Case Studies in Construction Materials 11 (2019) e00241

Contents lists available at ScienceDirect

Case Studies in Construction Materials

journal homepage: www.elsevier.com/locate/cscm

Short communication

Marine plastic pollution and affordable housing challenge: Shredded waste plastic stabilized soil for producing compressed earth bricks

Isaac I. Akinwumi*, Ayebaemi H. Domo-Spiff, Adeniyi Salami

Department of Civil Engineering, Covenant University, Ota, Ogun State, Nigeria

ARTICLE INFO

Article history:
Received 7 December 2018
Received in revised form 9 April 2019
Accepted 11 April 2019

Keywords:
Mud
Soil stabilization
Sustainable construction
Traditional building
Waste management

ABSTRACT

This research work was aimed at investigating the suitability of making compressed earth bricks (CEB) with a mixture of soil and varying percentages (0, 1, 3, and 7%) of shredded waste plastic. Specific gravity, particle size distribution, Atterberg limits and compaction tests were carried out on the soil to determine the engineering properties of the soil. The compressive strengths and erosion rates of the CEB made with the soil and the mixture of soil and varying proportions of shredded waste plastic of two size-categories (<6.3 mm and >9.6 mm) were determined. The soil was classified as clayey sand (SC). The highest compressive strength was obtained for the CEB containing 1% waste plastic of sizes <6.3 mm and its compressive strength amounted to a 244.4% increase. Of the CEB samples stabilized with shredded waste plastic, the sample containing 1% waste plastic of sizes <6.3 mm also had the least erosion rate. Provided the exterior surfaces of walls produced using the CEB are protected from erosion, the use of 1% shredded waste plastic with particle sizes <6.3 mm was recommended. The use of waste plastic that would have constituted an environmental nuisance has the potential to produce stronger and affordable bricks for providing affordable housing.

1. Introduction

There has been a general increase in housing prices worldwide and in many countries, the range of housing prices has also continued to widen. The average property prices in many countries have increased. The average property price increase across all capital cities in Australia was said to be by nearly 30% from 2008 to 2018 [1]. Glaeser et al. [2] reported a 72% increase in average housing prices and a 247% increase in the standard deviation of prices in the United States of America, after comparing housing data of the year 1970 with those of 30 years after. Housing rent, which has been described as a better indicator of housing affordability than property prices [1], has also increased over the years. Martin and Troy [3] stated that housing can be said to be unaffordable if an individual's or household's median rent is greater than 30% of its income. According to Carliner and Marya [4], an average of 32.3%, 31.1% and 30.1% of the income of persons renting houses in Spain, the United States and the United Kingdom, respectively, is spent on rent. In the report of Szekely [5] that ranked 30 cities, considered to present the best deal of opportunities to its residents, based on their rent-to-income ratio, it was found that cities with >30% rent-to-income ratio include Tokyo, Japan (31%), Hong Kong, Hong Kong (32%), Madrid, Spain (32%),

* Corresponding author.
E-mail address: isaac.akinwumi@covenantuniversity.edu.ng (I.I. Akinwumi).

https://doi.org/10.1016/j.cscm.2019.e00241

Stockholm, Sweden (34%), Amsterdam, Netherlands (35%), Jakarta, Indonesia (37%), Chicago, United States (US) (38%), Dubai, United Arab Emirate (39%), London, United Kingdom (40%), San Francisco, US (41%), Mumbai, India (41%), Singapore, Singapore (44%), Paris, France (46%), Los Angeles, US (47%), Lagos, Nigeria (57%), Manhattan, New York, US (59%), and Mexico City, Mexico (60%) (Fig. 1). The overall cost of property prices, housing rent and consequently, housing affordability seem to be influenced by the cost of the materials used for building construction [6,7].

The prices of frequently used conventional building materials like cement and steel have been on the increase. Consequently, requiring the search for alternative materials that are cheap and affordable. Some researchers have proposed the modified use of indigenous earth building technologies and the use of sustainable materials [8–10]. Some of these indigenous technologies include cob, earth or adobe bricks, rammed earth and, wattle and daub construction. On the other hand, agricultural and industrial wastes have been receiving the attention of researchers for improving earth materials [11–18].

Geyer et al. [19] estimated the total weight of virgin plastic that has ever been produced globally to be 8.3 billion tonnes, about 9% of which have been recycled and stated that except for about 12% that has been incinerated, almost all the plastic produced still exist today. Consequently, there is a growing campaign to reduce plastic waste because of the environmental nuisance its disposal is creating in the society and the risk waste plastic that gets into ocean poses to marine life. Improperly disposed plastic waste has resulted in the blockage of waterways and drainages causing flood in some cities [20,21]. The United Kingdom Government Office for Science, in its report titled “Foresight Future of the Sea”, stated that if nothing is quickly done, ten years from now the current amount of plastic in our oceans would have tripled [22]. Recently, plastic pollution was suspected to be the cause of the death of a whale in Indonesia, after plastic bags, bottles and 115 plastic cups (plastic waste weighing about 6 kg) were found in the stomach of the dead whale [23].

Some researchers have investigated the use of plastic waste or recycled plastic as a construction material in the built environment industry. Some researchers found that the incorporation of waste plastic reduced the self-weight of concrete and increased its resistance to corrosion and sulphuric acid attack [24–28]. Concrete blocks having waste plastic produced by Mondal et al. [25] contained 0–10% waste plastic, 15% Portland cement, 15% fly ash and 60–70% and it was found that they were good for constructing energy-efficient buildings. Some researchers have also investigated the use of waste plastic in the production of asphalt for road pavement construction [29–32]. Waste plastic bottles filled with earth or other dried solid waste have also been used to construct plastic bottle brick houses [33,34].

This study presents an exploratory investigation of the effects of stabilizing a soil with shredded waste plastic on the suitability of using the stabilized soil to produce compressed earth bricks (CEB). This study is unique in that no peer-reviewed article in open literature, as far as the authors know, has reported the use of waste plastic for the production of CEB. It was hypothesized that using low-cost building materials, such as CEB stabilized with plastic waste, will reduce housing prices and make housing more affordable.

2. Materials and methods

2.1. Materials preparation

Disturbed soil sample was obtained from a location in Ota, Ogun State, Nigeria corresponding to latitude 6°40'52” N and longitude 3°9'11” E. The soil sample collected was initially air-dried in the Geotechnical laboratory of Covenant University, Ota, Nigeria immediately after its collection and transportation to the laboratory. Soil lumps of the air-dried sample were broken (Fig. 2), using mortar and pestle. Only those passing the 4.75 mm sieve was used and nearly all the soil sample particles passed through this sieve opening.

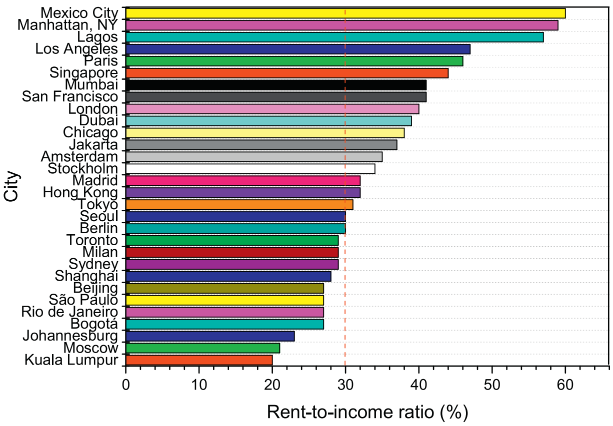
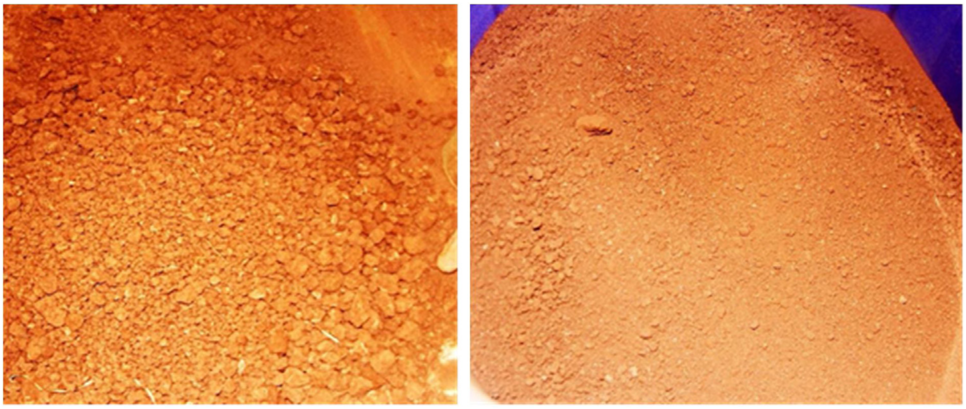


Fig. 1. The rent-to-income ratio of 30 cities (Adapted from Szekely [5]).



(a) (b)

Fig. 2. Collected soil samples (a) before and (b) after breaking soil lumps.

Polyethylene terephthalate (PET) bottles were collected within Covenant University, Ota, Ogun State Nigeria. They were crushed using an industrial crushing machine to sizes less than 6.3 mm and greater than 9.6 mm (Fig. 3).

2.2. Methods

Some of the geotechnical properties of the natural soil were investigated. The tests conducted include sieve analysis, specific gravity, Atterberg limits and compaction. Sieve and hydrometer analyses were carried out in accordance with ASTM D422-63 [35], while the specific gravity was done in accordance with ASTM D854-00 [36]. Atterberg limits tests were conducted in accordance with ASTM D4318-00 [37], while the standard Proctor compaction test was done in accordance with ASTM D698-07 [38].

The soil with varying percentages of waste plastic (0, 1, 3, and 7%) was proportioned by mass and mixed at optimum moisture content. The bricks were formed using a hydraulic compacting machine to produce the CEB (Fig. 4).

2.2.1. Compressive strength test

The test samples were allowed to gain strength, after which they were oven dried at a temperature of 125 °C for two days, the specimens were allowed to cool for 3 h. When the cooling time had elapsed the samples were placed in the crushing machine to be tested for strength. Compressive strength was determined using the formula in Eq. (1).

$$Compressive\ Strength = \frac{Compressive\ force\ on\ specimen}{Area\ of\ specimen} \quad (1)$$

(a) (b)

Fig. 3. Shredded waste plastic bottles with particle sizes (a) <6.3 mm and (b) >9.6 mm.

(a) (b)

Fig. 4. CEB Press (a) showing its hydraulic system and (b) after the compression of a brick with the shredded waste plastic.

2.2.2. Durability test

The Australian Bullet 5 Spray Erosion test was modified in this study to determine the durability of the test specimen in accordance with Obonyo et al. [39] and similar to the set up used by Arooz and Halwatura [40]. The specimens were placed 470 mm away from the nozzle of the setup and water at a pressure of between 2.07 and 4.14 MPa allowed to penetrate the specimens. Readings were taken after every 15 min to establish the depth of penetration, using a 10 mm diameter flat ended rod.

3. Results and discussion

3.1. Soil physical properties

The soil sample used in this study is brown (Fig. 2). Table 1 presents a summary of the physical properties of the soil. It has a specific gravity of 2.67 and its plasticity index is 15%. From Fig. 5, it can be seen that more than 50% of the particles of the soil sample was retained on the 75 μm opening sieve. Based on the Unified Soil Classification system (USCS), the soil was classified as SC – clayey sand. The results of the Atterberg limits indicate that the fines of the soil sample are of low plasticity.

The maximum dry unit weight and the optimum moisture content of the soil was found to be 17.1 kN/m^3 and 15.6%, respectively (Fig. 6).

3.2. Compressive strength of CEB

The compressive strength of earth bricks is one of its most important properties. The compressive strengths of bricks are a function of the soil type and the percentage of fiber in the bricks [41,42]. The variation of the compressive strength of the CEB with varying shredded waste plastic content is shown in Fig. 7. The compressive strength of the CEB was low having a value of 0.45 MPa. Irrespective of the particle size of the shredded plastic that was studied, the application of increasing percentage of shredded plastic resulted in an initial increase in the compressive strength before a progressive decrease. No brick could be formed for the soil sample containing 7% of shredded waste plastic of sizes greater than 9.6 mm. The highest compressive strength was obtained for CEB containing 1% shredded waste plastic, whose particle sizes were less than 6.3 mm. This

Table 1
Physical properties of the soil.

Properties	Value
Specific Gravity	2.67
Liquid Limit	43%
Plastic limit	28%
Plasticity Index	15%
% passing No. 200 (75 μm) sieve	36%
USCS soil classification	SC – Clayey Sand
Maximum Dry Unit Weight	17.1 kN/m^3
Optimum Moisture Content	15.6%

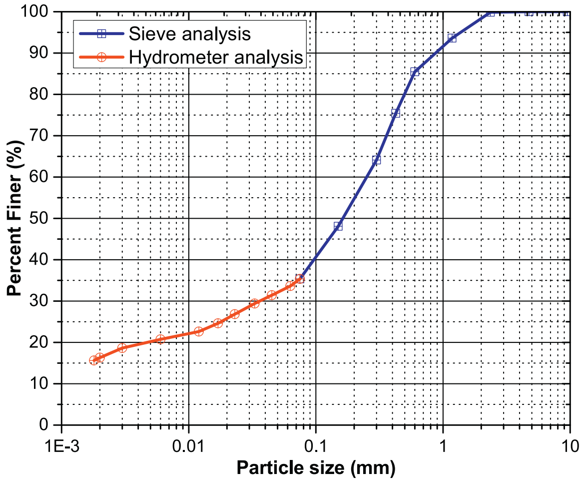


Fig. 5. Particle size distribution of the soil.

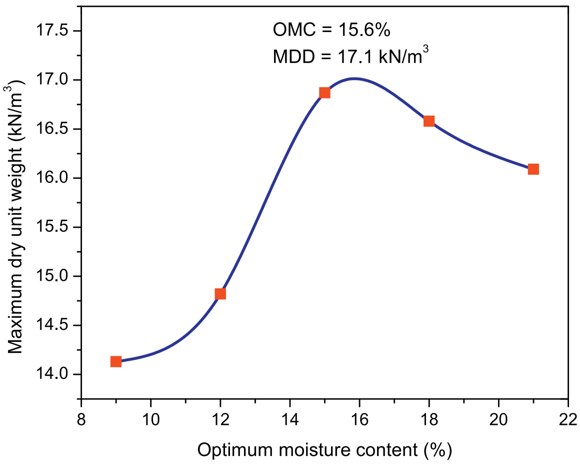


Fig. 6. Compaction characteristics of the soil.

compressive strength amounts to an increase of 244.4% when compared with that of the CEB containing no shredded waste plastic. Mondal et al. [25], who investigated the progressing replacement of sand with 0–10% waste plastic in a concrete containing 15% Portland cement and 15% fly ash, found that the compressive strength of the concrete bricks decreased with increasing percentage of waste plastic in the concrete bricks.

The strength development of the CEB containing shredded waste plastic was as a result of the adhesion (especially at the surface of the CEB) between the plastic fiber and soil matrix, facilitated by the application of heat for 24 h after the dense packing of the CEB brought about by compaction. However, the strength increase due to the application of the shredded waste plastic was limited to the application of 1% shredded waste plastic. With progressive increase in the shredded waste plastic in the CEBs beyond the 1% level, the CEBs progressively contained more shredded waste plastic imbedded in them that may not have melted. Consequently, creating more slip surface that the soil can slide over when subjected to compressive load. This, therefore, induced failure at progressively lower compressive strength with increasing content of shredded waste plastic. Similarly, the CEBs containing shredded waste plastic with larger particle sizes created more slip surfaces (several discontinuities) within the CEBs and potential weak points for strength failure.

According to the Turkish Standards Institution [43,44], the minimum compressive strength for an unfired clay brick should be 1 MPa. Only the CEB samples containing 1% shredded waste plastic, irrespective of the size of the plastic particles, satisfied this requirement. This imply that the CEB samples containing 1% shredded waste plastic can be used in the construction of earth brick walls that are lightly-loaded or non-load bearing. For use in constructing heavily-loaded walls, the earth bricks will need to be stabilized.

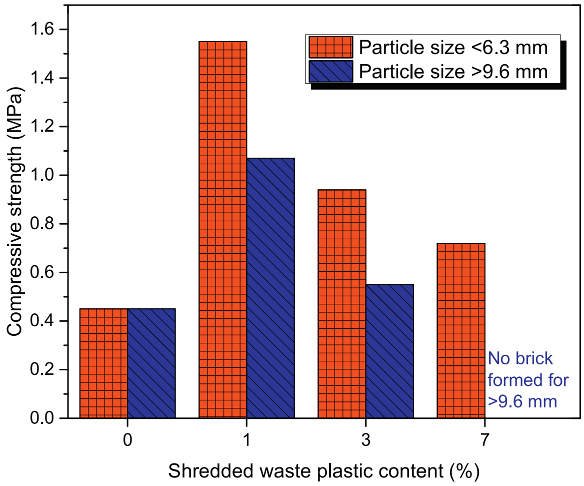


Fig. 7. Variation of compressive strength with shredded waste plastic.

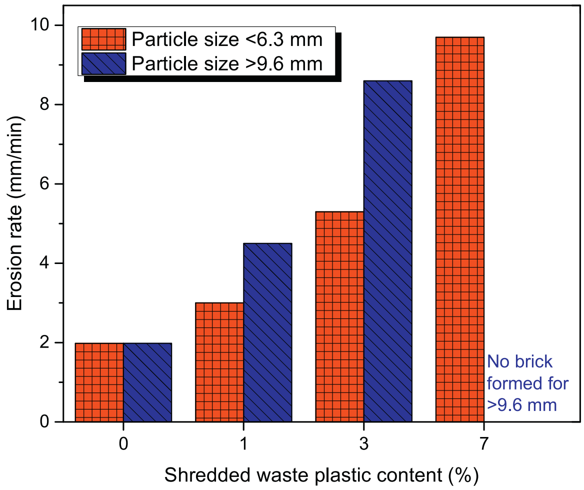


Fig. 8. Variation of erosion rate with shredded waste plastic.

3.3. Erosion rate test

The erosion rate test results were considered an indication of the durability of the CEB. Fig. 8 presents the erosion rates of the compressed earth bricks containing various percentages of the shredded waste plastic. The erosion rate of the CEB with no shredded waste plastic is 2 mm/min. The erosion rate increased with increasing percentage of shredded waste plastic. For the CEB containing 7% of shredded waste plastic of particle sizes of less than 6.3 mm, the erosion rate increased by 389.8%, when compared with the erosion rate of the CEB containing no shredded waste plastic. These results indicate that the durability of the CEB decreased with the increasing percent of shredded waste plastic. The decreased durability of the CEB with shredded waste plastic was attributed to the weak interface between the shredded waste plastic and the soil. Having the shredded waste plastic pulverized to finer particles and the use of a binder may improve the erosion rate. However, if the CEB containing shredded waste plastic is to be used for building walls of houses, the external surfaces of the walls may need to be covered with mortar or stucco installed.

4. Conclusions

The purpose of this research work was to investigate the effects of stabilizing a soil with shredded waste plastic on the suitability of using the stabilized soil to produce compressed earth bricks (CEB). The soil used was classified as SC – clayey sand, based on the Unified Soil Classification system. Two categories of shredded waste plastic were used, one with particle sizes less than 6.3 mm and the other having particle sizes greater than 9.6 mm. The shredded waste plastic was applied to the soil in varying percentages (0, 1, 3 and 7%) and CEBs were produced. The effects of the application of the shredded waste plastic on the strength and durability of the CEB were investigated.

It was found that the compressive strength of the CEB with no additive was low (0.45 MPa). There was an initial increase in the compressive strength of the CEB with increasing content of shredded waste plastic before a progressive decrease was experienced. An optimal compressive strength for this study was obtained for CEB containing 1% shredded waste plastic, whose particle sizes were less than 6.3 mm. The compressive strength increase was by 244.4% when compared with that of the CEB containing no shredded waste plastic. Also, only the CEB samples containing 1% shredded waste plastic satisfied the Turkish Standards Institution required minimum compressive strength of 1 MPa for an unfired clay brick.

The erosion rate of the CEB was found to increase with an increasing percentage of shredded waste plastic content. For the CEB containing 1% of shredded waste plastic of particle sizes of less than 6.3 mm, the erosion rate increased by 50%, when compared with the erosion rate of the CEB containing no shredded waste plastic. Since the erosion rate gives a measure of the durability of the CEB, it was recommended that exterior walls made using CEB containing shredded waste plastic be covered with mortar or installed stucco.

Based on these results, the use of an optimal shredded waste plastic content of 1% was recommended for the production of CEB of higher compressive strength. The use of waste plastic in the built environment industry has the potential of minimising the waste plastic that would have been improperly disposed of in public spaces blocking drainages and causing flood or washed away into water bodies causing marine pollution and endangering marine life. Also, since waste plastic is cheap to get and its inclusion at the optimal level in the CEB improved its compressive strength, it may become valuable for the provision of affordable housing in developing countries.

To improve the compressive strength and durability of CEB containing shredded waste plastic, a binder such as cement, lime or another additive with adhesive properties may be mixed with the soil and shredded waste plastic during the production of the CEB. However, a binder that is cheap, environmentally-friendly and readily-available locally should be preferred.

Conflict of interest disclosures

The authors declare that there are no conflict of interest.

Acknowledgements

The authors are grateful to the Covenant University Centre for Research, Innovation and Discovery (CUCRID), Covenant University, Ota, Nigeria for sponsoring the publication of this article.

References

[1] R.O. ViforJ, Why Rents, Not Property Prices, Are Best to Assess Housing Supply and Need-driven Demand, Conversat, (2018) . (accessed November 17, 2018) https://theconversation.com/why-rents-not-property-prices-are-best-to-assess-housing-supply-and-need-driven-demand-100383.
[2] E.L. Glaeser, J. Gyourko, R.E. Saks, Why have housing prices gone up? Am. Econ. Rev. 95 (2005) 329–333, doi:http://dx.doi.org/10.1257/000282805774669961.
[3] C. Martin, L. Troy, Two Pictures of Rental Housing Stress and Vulnerability Zero in on Areas of Need, Conversat, (2017) . (accessed November 17, 2018) https://theconversation.com/two-pictures-of-rental-housing-stress-and-vulnerability-zero-in-on-areas-of-need-77714.
[4] M. Carliner, E. Marya, Rental housing: an international comparison, Res. Brief (2016) 1–7. http://www.jchs.harvard.edu/sites/default/files/brief_international_housing_carliner_marya.pdf.
[5] B. Szekely, In search of the world's best city for renters—rental affordability in the finest cities around the globe, RENTCafé Rent. Blog. (2018). (accessed November 21, 2018) https://www.rentcafe.com/blog/rental-market/rent-to-income-ratio-in-cities-of-opportunity-around-the-world/.
[6] P.W. Ihuah, Building materials costs increases and sustainability in real estate development in Nigeria, Afr. J. Econ. Sustain. Dev. 4 (2015) 218–233, doi:http://dx.doi.org/10.1504/AJESD.2015.071907.
[7] F.P. Eshofonie, Factors Affecting Cost of Construction in Nigeria, Master's Degree Dissertation, University of Lagos, Lagos, 2008 44 p.
[8] I.I. Akinwumi, Earth building construction processes in Benin city, Nigeria and engineering classification of earth materials used, Indian J. Tradit. Knowl. 13 (2014) 686–690.
[9] I.I. Akinwumi, P.O. Awoyera, O.O. Bello, Indigenous earth building construction technology in Ota, Nigeria, Indian J. Tradit. Knowl. 14 (2015) 206–212.
[10] I.I. Akinwumi, O.M. Olatunbosun, O.M. Olofinnade, P.O. Awoyera, Structural Evaluation of Lightweight Concrete Produced Using Waste Newspaper and Office Paper, 6(2014) .
[11] A.A. Busari, I.I. Akinwumi, P.O. Awoyera, O.M. Olofinnade, J.C. Tenebe, T.I. Nwanchukwu, Stabilization effect of aluminum dross on tropical lateritic soil, Int. J. Eng. Res. Africa 39 (2018) 86–96.
[12] G.P. Ganapathy, R. Gobinath, I.I. Akinwumi, S. Kovendiran, M. Thangaraj, N. Lokesh, S.M. Anas, R. Arul, P. Yogeswaran, S. Hema, Bio-enzymatic stabilization of a soil having poor engineering properties, Int. J. Civ. Eng. 15 (2017) 401–409, doi:http://dx.doi.org/10.1007/s40999-016-0056-8.
[13] I.I. Akinwumi, I. Ukegbu, Soil modification by addition of cactus mucilage, Geomech. Eng. 8 (2015) 649–661, doi:http://dx.doi.org/10.12989/gae.2015.8.5.649.
[14] I.I. Akinwumi, C.A. Booth, Experimental insights of using waste marble fines to modify the geotechnical properties of a lateritic soil, J. Environ. Eng. Landsc. Manage. 23 (2015) 121–128.
[15] I.I. Akinwumi, O.I. Aidomojie, Effect of Corncob ash on the geotechnical properties of lateritic soil stabilized with Portland cement, Int. J. Geomatics Geosci. 5 (2015) 375–392.
[16] I. Akinwumi, Soil modification by the application of steel slag, Period. Polytech. Civ. Eng. 58 (2014) 371–377, doi:http://dx.doi.org/10.3311/PPci.7239.
[17] I.I. Akinwumi, Plasticity, strength and permeability of reclaimed asphalt pavement and lateritic soil blends, Int. J. Sci. Eng. Res. 5 (2014) 631–636.
[18] I.I. Akinwumi, O.O. Ajayi, M.C. Agarana, A.S. Ogbiye, O.O. Ojuri, A.O. David, Investigation of calcium carbide residue as stabilizer of tropical sand for use as pavement material, Proc.24th Int. Conf. Urban Transp. Environ. (2018).

[19] R. Geyer, J.R. Jambeck, K.L. Law, Production, use, and fate of all plastics ever made, Sci. Adv. 3 (2017) 1–5, doi:http://dx.doi.org/10.1126/sciadv.1700782.
[20] A. Yekeen, Investigation: FG's N392m waste recycling plants in Osun, Ekiti, Kaduna lie in ruins, Int. Cent. Investig. Rep. (2018). (accessed April 1, 2019) https://www.icirnigeria.org/investigation-fgs-n392m-plastic-waste-recycling-plants-in-osun-ekiti-kaduna-lie-in-ruins/.
[21] IANS, Urban Flooding Caused by Plastic Clogging, Poor Drainage: Experts, News Minute, (2017) . (accessed April 1, 2019) https://www.thenewsminute.com/article/urban-flooding-caused-plastic-clogging-poor-drainage-experts-68194.
[22] United Kingdom Government Office for Science, Foresight Future of the Sea: A Report From the Government Chief Scientific Adviser, (2018) .
[23] J. Guy, Dead Whale in Indonesia Had Swallowed 1,000 Pieces of Plastic, CNN, 2018. https://edition.cnn.com/2018/11/20/asia/indonesia-whale-plastic-scli-intl/index.html.
[24] H. Janfeshan Araghi, I.M. Nikbin, S. Rahimi Reskati, E. Rahmani, H. Allahyari, An experimental investigation on the erosion resistance of concrete containing various PET particles percentages against sulfuric acid attack, Constr. Build. Mater. 77 (2015) 461–471, doi:http://dx.doi.org/10.1016/j.conbuildmat.2014.12.037.
[25] M.K. Mondal, B.P. Bose, P. Bansal, Recycling waste thermoplastic for energy efficient construction materials: an experimental investigation, J. Environ. Manage. 240 (2019) 119–125, doi:http://dx.doi.org/10.1016/j.jenvman.2019.03.016.
[26] I.I. Akinwumi, O.O. Ojuri, D. Edem, A.S. Ogbiye, Sawdust stabilization of lateritic clay as a landfill liner to retain heavy metals, Geotech. Spec. Publ. (2016), doi:http://dx.doi.org/10.1061/9780784480144.047.
[27] S.R. Rahimi, I.M. Nikbin, H. Allahyari, T.S. Habibi, Sustainable approach for recycling waste tire rubber and polyethylene terephthalate (PET) to produce green concrete with resistance against sulfuric acid attack, J. Clean. Prod. 126 (2016) 166–177, doi:http://dx.doi.org/10.1016/j.jclepro.2016.03.074.
[28] I.M. Nikbin, R. Saman Rahimi, H. Allahyari, F. Fallah, Feasibility study of waste poly ethylene terephthalate (PET) particles as aggregate replacement for acid erosion of sustainable structural normal and lightweight concrete, J. Clean. Prod. 126 (2016) 108–117, doi:http://dx.doi.org/10.1016/j.jclepro.2016.02.143.
[29] A.A. Badejo, A.A. Adekunle, O.O. Adekoya, J.M. Ndambuki, K.W. Kupolati, B.S. Bada, D.O. Omole, Plastic waste as strength modifiers in asphalt for a sustainable environment, Afr, J. Sci. Technol. Innov. Dev. 9 (2017) 173–177, doi:http://dx.doi.org/10.1080/20421338.2017.1302681.
[30] Z. Leng, R.K. Padhan, A. Sreeram, Production of a sustainable paving material through chemical recycling of waste PET into crumb rubber modified asphalt, J. Clean. Prod. 180 (2018) 682–688, doi:http://dx.doi.org/10.1016/j.jclepro.2018.01.171.
[31] A.F. Ahmad, A.R. Razali, I.S.M. Razelan, Utilization of polyethylene terephthalate (PET) in asphalt pavement: a review, IOP Conf. Ser. Mater. Sci. Eng. (2017) 1–7, doi:http://dx.doi.org/10.1088/1757-899X/203/1/012004.
[32] S. Angelone, M. Cauhapé Casaux, M. Borghi, F.O. Martinez, Green pavements: reuse of plastic waste in asphalt mixtures, Mater. Struct. Constr. 49 (2016) 1655–1665, doi:http://dx.doi.org/10.1617/s11527-015-0602-x.
[33] M. Oyinlola, T. Whitehead, A. Abuzeinab, A. Adefila, Y. Akinola, F. Anafi, F. Farukh, O. Jegede, K. Kandan, B. Kim, E. Mosugu, Bottle house: a case study of transdisciplinary research for tackling global challenges, Habit. Int. 79 (2018) 18–29, doi:http://dx.doi.org/10.1016/j.habitatint.2018.07.007.
[34] Z. Muyen, T. Barna, M. Hoque, Strength properties of plastic bottle bricks and their suitability as construction materials in Bangladesh, Progress. Agric. 27 (2016) 362–368, doi:http://dx.doi.org/10.3329/pa.v27i3.30833.
[35] ASTM D422-63, Standard Test Method for Particle-Size Analysis of Soils, ASTM International, West Conshohocken, PA, 2007.
[36] ASTM D854-00, Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer, ASTM International, West Conshohocken, PA, 2000.
[37] ASTM D4318-00, Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, ASTM International, West Conshohocken, PA, 2000.
[38] ASTM D698-07, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft3 (600 kN-m/m3)), ASTM International, West Conshohocken, PA, 2007.
[39] E. Obonyo, J. Exelbirt, M. Baskaran, Durability of compressed earth bricks: assessing erosion resistance using the modified spray testing, Sustainability 2 (2010) 3639–3649, doi:http://dx.doi.org/10.3390/su2123639.
[40] F.R. Arooz, R.U. Halwatura, Mud-concrete block (MCB): mix design & durability characteristics, Case Stud. Constr. Mater. 8 (2018) 39–50, doi:http://dx.doi.org/10.1016/j.cscm.2017.12.004.
[41] B.S. Waziri, Z.A. Lawan, M. Mala, B. Shehu Waziri, Z. Alhaji Lawan, A. Mala, Properties of compressed stabilized earth blocks (CSEB) for low- cost housing construction: a preliminary investigation, Int. J. Sustain. Constr. Eng. Technol. 4 (2013) 2180–3242. http://penerbit.uthm.edu.my/ojs/index.php/IJSCET.
[42] I.B. Muhit, Evaluation of stabilized soil blocks with the inclusion of 'Plastic Fibre' as sustainable building material: a complete review, Int. Conf. Mech. Ind. Mater. Eng. (2013) 1–5 Rajshahi, 2013.
[43] Turkish Standards Institution (TS 704), Clay Bricks-Wall Tile, Turkish Standard Institution, Ankara, 1983.
[44] Turkish standards institution (TS 705), Solid Bricks and Vertically Perforated Bricks, Turkish standards institution, Ankara, 1985.