soils produce compacted stabilized subgrade soils with high rigidity, density and stability. This behavior gives rise to the improvement of the resilient modulus of the treated material at optimum molding moisture conditions [1]. The objectives of this work were to evaluate the effect of crushed ceramics wastes on the deviatoric stress and resilient modulus of the treated soils.

2. Materials

2.1 Soils

Four borrow pits in four different locations in Abia State, Nigeria were the source of the soil samples. These borrow pits are located on coordinates 5°29'16" North and 7°28'58" East (for Olokoro location soil), 5°27'0" North and 7°31'60" East (for Amaba location soil), 5°31'0" North and 7°26'0" East (for Ohiya location soil) and 4°53'14" North and 7°21'26" (for Akwete location soil). The samples were sundried for 7 days, 500 grams each was measured and prepared for use.

2.2 Crushed waste ceramics

The ceramics were collected from dumpsites within Umuahia urban area, sundried for two days and crushed by ball milling. The crushed ceramic waste was characterized and sieved to determine its gradation and particle distribution. Afterwards, it was stored for use in the stabilization exercise.

2.3 Ordinary Portland cement

Portland cement was used at a steady rate of 2.5%, that meets the requirements of ASTM C618 [18], as a binder as shown in the chemical oxide composition presented in *Table 2*. The preliminary characterization exercises were conducted on the test materials to determine their gradation and chemical oxide composition (aluminosilicates content). These test admixtures were utilized in the percentages of 10% to 120% in an incremental rate of 10% to treat the soils.

3. Methods

The particle size distribution, compaction, Atterberg limits, shrinkage limits, free swell index, and specific gravity were generally conducted on the test soils in accordance with BS 1377 [19]. This was carried out to determine the characterization and basic properties of the test soils. Similarly, chemical oxide composition and particle size distribution tests were conducted to determine the aluminosilicate content and gradation respectively in accordance with ASTM C618 [18] and BS 1377 [19] respectively. Of particular interest to this work was the stiffness of the treated soils as subgrade or pavement materials, which was determined with the resilient modulus test carried out on the CWC treated soils in accordance with AASHTO [10] , AASHTO T 22-03 [1], and BS 1924 [20]. Specifically, the resilient modulus of both the control specimen and treated test soils was determined under the laboratory conditions. This represented the simulated physical and stress conditions of geomaterials treated soils A, B, C and D overlain by flexible pavements subjected to dynamic traffic loads. A cyclic axial stress of fixed magnitude under deviatoric stress, load duration of 0.1s, and cyclic duration of 3s is applied to prepared cylindrical test specimens in a modified triaxial compression set up. The final recoverable axial deformation response (recoverable strain) and the deviatoric stress of the test specimens were measure and the resilient moduli at different proportions of the additives were determined with Eq. 1.

$$M_R = \frac{\rho_d}{\varepsilon_r} \tag{1}$$

where:

M_R = resilient modulus, ρ_d = deviatoric stress, ε_r = strain

4. Results and analytical remarks

4.1 Classification Characteristics of Test Materials

The basic properties of the test soils are presented in *Table 1*, *Fig. 1* and *Table 2*. The test soil were observed to possess 2.85%, 10%, 4.6% and 7.6% passing sieve No. 200, and classified as A-2-7, A-2-6, A-7 and A-7-5 respectively according to AASHTO classification method. Test soils A, B, C and D were classified as poorly graded according to unified soil classification system. The results of the consistency protocol show that the test soils are highly plastic soils (> 17%) with high free swell index. The basic results of the resilient modulus show that the soils fall under clayey subgrade (0.345E+05 to 1.034E+05 kN/m^2) [16]. The chemical oxides composition test results presented in *Table 2* show that the test materials possess high aluminosilicates responsible for the pozzolanic, calcination and hydration reactions that take place in a stabilization process.

Property description of test soils and units	Values			
	Test soil (A)	Test soil (B)	Test soil (C)	Test soil (D)
% Passing Sieve, No 200	2.85	10	4.6	7.6
NMC (%)	12.1	13.49	14	16
LL (%)	40	46	64	65
PL (%)	18	21	36	33
PI (%)	22	25	28	32
SL (%)	8	8	7	10
FSI (%)	250	234	275	296
G_s	2.6	2.43	2.12	2.08
AASHTO Classification	A-2-7	A-2-6	A-7	A-7-5
USCS	GP, CH	GP	GP, CH	GP, CH
MDD (g/cm3)	1.76	1.85	1.80	1.56
OMC (%)	13.1	16.2	13.13	15.4
CBR (%)	12	13	8	7
R-Value	11.74	11.70	11.70	11.50
MR (kN/m2)	0.42E+05	0.42E+05	0.42E+05	0.72E+05
Color	Reddish Brown	Reddish Gray	Reddish Ash	Ash

Table 1 Basic properties of test soils
1. táblázat A vizsgált talajok alapvető tulajdonságai

Materials	Oxides Composition (content wt %)												
	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	K_2O	Na_2O	TiO_2	LOI	P_2O_5	SO_3	IR	Free CaO
Soil A	76.56	15.09	2.30	2.66	0.89	2.10	0.33	0.07	-	-	-	-	-
Soil B	77.57	14.99	3.11	1.78	0.86	1.45	0.23	0.01	-	-	-	-	-
Soil C	77.73	16.65	1.42	3.22	0.07	0.89	0.02	-	-	-	-	-	-
Soil D	72.34	17.30	5.40	2.32	0.34	2.13	0.17	-	-	-	-	-	-
CWC	64.45	24.14	0.25	1.3	0.28	3.69	2.51	0.18	1.09	-	2.11	-	-
DOPC	21.45	4.45	63.81	3.07	2.42	0.83	0.20	0.22	0.81	0.11	2.46	0.16	0.64

**IR is Insoluble Residue, LOI is Loss on Ignition, CWC: Crushed Waste Ceramics*
DOPC: Dangote Ordinary Portland cement

Table 2 Chemical oxides composition of the materials used in this paper
2. táblázat A felhasznált anyagok kémiai oxidos összetétele

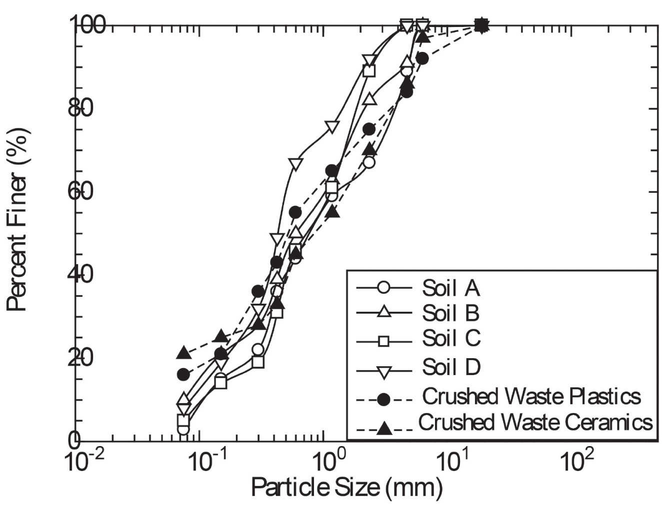

Fig. 1 Grain size distribution of studied materials
1. ábra A vizsgált anyagok szemcseméret eloszlása

4.2 Deviatoric stress and resilient modulus (M_R) of the treated cemented soils

The results of the resilient modulus of the CWC treated soils used to characterize the treated matrix as a subgrade material is presented in *Figs. 2* and *3*. The applied deviator stress and the recoverable strain of the modified triaxial test on the treated specimens were used. The four test soils behaved in almost the same pattern with similar reactions with increased crushed waste ceramics (CWC). The deviatoric stress consistently increased with increase in the proportion of the admixture for test soils A, B, C and D. It is important to note at this point that the additive CWC is a highly aluminosilicate compound according to the requirements of American Standard for Testing and Materials [18], with a crystal texture prior to its utilization in the stabilization procedure. These compounds are responsible for pozzolanic reaction, and strengthening by forming silicates of calcium hydrates and aluminates. These further forms floc, which condense to the strength buildup of the treated materials. Test soils A, B and C had an improvement index of about 21%, while test soil D had an improvement index of 25%. The higher improvement index recorded with test soil D is in line with its natural soil high resilient modulus of 0.72E+05, which was improved upon. The hydration reaction between compounds of strengthening from the additive and the dissociated soil ions

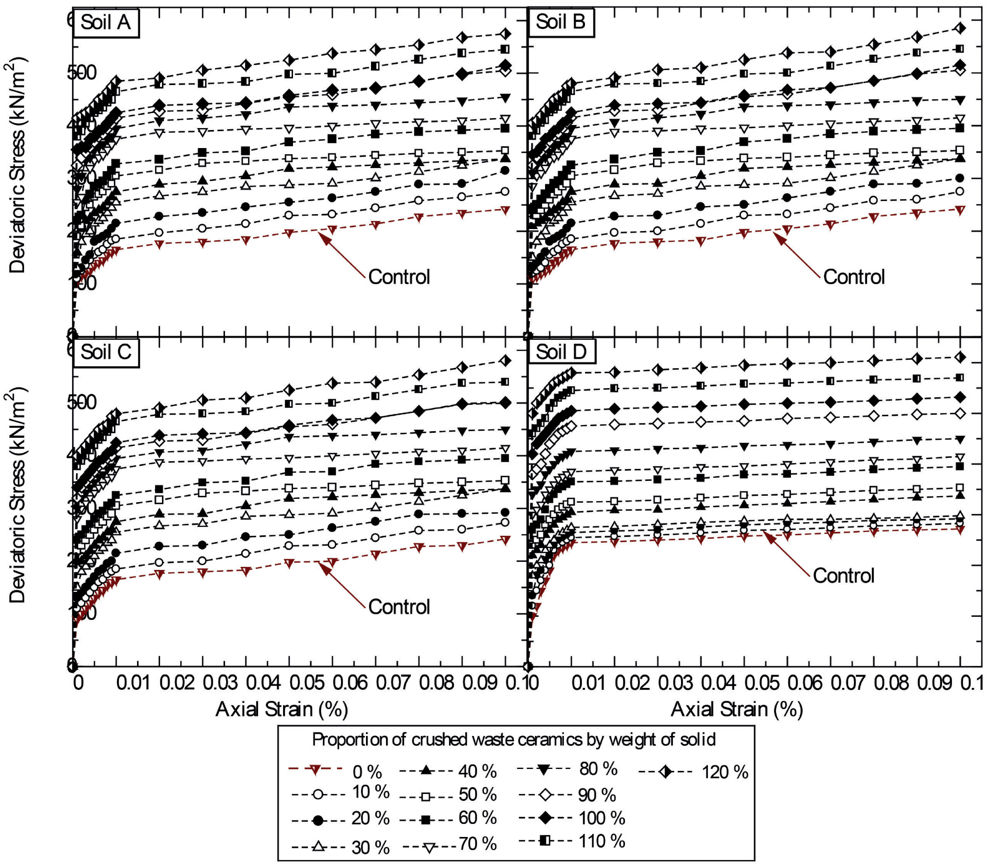

Fig. 2 Effects of CWC on deviatoric stress of the treated cemented soils
2. ábra CWC hatása a cementált talajok deviátoros feszültségére

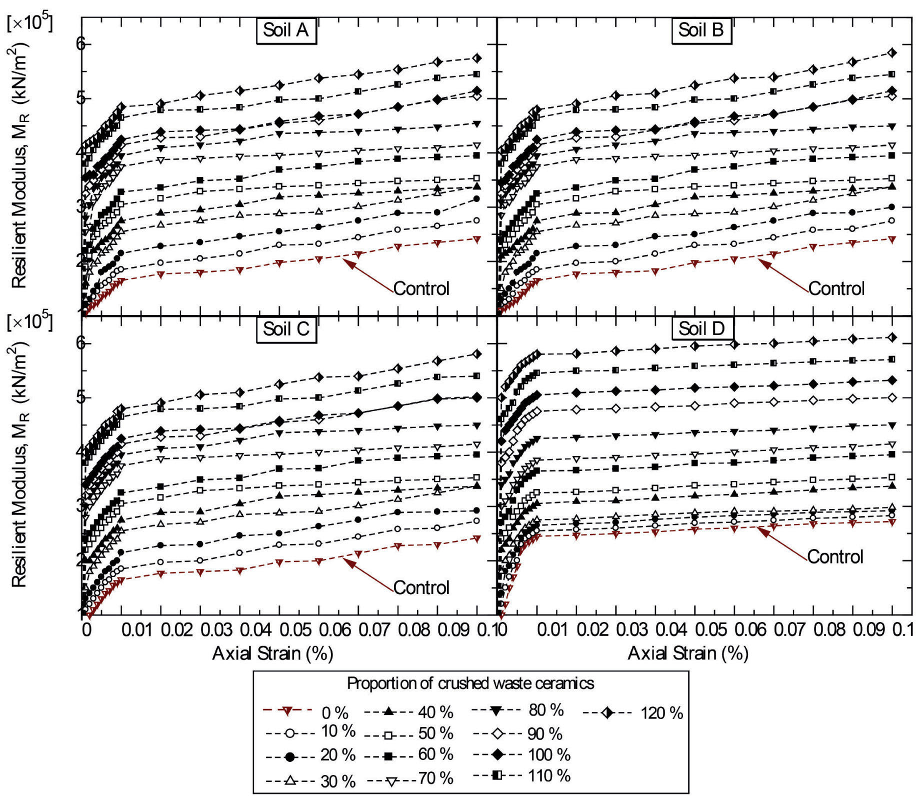

Fig. 3 Effects of CWC on resilient modulus, M_R, of the treated cemented soils
3. ábra CWC hatása a cementált talajok rugalmassági modulusára (M_R)

in contact with moisture caused the improvement on both deviatoric stress and resilient modulus of the treated soils. In addition, the cation exchange reaction between the dipole ions of the additive when in contact with molding moisture and those of soils caused the improved properties of the test soils [21, 22]. These results were recorded under cyclic loading on specimens subjected to testing sequences. The physical conditions that affect the resilient modulus (moisture and unit weight) were influenced by the introduction of the highly aluminosilicate CWC hence improving the strength behavior of the treated soils.

5. Conclusions

The experimental results of the treatment of soils with crushed waste ceramics have been observed and tabulated. The following remarks can be made; (i) the crushed waste ceramics was characterized and sampled as a silicate-based geomaterial with similarly particle gradation with the test soils and results show that the prepared materials contains binding properties that make it useful as a supplementary cementitious material. (ii) the soils were also tested for their basic properties which showed that they belong to A-2-7, A-2-6, A-7 and A-7-5 groups according to the American Association of State Highway and Transportation Officials classification method. Further characterization exercise on the soils shows that the soils are highly plastic soils, which implies that they are problematic and need modification to meet the requirements for use as construction materials. (iii) the soils were treated with the crushed waste ceramics at the rate of 10% to 120% by weight of solid in a steady increment of 10% by mixing and compacting to maximum dry density at an optimum moisture. (iv) the resilient modulus of the soils was tested and results show that it improved consistently and substantially with increased rate of crushed waste ceramics. (v) the crushed waste ceramics showed that it can be utilized as a supplementary cementing construction material with its high content of aluminosilicates to improve the properties of soils used as pavement subgrade materials.

Acknowledgement

Vietnam Ministry of Education and Training for funding this research, based on Decision No. 5652/QD-BGDDT on December 28, 2018 with Grant No. MOET /2019 and with project number B2019-MDA-08.

References

[1] American Administration of State Highway and Transportation Officials (2014). Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens: AASHTO T 22–03, Washington DC.

[2] Onyelowe, K. C. – Bui Van, D. (2018a): Durability of nanostructured biomasses ash (NBA) stabilized expansive soils for pavement foundation, International Journal of Geotechnical Engineering. https://doi.org/10.1080/19386362.2017.1422909

[3] Onyelowe, K. C. – Bui Van, D. (2018b): Predicting Subgrade Stiffness of Nanostructured Palm Bunch Ash Stabilized Lateritic Soil for Transport Geotechnics Purposes. Journal of GeoEngineering of Taiwan Geotechnical Society, 2018 (in press). http://140.118.105.174/jge/index.php

[4] Onyelowe, K. C. – Bui Van, D. (2018c): Structural analysis of consolidation settlement behaviour of soil treated with alternative cementing materials for foundation purposes. Environmental Technology & Innovation, Vol. 11, pp. 125-141. https://doi.org/10.1016/j.eti.2018.05.005

[5] Onyelowe, K. C. – Bui Van, D. (2018d): Predicting Strength Behavior of Stabilized Lateritic Soil- Ash Matrix using Regression Model for Hydraulically Bound Materials Purposes, International Journal of Pavement Research and Technology. https://doi.org/10.1016/j.ijprt.2018.08.004

[6] Eberemu, A. O. – Afolayan, Joseph O.– Abubakar, Idris – Osinubi, Kolawole J. (2014): Reliability Evaluation of Compacted Lateritic Soil Treated With Bagasse Ash as Material for Waste Land Fill Barrier. Geo-Congress 2014 Technical Papers, GSP 234, 911-920.

[8] Mei Fong, Chong – Kah Peng, Lee – Hui Jiun, Chieng – Ramli, Syazwani Binti – Izyan, Ili (2009): Removal of boron from ceramic industry wastewater by adsorption-flocculation mechanism using palm oil mill boiler (POMB) bottom ash and polymer. Water Research, vol. 43 (13), Pp. 3326-3334. https://doi.org/10.1016/j.watres.2009.04.044

[9] Ba, M. – Nokkaew, K. – Fall, M. – Tinjum, J. M. (2013): Effect of Matric Suction on Resilient Modulus of Compacted Aggregate Base Courses. Geotechnical and Geological Engineering, An International Journal, Vol. 31 (3). https://doi.org/10.1007/s10706-013-9674-y

10] K. C. Onyelowe, – Duc Bui Van, – Obiekwe Ubachukwu, – Charles Ezugwu, – Bunyamin Salahudeen, – Manh Nguyen Van, – Chijioke Ikeagwuani, – Talal Amhadi, – Felix Sosa, – Wei Wu, – Thinh Ta Duc, – Adrian Eberemu, – Tho Pham Duc, – Obinna Barah, – Chidozie Ikpa, Francis Orji, – George Alaneme, – Ezenwa Amanamba, – Henry Ugwuanyi, – Vishnu Sai, – Chukwuma Kadurumba, – Subburaj Selvakumar – Benjamin Ugorji (2019): Recycling and Reuse of Solid Wastes; a Hub for Ecofriendly, Ecoefficient and Sustainable Soil, Concrete, Wastewater and Pavement Reengineering. International Journal of Low-Carbon Technologies. Vol. 14(3), pp. 440-451. https://doi.org/10.1093/Ijlct/Ctz028

[11] American Administration for State Highway Officials., (1993). Guide for Design of Pavement Structures, AASHTO, California, USA

[12] Osinubi, K. J. – Eberemu, A. O. (2019): Compatibility and Attenuative Properties of Blast Furnace Slag Treated Laterite. Journal of Solid Waste Technology and Management, 35(1 8), P*p. 7-16.*

[13] Atahu, M. K. – Saathoff, F. – Gebissa, A. (2019): Mechanical behaviors of expansive soil treated with coffee husk ash. Journal of Rock Mechanics and Geotechnical Engineering. https://doi.org/10.1016/j.jrmge.2018.11.004

[14] Onyelowe, K. C. – Salahudeen, A. B. – Eberemu, A. O. – Ezugwu, C. N. – Amhadi, T. – Alaneme, G. (2020a): Oxides of Carbon Entrapment for Environmental Friendly Geomaterials Ash Derivation. In book: Recent Thoughts in Geoenvironmental Engineering, Proceedings of the 3rd GeoMEast International Congress and Exhibition, Egypt 2019 on Sustainable Civil Infrastructures – The Official International Congress of the Soil-Structure Interaction Group in Egypt (SSIGE), pp. 58-67. https://doi.org/10.1007/978-3-030-34199-2_4

[15] Onyelowe, K. C. – Salahudeen, A. B. – Eberemu, A. O. – Ezugwu, C. N. – Amhadi, T. – Alaneme, G. – Sosa, F. (2020b): Utilization of Solid Waste Derivative Materials in Soft Soils Re-engineering. In book: Recent Thoughts in Geoenvironmental Engineering, Proceedings of the 3rd GeoMEast International Congress and Exhibition, Egypt 2019 on Sustainable Civil Infrastructures – The Official International Congress of the Soil-Structure Interaction Group in Egypt (SSIGE), pp. 49-57. https://doi.org/10.1007/978-3-030-34199-2_3

[16] Onyelowe, K. C. – Amhadi, T. – Ezugwu, C. N. – Onukwugha, E. – Ugwuanyi, H. – Jideoffor, I. – Ikpa, C. – Iro, U. – Ugorji, B. (2020c). Cemented Lateritic Soil as Base Material Improvement Using Compression. In book: Innovative Infrastructure Solutions using Geosynthetics, Proceedings of the 3rd GeoMEast International Congress and Exhibition, Egypt 2019 on Sustainable Civil Infrastructures – The Official International Congress of the Soil-Structure Interaction Group in Egypt (SSIGE), pp. 58-67. https://doi.org/10.1007/978-3-030-34242-5_4

[17] Tan, Y. – Hu, M. – Li, D. (2016). Effect of agglomerate size on California bearing ratio of lime treated lateritic soils. International Journal of Sustainable Built Environment, Vol. 5 (1), Pp. 168-175. https://doi.org/10.1016/j.ijsbe.2016.03.002

[18] Boukhelkhal, A. – Benabed, B.: Fresh and hardened properties of self-compacting repair mortar made with a new reduced carbon blended cement Epitő anyag – Journal of Silicate Based and Composite Materials, Vol. 71 (4), 2019, Pp. 108–113. https://doi.org/10.14382/epitoanyag-jsbcm.2019.19

[19] American Standard for Testing and Materials (ASTM) C618 (1978). Specification for Pozzolanas. ASTM International, Philadelphia, USA.

[20] BS 1377 - 2, 3. (1990). Methods of Testing Soils for Civil Engineering Purposes, British Standard Institute, London.

[21] BS 1924. (1990). Methods of Tests for Stabilized Soil, British Standard Institute, London

[22] El-Fakharany, M. E. – Ezzat, M. – Gad, A. – Ghafour, N. G. Abdel, – Baghdady, A. R.: Performance of dolomitic cementitious mortars as a repairing material for normal concrete in Egypt. Építőanyag – Journal of Silicate Based and Composite Materials, Vol. 71 (2), 2019, Pp. 33–42. https://doi.org/10.14382/epitoanyag-jsbcm.2019.7

[23] Onyelowe, K. C. – Bui Van, D. – Eberemu, A. O. – Xuan, M. N. – Salahudeen, A. B. – Ezugwu, C. – Van, M. N. – Orji, F. – Sosa, F. – Duc, T. T. – Amhadi, T. – Ikpa, C. – Ugorji, B. (2019): "Sorptivity, swelling, shrinkage, compression and durability of quarry dust treated soft soils for moisture bound pavement geotechnics". *Journal of Materials Research and Technology*, 8(4):3529–3538. https://doi.org/10.1016/j.jmrt.2019.06.029

Ref.:

Onyelowe, Kennedy Chibuzor – **Bui Van**, Duc – **Ikpa**, Chidozie – **Osinubi**, Kolawole – **Eberemu**, Adrian – **Salahudeen**, A. Bunyamin – **Nnadi**, Oscar C. – **Chima**, Moses C. – **Obimba-Wogu**, Jesuborn – **Ibe**, Kizito – **Ugorji**, Benjamin: *Resilient modulus and deviatoric stress of cemented soils treated with crushed waste ceramics (CWC) for pavement subgrade construction* Építőanyag – Journal of Silicate Based and Composite Materials, Vol. 72, No. 3 (2020), 86–90. p. https://doi.org/10.14382/epitoanyag-jsbcm.2020.14

View publication stats