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Overview of ash as supplementary cementitious silicate-based composite and construction material

Salak építőanyagként és cement kiegészítő anyagként való alkalmazásának áttekintése

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Abstract

The potential of ash as supplementary cementitious material with high silicate-based pozzolanic composition has been reviewed. Construction activities based on the utilization of ordinary cement have contributed hugely to the greenhouse emission due to the release of CO_2 into the atmosphere. The review was aimed at presenting the achievements that have been made using ash as a replacement for ordinary cement. Also, the source of ash from biomass and the biotechnological procedure involved in its usage have been reviewed. From the results so far reviewed, it has been observed that ash is an amorphous nonbiodegradable material with high aluminosilicates composition. This behavior makes it suitable for it to be utilized as alternative binder in problematic soils stabilization. Results also showed that the index and strength characteristics of expansive soils were improved substantially with increased proportion of ash, which included plasticity index, compaction, gradation, compression, California bearing ratio, resilient modulus and resistant value. Generally, it can be observed that ash is a good replacement for cement as a construction material.

Keywords: biomass, bio-based ash, solid waste recycling (SWR), biotech soil stabilization, supplementary cementitious materials (SCM), geotechnics, silicate based composite materials

Kulcsszavak: biomassza, bioalapú salak, szilárd hulladék újrahasznosítása, biotechnológiai talaj stabilizálás, cement kiegészítő anyagok, geotechnika, szilikát alapú kompozit anyagok

1. Introduction

Supplementary cementitious potentials found in ash amorphous in nature, is strongly due to the aluminosilicate composition contained in it [1, 2, 3]. For a material like ash to be considered cementitious or otherwise considered pozzolanic, the aluminosilicate composition i.e., the composition of Al_2O_3, SiO_2 and Fe_2O_3 must be greater than or equal to 70% in accordance with the American Society for Testing and Materials [1] for pozzolanas. By this composition, it can be seen that these materials are silicate-based composites utilized as construction materials [4, 5]. It is also important at this point to note that ash is only derived by direct combustion of biomass, lignocellulosic materials, agro-industrial wastes, household wastes and municipal wastes in a setup presented in *Fig. 1* and in a materials activity, cycle presented in *Fig. 2* [2, 3]. However, in a world faced with the dangers of global warming resulting from the emissions of carbon and its oxides, which contribute to the depletion of the ozone layer, it is only understandable that the future technological advancement should move quickly towards ways of solving this condition [2, 3, 6, 7, 8]. It is equally important to note that one of the many ways through which oxides of carbon are released into the atmosphere is through construction activities during the utilization of ordinary cement. Results from environmental impact assessment on the use of ordinary Portland cement and other conventional cements products in construction activities show that an equivalent amount of CO_2 is emitted into the atmosphere [3]. As a result, there have been technological effort to develop supplementary cementing or cementitious materials that would partially or totally replace ordinary and conventional cements. These supplementary cementitious materials (SCMs) are known to possess aluminosilicates at substantial amounts that enables them exhibit high pozzolanic properties enough to replace ordinary cements [3, 9]. They are divided into ash and powder materials. The ash materials are derived through the direct combustion of solid wastes while powder materials are derived through crushing or ball milling of selected solid waste materials [2, 3]. Research results have shown that ash materials are more efficient as supplementary binders than powder materials because ash materials are amorphous and nonbiodegradable while powder materials are biodegradable [10, 11, 12, 13, 14]. Further on this effort is the development of silicate-based composite materials with higher aluminosilicate contents because they are derived from the blending of more than one material [2, 3]. Geopolymer cements belong to this group of composite binders because they are developed by combining in proportions, which are dependent on the ash with the predominant aluminosilicates [15, 16]. These ashes of different pozzolanic composition are mixed under the reactive influence of alkali activators as presented in Fig. 2 [2, 3, 17, 18]. It can be observed from previous findings that these materials of biomass and agro-industrial origin have shown to be good replacement for ordinary cement in construction operations. The aim and main objective of this work is reviewing relevant literatures that have shown that ash materials, as silicate-based materials are good replacements for cement as supplementary cementitious and composites materials for construction purposes. This is to bring an overview at a glance of the effects of these amorphous materials of ash and its associated composites on the mechanical properties of soils utilized as foundation and construction materials.

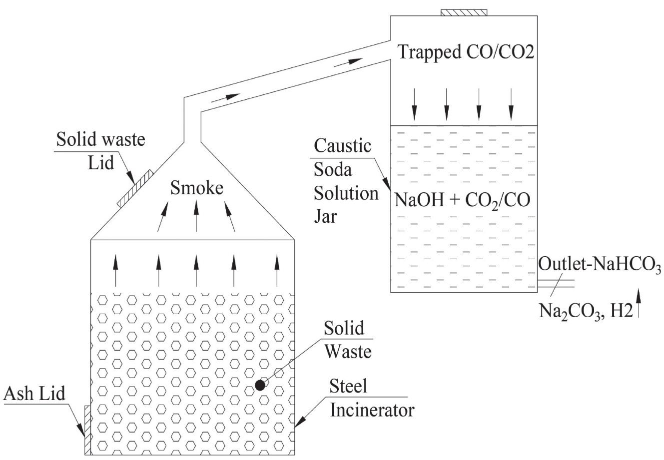

Fig. 1 Bio-waste controlled direct combustion setup [3]
1. ábra Biohulladék szabályozott elégetéséhez használt rendszer összeállítása [3]

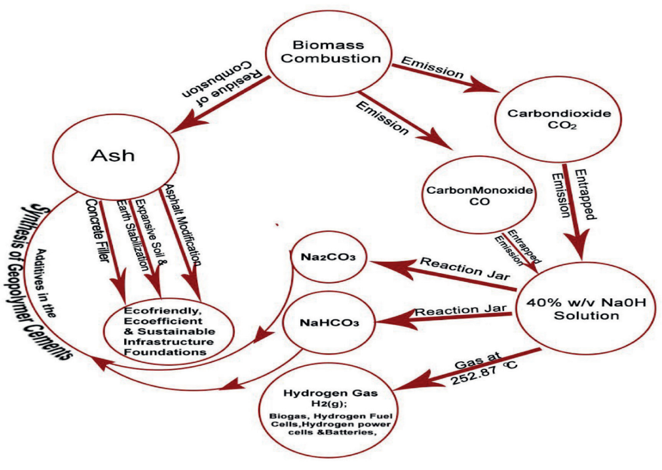

Fig. 2 Bio-waste valorization by combustion and the derivation of ash cycle [2]
2. ábra Biohulladék újrahasznosítása égetés által [2]

2. Overview of relevant resources

Ash has found been predominantly used as an admixture in the stabilization of soils to improve their geotechnical and mechanical properties for the purpose of foundation constructions and other civil engineering purposes. These also include concrete production and asphalt production as modifiers due to its constituents. This procedure has been successful due to the fact that; (i) ash particles are in the silt to sand size range, (ii) they are composed predominantly of amorphous alumina-silicate, (iii) the basic mineral found in waste ashes is silica, and (iv) ashes contain high percentages of 0-5% of clay size, 20-70% of silt size, 30-70% of sand size and 0-5% of gravel size making it suitable for homogenous mixture with soil during admixture stabilization of soils. An extensive look into the relevant resources available from previous findings from the use of ash as supplementary cementing material, will expand the horizon of knowledge on the successes recorded in this area of investigation. In the area of geotechnical engineering experimentations, soil, which is the major geomaterial used in various disciplines of the area are adapted into many forms either as a single material or treated coupled materials in composite forms. It is developed into a coupled material during stabilization or soil improvement for foundation purposes. Pavement foundations (airfield and highway), landscapes and parking lots underlain, embarkments, backfills, lateritic blocks, laterized marbles, etc. are geotechnical engineering activities that go on daily with soils. When these activities are suspected to be affected by problematic soils, a stabilization and ground improvement exercise is undertaken to enhance the properties of the soil to meet required standards. The binding effect and properties of the admixtures utilized during geotechnical engineering procedures have been harnessed over the years to substantially improve on the mechanical properties of soils used as foundation materials [2, 3]. It is important to note that the success of admixture or silicate-based binder stabilization rests on the ability of cations released from the oxides of the additive materials to migrate to the surface of the clayey soils being stabilized. This is where the diffused double layer or the adsorbed complex is formed, which gives rise to the formation of flocs; a resultant effect of hydration reaction, cation exchange reaction, carbonation, calcination and pozzolanic reaction as the case may be [10, 11, 12, 13, 14]. So, it is important that the mixing of the soils and the additive be done deeply to enhance reaction.

2.1 Review of selected ashes and their silicate-based potentials in accordance with ASTM C618, 1978

Rice husk is an agro-industrial waste discharged from rice farming and production. It has been observed through research that over 108 tons of rice husk is being generated annually across the world. The agro-industrial production of rice in Nigeria is over 2.0 million tons annually (see *Fig. 3*). While Niger state produces approximately 96.60 kilo-tons of rice, Ebonyi state produces well over 187.5 kilo-tons annually and this capacity has increased over the period due to increased demand for food. Moreover, the ash has been classified as a pozzolana, with silicon oxide component ranging between 67-70% with about 4.9% and 0.95% aluminum oxide and iron oxide respectively. The silicate-based composition of the pozzolanic ash is contained in amorphous state, which reacts with the ionized components of problematic soils throughout the hardening and strength gaining of the treated soils [19, 20].

Fig. 3 Rice husk
3. ábra Rizs héj

Fig. 4 Coconut shell
4. ábra Kókuszhéj

Fig. 5 Snail shells
5. ábra Csigaház

According to E. S. Nnochiri *et al.* [22], snail shells ash (SSA) with a specific gravity of 3.07, is a product of the combustion of snail shells (see *Fig. 5*) discharged as agricultural and household wastes disposed on landfills that hardly decay. They are burnt and pulverized to fineness and then used as additives in the stabilization of weak engineering soils. This has been classified as a supplementary cementing material because of its silicate-based component having aluminosilicates composition of more than 70% according to ASTM C618.

According to Nnochiri [23], periwinkle shell ash derived by combusting periwinkle shells (see *Fig. 6*) and pulverizing the residue. Periwinkle shells are agricultural, biological and household wastes found in the coastal region of Nigeria and across the world. They are disposed as wastes on landfills. The shells are v-shaped, hard, brittle and usually black. The ash has also been classified as pozzolanic because of the aluminosilicate composition, which satisfies the condition for materials to be classified as supplementary cementitious materials (SCM) in accordance to the ASTM C618.

Fig. 6 Periwinkle shells
6. ábra Tengeri csigaház

Fig. 7 Wood
7. ábra Fa

According to A. W. Otunyo and C. C. Chukuigwe [24], palm bunch ash and palm oil fuel ash are derived from the combustion of palm bunch as a biomass and a bio-based agricultural waste and the milling of palm oil from palm fruits respectively. Research results have shown also that this ash consists of aluminosilicates composition by weight over 70% thereby fulfilling the requirement for a material to be classified as a pozzolana. This composition makes palm bunch ash suitable as a construction material to supplement for cementation potentials.

According to B. D. Nath *et al.* [25], wood ash has been utilized in the modification of problematic soils for construction purposes. It is also the derivative of combusted wood materials in logs (see *Fig. 7*) or dusts, which are bio-based agricultural wastes. Wood ash contains high composition of aluminosilicates, which satisfies its utilization as a pozzolanic material in soft soils stabilization.

According to G. M. Ayininuola and A. O. Sogunro [26] and O. A. Adetayo *et al*. [27], bone ash was utilized in the modification of expansive soil to evaluate its effect on the shear properties of the soil. This was necessitated due to the calcium silicate based binding properties of the bone ash. Bone ash is an agricultural and household solid waste materials from animal bones (see *Fig. 8*). The high C-S composition satisfies the minimum pozzolanic requirements for use as a supplementary cementing construction material.

Fig. 8 Animal bones
8. ábra Állati csontok

Bello *et al*. [28] and Ramonu, J. A. L. *et al*. [29] had in different researches investigated the potential of cassava peel ash (CPA) and yam peel ash (YPA) as supplementary binders in soft and expansive soils stabilization. CPA and YPA are gotten from the peeling of the bark of cassava and yam peels (see *Fig. 9*) during garri and flour production. It was shown that CPA and YPA exhibited high composition of silicate based pozzolanic properties. This property enhanced the ashes suitability to be utilized as alternative binders in the stabilization of problematic soils.

Fig. 9 Cassava and yam peels
9. ábra Manióka és jam héj

According to Chou-Fu Liang and Hung-Yu Wang [30], G. M. Ayininuola and O. D. Afolayan [31] and Ubachukwu and Okafor [32], oyster shell (see *Fig. 10*) collected from the coastal regions of Nigeria- Rivers State, Delta State, Bayelsa State and across the world discharged as agricultural and bio-based waste has been studied for its potential property to be utilized as a supplementary binder in its ash and crushed form. Results of the investigations show that oyster shell ash and powder possess high composition of aluminosilicates, which makes it suitable to be utilized as a pozzolana in accordance with appropriate standards.

Fig. 10 Oyster shells
10. ábra Osztriga héj

According to Oriola and Moses [33], groundnut shell ash (GSA) potential for use as a pozzolanic material in the modification of the index and mechanical properties of plastic soils was investigated and encouraging results were achieved. Groundnut shells (see *Fig. 11*) are discharged after separating the edible nuts and leaving the littered shells as solid wastes. After sun drying, combustion and pulverization, the ash is obtained. The alumina-silicate-based composition of the ash has been determined to be more than the minimum standard for pozzolanas and suitable as a supplementary silicate-based binder.

Fig. 11 Groundnut shells
11. ábra Földimogyoró héjak

According to Sadeeq *et al.* [34], the potential of bagasse ash (BA) to be used as an alternative binder to replace ordinary cement has been studied. Bagasse ash derived from the combusted sugarcane biomass discharged after the extraction of the fluid. Bagasse (see *Fig. 12*) is an agro-industrial waste material discharged on landfills. It is predominantly common in the northern states of Nigeria where sugarcane farming is the trade of the people living in these areas. Research has shown that BA contains high amount by weight of the aluminosilicates responsible for cementation behavior of construction materials. Hence its potential utilization as a supplementary cementitious material in construction activities.

Fig. 12 Sugarcane farm
12. ábra Cukornád farm

3. Overview of results from relevant resources

3.1 Gradation characteristics of soils treated with ashes

Results of previous investigation on the potentials of ashes utilized as supplementary cementitious additives have shown that the gradation of the soils improved substantially and consistently with increased addition of ash by weight proportion of treated solids. This was due to the fineness of ash derived by drying-in most cases, combusting and pulverizing to fineness [35]. The texture of ash achieved through this procedure changes the particle size distribution of the treated soils blended with ashes. Gradation is a very important factor in construction materials' characterization and structural behavior [36].

3.2 Index and strength characteristics of soils treated with ashes

Index and strength characteristics of soils especially the expansive and problematic soils are very important factors considered in the design and performance monitoring of flexible pavements across the world. The overall performance and durability of these structures depend ultimately on the strength of the foundation. For instance, when pavements are laid on weak or expansive subgrade, the behavior of the entire structure is compromised. More importantly, if the structure is under a hydraulically bound condition like the pavement foundations subjected to the rise and fall of water table, it becomes even a more difficult problem due to the swell and shrink potentials of the compacted earth underlain. Over the years, ordinary cement has been used to improve on these properties of soils utilized as subgrade materials with its attendant greenhouse emissions. In recent developments in geo-environmental engineering, ash materials due to their amorphous nature and high composition of aluminosilicates have been utilized in single forms and in composite forms to modify weak soils. This was targeted at making the compacted earth suitable to withstand the adverse conditions it is subjected to in the sub structural level. Ash is environmentally friendly and possesses properties that are resistant to heat, moisture, sulfates, crack and shrinkage [2, 3, 35]. Because of these characteristics, soils treated with ash have shown to improve in their plasticity index condition, compaction behavior, and other strength properties like California bearing ratio, resilient modulus, resistant value, deviatoric stress and durability potentials.

4. Conclusions

The use of ash as supplementary cementitious material has been reviewed and the following remarks can be made; (i) ash is derived by combusting bio-based materials, (ii) because of its amorphous nature, ash doesn't decompose, (iii) ash is composed of silicate-based pozzolanic properties i.e. aluminosilicates and this makes it suitable as alternative cement, (iv) ash has proven to be an environmentally friendly cement with no greenhouse effects, (v) the addition of ash to soil as a mixed blend improves the mechanical properties of problematic soils in a stabilization protocol, (vi) ash from various sources is readily available and its utilization in construction works is highly sustainable and (vii) ash is a good alternative and appropriate replacement for ordinary cement in an environment yearning to be saved from hazards and global warming.

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References

[1] American Standard for Testing and Materials (ASTM) C618, 1978. Specification for Pozzolanas. ASTM International Annual Book of ASTM Standards, West Conshohocken, Philadelphia, USA.

[2] Onyelowe, K. C. – Onyelowe, Favour Deborah A. – Van, Duc Bui – Ikpa, Chidozie – Salahudeen, A. Bunyamin – Eberemu, Adrian O. – Osinubi, Kolawole J. – Onukwugha, Eze – Odumade, Adegboyega O. – Chigbo, Ikechukwu C. – Amadi, Agapitus A. – Igboayaka, Ekene – Obimba-Wogu, Jesuborn – Saing, Zubair – Amhadi, Talal (2020): Valorization and sequestration of hydrogen gas from biomass combustion in solid waste incineration NaOH oxides of carbon entrapment model (SWI-NaOH-OCE Model). Materials Science for Energy Technologies, Vol. 3, Pp. 250-254. https://doi.org/10.1016/j.mset.2019.11.003

[3] Onyelowe, K. C. – Van, Duc Bui – Ubachukwu, O. – Ezugwu, C. – Salahudeen, B. – Nguyen Van, M. – Ikeagwuani, C. – Amhadi, T. – Sosa, F. – Wu, W. – Duc, T. Ta – Eberemu, A. – Duc, T. Pham – Barah, O. – Ikpa, C. – Orji, F. – Alaneme, G. – Amanamba, E. – Ugwuanyi, H. – Sai, V. – Kadurumba, C. – Selvakumar, S. – Ugorji, B. (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

[4] Kotova, O. B. – Shushkov, D. A. – Gömze, L. A. – Kurovics, E. – Ignatiev, G. V. – Sitnikov, P. A. – Ryabkov, Y. I. – Vaseneva, I. N.: Composite materials based on zeolite-montmorillonite rocks and aluminosilicate wastes. Epitő anyag – Journal of Silicate Based and Composite Materials, Vol. 71 (4), 2019, Pp. 125–130. https://doi.org/10.14382/epitoanyag-jsbcm.2019.22

[5] 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

[6] Onyelowe, K. C. – Salahudeen, A. B. – Eberemu, A. O. – Ezugwu, C. N. – Amhadi, T. – Alaneme, G. (2020): Oxides of Carbon Entrapment for Environmentally 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

[7] Onyelowe, K. C. – Salahudeen, A. B. – Eberemu, A. O. – Ezugwu, C. N. – Amhadi, T. – Alaneme, G. – Sosa, F. (2020): 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

[8] Onyelowe, K. C. – Amhadi, T. – Ezugwu, C. N. – Onukwugha, E. – Ugwuanyi, H. – Jideoffor, I. – Ikpa, C. – U. Iro – Ugorji, B. (2020): 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

[9] 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

[10] Onyelowe, K. C. – Bui Van, D.: 2018. 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

[11] Onyelowe, K. C. – Bui Van, D.: 2018. 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

[12] Onyelowe, K. C. – Bui Van, D. (2018): 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

[13] Onyelowe, K. C. – Bui Van, D. (2018): Predicting Strength Behaviour 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

[14] 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*, Vol. 8(4). Pp. 3529–3538. https://doi.org/10.1016/j.jmrt.2019.06.029

[15] Szabó R. 2019: Control of mechanical properties of lignite fly ash based geopolymers by vibrating compression. Építőanyag – Journal of Silicate Based and Composite Materials, Vol. 71 (2), 2019, Pp. 66–71. https://doi.org/10.14382/epitoanyag-jsbcm.2019.12

[16] Khater, Hisham Mustafa Mohamed: Preparation and characterization of lightweight geopolymer composites using different aluminium precursors. Építőanyag – Journal of Silicate Based and Composite Materials, Vol. 70 (6), 2018, Pp. 186–194. https://doi.org/10.14382/epitoanyag-jsbcm.2018.33

[17] Davidovits, J. (2013): Geopolymer Cement a review. Institute Geopolymer, F-02100 Saint-Quentin, France. [online]

[18] Hamidi, R. M. – Man, Z. – Azizli, K. A. (2016): Concentration of NaOH and the Effect on the Properties of Fly Ash Based Geopolymer. 4th International Conference of Process Engineering and Advanced Materials; Procedia Engineering, Vol. 148, Pp. 189-193. http://dx.doi.org/10.1016/j.proeng.2016.06.568

[19] Qasim, M. – Bashir, A. – Tanvir, M. – Anees, M. M. (2015): Effect of Rice husk ash on soil stabilization. Bulletin of Energy Economics, 3(1), 10-17.

[20] Candido, K. – Braga, Jener – Gutierrez II, Rodel – Tambal, Jeffrey – Orale, Ronald L. (2016): Fine-Grained Soil as Subgrades with Coconut Husk Ash. *Journal of Academic Research* 01:2 (2016), Pp. 19-26

[21] Oluremi, J. R. – Adedokun, S. I. – Osuolale, O. M. (2012): Stabilization of poor lateritic soils with coconut husk ash. International Journal of Engineering Research & Technology (IJERT) Vol. 1 Issue 8, October – 2012.

[22] Nnochiri, E. S. – Ogundipe, O. M. – Emeka, Helen O. (2018): Effects of Snail Shell Ash on Lime Stabilized Lateritic Soil. Malaysian Journal of Civil Engineering 30(2):239-253

[23] Nnochiri, E. S. (2017): Effects of Periwinkle Shell Ash on Lime-Stabilized Lateritic Soil. J. Appl. Sci. Environ. Manage., Vol. 21 (6) 1023-1028. https://dx.doi.org/10.4314/jasem.v21i6.4

[24] Otunyo, A. W. – Chukuigwe, C. C. (2018): Investigation of The Impact of Palm Bunch Ash on The Stabilization of Poor Lateritic Soil. Nigerian Journal of Technology (NIJOTECH), Vol. 37, No. 3, July 2018, pp. 600 – 604. http://dx.doi.org/10.4314/njt.v37i3.6

[25] Nath, B. D. – Sarkar, Grytan – Siddiqua, Sumi – Rokunuzzaman, Md. – Islam, Md. Rafiqul (2018): Geotechnical Properties of Wood Ash-Based Composite Fine-Grained Soil. Advances in Civil Engineering, Vol. 2018. https://doi.org/10.1155/2018/9456019

[26] Ayininuola, G. M. – Sogunro, A. O. (2013): Bone Ash Impact on Soil Shear Strength. World Academy of Science, Engineering and Technology International Journal of Environmental and Ecological Engineering Vol.7 (11). Pp. 793-797.

[27] Adetayo, O. A. – Amu, O. O. – Ilori, A. O. (2019): Cement Stabilized Structural Foundation Lateritic Soil with Bone Ash Powder as Additive. Arid Zone Journal of Engineering, Technology & Environment, Vol. 15 (2). Pp. 479-487.

[28] Bello, A. A. – Adebayo Ige, Joseph – Ayodele, Hammed (2015): Stabilization of Lateritic Soil with Cassava Peels Ash. British Journal of Applied Science & Technology, Vol. 7(6). Pp. 642-650.

[29] Ramonu, J. A. L. et al., (2018): Geotechnical properties of lateritic soil stabilized with yam peel ash for subgrade construction. International Journal of Civil Engineering and Technology (IJCIET), Vol. 9 (13), Pp. 1666-1681.

[30] Liang, Chou-Fu – Wang, Hung-Yu (2013): Feasibility of Pulverized Oyster Shell as a Cementing Material. Advances in Materials Science and Engineering, Volume 2013. http://dx.doi.org/10.1155/2013/809247

[31] Ayininuola, G. M. – Afolayan, O. D. (2018): Potential of Oyster Shell Ash Activated with Cement as soil Stabilizer for Road Construction. International Journal of Engineering and Advanced Technology (IJEAT), Vol. 7 (5). Pp. 118-126.

[32] Ubachukwu, O. A. – Okafor, F. O. (2019): Investigation of the Supplementary Cementitious Potentials of Oyster Shell Powder for Eco-Friendly and Low-cost Concrete. *Electronic Journal of Geotechnical Engineering*, Vol. 24 (5), Pp 1297-1306.

[33] Oriola, F. – Moses, G. (2010): Groundnut Shell Ash Stabilization of Black Cotton Soil. Electronic Journal of Geotechnical Engineering, Vol. 15, Pp. 415-428.

[34] Sadeeq, J. A. – Ochepo, J. – Salahudeen, A. B. – Tijjani, S. T. (2015). Effect of Bagasse Ash on Lime Stabilized Lateritic Soil. Jordan Journal of Civil Engineering, Vol. 9 (2), Pp. 203-213.

[35] Nigerian General Specification, 1997. Specification for Construction of Roads and Bridges, Nigeria.

[36] Roads and Maritime Services, 2012. Erodibility of stabilized road construction materials: Test Method T186, New South Wales.

Ref.:

Onyelowe, Kennedy Chibuzor – **Onyelowe**, Favour Adaugo Deborah – **Bui Van**, Duc: *Overview of ash as supplementary cementitious silicate-based composite and construction material*
Építőanyag – Journal of Silicate Based and Composite Materials, Vol. 72, No. 3 (2020), 80–85. p.
https://doi.org/10.14382/epitoanyag-jsbcm.2020.13