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Review on the role of solid waste materials in soft soils reengineering

Kennedy Chibuzor Onyelowe *

Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike, P. M. B. 7267, Umuahia 440109, Abia State, Nigeria
Research Group of Geotechnical Engineering, Construction Materials and Sustainability, Hanoi University of Mining and Geology, Hanoi, Viet Nam

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ABSTRACT

Environmental degradation resulting from CO_2 emission and the constant collapse of foundation of facilities more especially pavements in Nigeria has posed serious threat to the overall economic growth of the nation. More so, Nigeria lacks an efficient solid waste disposal mechanism and policies hence indiscriminate disposal of waste poses yet another threat. This review work has brought to bear the interrelations between these problems. Geotechnical engineering in this paper serves as a locus to bring these threatening environmental conditions into workable and beneficial stream. First this paper tries to outline selected solid waste materials from which geomaterials utilized in the stabilization of soft soils are derived by direct combustion or crushing. Secondly, the utilization of these derivatives, which serve as alternative cement in stabilization of soft soils presents construction methods devoid of CO_2 emission because these materials are eco-friendly. Lastly, by adapting the use of these materials in soil strength improvement, the solid wastes find their way out through the recycling process and eventual usage as geomaterials sources. Research results have shown that these materials derived from solid waste because of their high aluminosilicate content improved the mechanical and strength properties of soils.

Contents

* Address: Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike, P. M. B. 7267, Umuahia 440109, Abia State, Nigeria.
E-mail address: konyelowe@mouau.edu.ng

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1. Introduction

Soft soils encountered in construction works pose a big threat to the overtime performance and operation of facilities whose foundation or underlain structure is made of these materials [1–6]. Pavements and pavement foundations are subjected to traffic loads like the form presented in Fig. 1, which could be axial or lateral pressure [7]. The structures suffer lots of unacceptable behaviour from construction cracks, volume changes to total collapse like the form presented in Figs. 2 and 3 if the foundation is such that the material is weak and lacks the sufficient strength to bear the loads [7–15]. On the other hand, reengineering of soft clay soils is a procedure or method adopted by the experts in geotechnical engineering and soil mechanics to improve the properties of soils to meet minimum standard requirements [7,15–21]. These minimum standard requirements are the conditions that justify the materials use as a foundation material or as a geomaterial [19,22]. Soil reengineering involves mechanical, chemical and biochemical procedures. Through the application of these methods, soft soils achieve strength, density and durability [23–29]. In recent years, the problem of choosing between which of these methods will give a more sustainable approach has been there [27,30–32]. Earlier, Portland cement and other chemical additives and chlorides have been the only materials utilized as binders or pozzolans to improve on the mechanical properties of the soft soils or expansive soils [33]. Upon the use of these mentioned materials, there has been a build-up of the CO_2 emission into the atmosphere. This consequently contribute to global warming and eventually

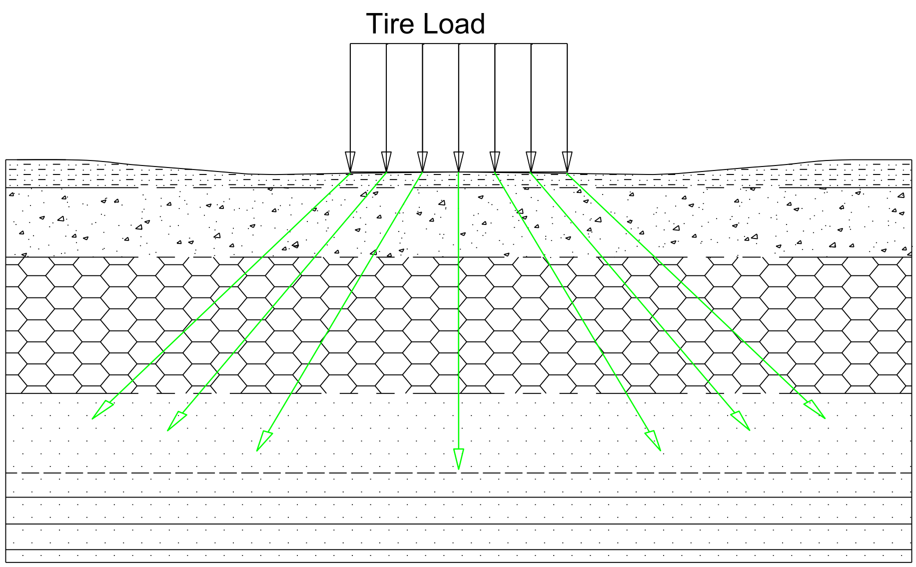

Fig. 1. Cross section of pavement under traffic cyclic loading [7].

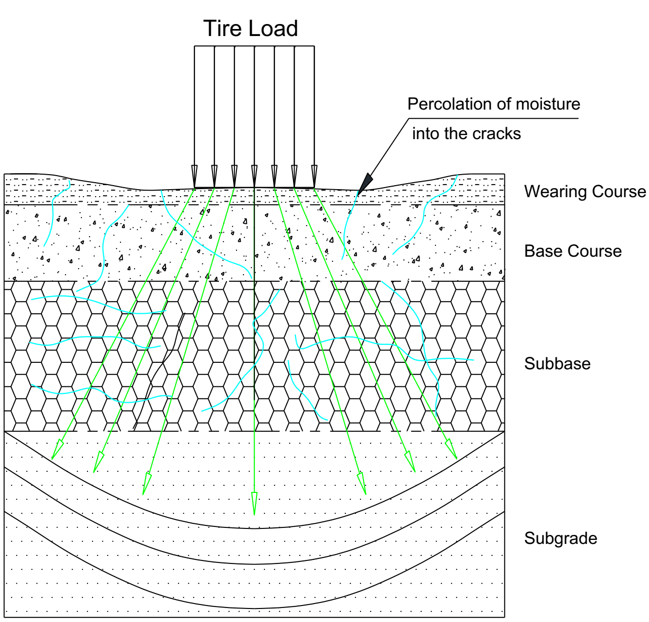

Fig. 2. Cross section of pavement with crack propagation at subgrade failure under traffic cyclic loading [7].

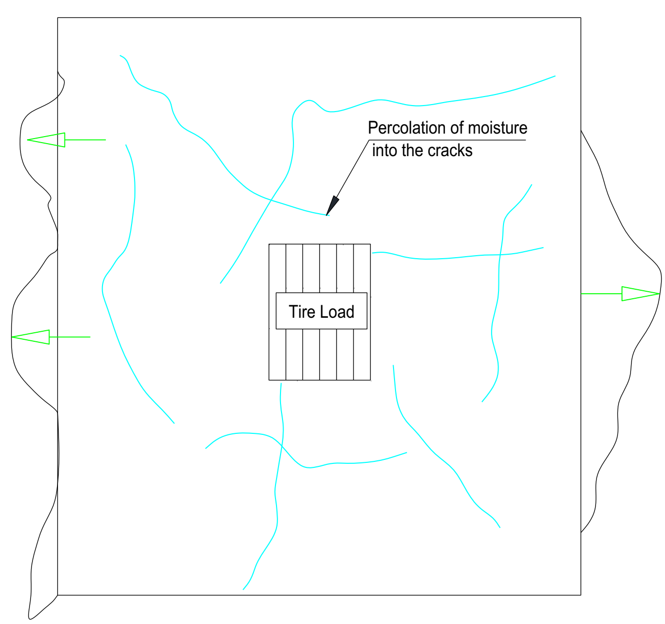

Fig. 3. Plan of pavement with crack propagation at subgrade failure under traffic cyclic loading [7].

continue to put the environment at risk. For each tonne of Portland cement used in construction works, an equivalent amount of CO_2 is released into the atmosphere. Research has been ongoing to search for an alternative for Portland cement. It has been discovered that most ash materials are pozzolanic in nature with very high content of aluminosilicates [33]. So also are most crushed materials into powder form. These ash and powder are all derived from solid waste materials [34–40]. For example, palm bunch ash, paper ash, periwinkle shell ash and snail shell ash, egg shell ash, bagasse ash, wood ash, rice husk ash, etc. are derived from palm bunch, waste paper, periwinkle shell, snail shell, egg shell, sugarcane fibre, wood, rice husk, etc. respectively [7,34–47]. Again, oyster shell powder, quarry dust, snail shell dust, sawdust, crushed ceramics, crushed glasses, crushed plastics, etc. are derived from oyster shell, quarrying, snail shell, wood sawing, waste ceramics, waste glasses, waste plastics, etc. respectively [3–10,34–47]. Research has shown that these materials contain high content of aluminosilicates hence highly pozzolanic [33]. This means that they can replace Portland cement as alternative cementing materials or supplementary cementing materials. They are all derivatives of solid wastes and sustainably serve the purpose of soft soil reengineering. A step further has been the synthesis of geopolymer cements with the derivatives of these solid waste materials as the base materials [28]. Pavement facilities fail every day and this is caused by use of soils that are inadequate in strength and durability more especially in hydraulically bound conditions [20–34]. The aim of this work is to review the improvement that have been recorded in the utilization of geomaterials derived from solid waste in the reengineering of soft clay soils with emphasis on; (i) review of selected geomaterials derived from solid waste recycling, (ii) review of the reengineering process with these materials, and (iii) review of the improvements made or results achieved.

2. Methodology

2.1. Selected solid waste materials

There have been lots of solid waste materials disposed into the environment more especially in the developing countries where solid waste management has been a huge problem. The selected solid waste materials from where the geomaterials are derived are palm bunch, quarry materials, palm kernel shell, snail shell, periwinkle shell, sugarcane fibre, waste ceramics, waste plastics, waste glasses, rice husk, wood, etc. These materials are solid wastes from industries, farms, homes, etc. and they are disposed indiscriminately into the environment. Geotechnical experts found need for these materials because of their aluminosilicate contents when burnt into amorphous ash or crushed into powder form [33]. The crushed materials most cases are biodegradable materials i.e. for those that are bio-based like snail shell powder, oyster shell powder, periwinkle shell powder. These are better when converted to ash by direct combustion. Oxide composition test conducted on these ash and powder materials showed that the alumina, silica ferrite composition was above 70% which is the minimum requirement for a materials to be considered pozzolanic [33]. The ash and powder materials are prepared and stored in bags. The methods of preparation are by direct combustion and crushing. And they are utilized in the stabilization of soft soils by measuring proportions in percentage by weight of solid and blended in matrix form with the treated soil. The number of proportions, which effects are to be examined determine the number of specimens to be prepared for the test procedure. In the case of biomass, ash or dust based geopolymer cement, the synthesis is enhanced under the reactive stimulus of Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) which act as activators [23–32]. These solid waste derivatives are all eco-friendly materials and with the utilization as a replacement for Portland cement in soft soil reengineering, CO2 emission is reduced to zero. Within the mixed soil-additive blend, reactions take place with produce compounds responsible for strength gain and durability. This happens at the adsorbed complex or the double diffused layer (DDL). This is the interface of the dipole rearrangement where cation exchange reaction take place between the clay dipolar network and the additive dissociated ions. The formation of calcium aluminate hydrate (CAH) and calcium silicate hydrate (CSH) is of utmost importance because these are the compounds responsible for strength gain and durability.

2.2. Experimental programs

Preliminary tests are conducted to determine the basic properties of the test soils. It has been observed that a good number test soil collected for construction purposes don't meet the requirement for a soil material to be considered acceptable for foundation works [48–52]. This is due to their formation, plasticity index, swelling potential, shrinkage limit, strength properties, etc. the results of these tests will determine whether the soil requires improvement, modification or reengineering. Problem soils, that is, soils that are expansive, highly plastic, high swelling potentials, low shrinkage limits, high cracking tendencies, weak, etc. require soil improvement to enhance these mechanical properties to enable it meet the requirements required for soils to be used as foundation materials [48–54]. These treatment experimentations are carried out in accordance with British standard and Nigerian General Specifications [48–51,53,54]. These geomaterials utilized to improve the properties of soft soils are measured as proportions in percentage of the solid and mixed. Specimens are prepared according to the test being conducted which of course determines the number of specimens to be prepared for test experiments. In very common cases, the additives are measure in an increment of 5% or 10% by weight of the solid. The effect of increased proportions of the additives on the properties is closely observed and recorded. General test methods are mostly used but in some cases some modified methods are adopted like in the case of durability test by loss of strength on immersion method, and stiffness test like resilient modulus and resistance value tests, which are modified methods of triaxial compression test.

3. Review of results and discussions

3.1. Compaction characteristics

Research results have shown that the materials derived from solid wastes exhibit binding properties because of their aluminosilicates content and applied to soft soils as admixtures in a stabilization process improve the maximum dry density consistently with increased proportions of the additives [7,55–61]. This according results is due to the cation exchange reactions and the admixtures filling the voids within the soil matrix [59]. In addition, it is due also to the formation of floccs and agglomeration of the clay particles due to polarization, release and exchange of ions. The cause of this trend is because there was increasing desire for water, which makes up with the higher amount of admixtures. This is because more water was needed for the dissociation of the ions of admixtures with Ca^{2+} and OH^{-} ions to supply more Ca^{2+} for the cation exchange reaction [33,61–69]. It was also observed that optimum moisture content reduced consistently with addition of these additives. This is due to the formation of flocs within the clay complex. The additives are highly pozzolanic materials and require water for hydration thereby improving the dry density development of the treated soils [65–68].

3.2. Consistency limits

The utilization of geomaterials derived from solid waste has consistently caused an improvement of the consistency limits. Most of the soils we encounter in construction around here have a plasticity index of above 17%, which is highly plastic [7,69–71]. The admixtures we have utilized in soils stabilization have improved the Plasticity Index (PI) from "highly plastic" soils to "medium plastic" consistency at the addition of the ash or powder materials. This trend showed that further addition of the admixtures will equally reduce the PI further [7,69–71]. The hydration of the stabilized soil and its increased reactive surface has contributed to the improved behaviour of the soft soils and also due to molecular rearrangement in the formation of transitional compounds. This improvement is due to the hydration of the highly pozzolanic additives with the treated matrix, which reduced the PI consistently thereby producing a stiff mixture of stabilized soft soil. Also, the release of cations from the ash or powder materials and quarry dust during the cation exchange reaction has contributed to the enhanced behaviour of the treated soil. This behaviour agrees with Meegoda and Ratanweera [72], which showed that if water is used as pore fluid, the influence of the mechanical factors would remain same with a general decrease in LL on addition of any of the admixtures [7]. Consequently, the use of the treated soft soil as a subgrade and base material has been improved by the presence of the additives and this also achieved non-frost-susceptible materials with PI less than 15; a very important factor affecting the durability of pavements and other civil engineering works founded on soil [72]. The achieved subgrade improvement will reduce the required pavement thickness; wearing course + base course, hence a cost effective and more durable pavement construction.

3.3 Volume. change characteristics

3.3.1. Swelling potential

In hydraulically bound conditions like the pavement subgrade and the entire pavement, and other substructures constantly exposed to moisture attack, the foundation materials suffer changes in volume [7]. This is because the foundation materials are majorly clay or of high clay content like the problem soils we encounter in construction. When this underlain materials swell beyond the acceptable limits because of the rate at which moisture migrate to the clayey soil materials, they form heaves and cracks develop [34–39]. This cracks give way for more intake of moisture down the foundation and eventual collapse of the structure becomes evident. So, there is need to improve on the swelling behaviour of the foundation materials by admixture stabilization and of course the mechanical means by which densification is achieved. Research conducted has shown that these geomaterials utilized in the process of stabilizing soft clay soils improve the swelling potential of the treated soils to within acceptable limits [72]. This behaviour was due to that the higher content of sodium silicates activator for the case of solid waste based geopolymer cements and aluminosilicate in all other solid waste derivatives tend to increase the release of Ca^{2+}, Si^{4+} and Al^{3+} from the soft soil complex, which eventually speeded up geopolymerization and pozzolanic reaction rates. The Na_2SiO_3 activator acted as a nucleating site then increased with the amount of silicates released leading to the formation of more hydration points. And as the concentration of hydration materials increased, the number of contact points between hydration materials also increased consequently forming a solid microstructure within the treated soils matrixes reducing swelling potential

3.3.2. Shrinkage limits

On the other hand, when soft clay soils increase in volume as a result of water intake, it takes some time to revert to its original volume. In the case of clay, this reduction exceeds even the original volume to what we call shrinkage. There are acceptable limits for shrinkage problems in problem soils. When the soils shrink beyond the acceptable limit, then it leads to the formation of cracks. Crack formation is the major problem faced with use of Portland cement. But with use of biomass based geomaterials or geopolymer cements, crack resistant structure is achieved [7,33].

3.4. Strength developments characteristics

3.4.1. California bearing ratio (CBR)

The CBR is the measure of a material to withstand shear failure by punching or penetration. It is an axial failure test conducted on soils to be used as foundation or subgrade materials. Various solid waste derivatives utilized as stabilizing agents have shown a consistent improvement in the CBR of the treated soft soils. These improved values >20%, satisfy the material condition for use as improved sub-grade material on Nigeria's south eastern roads (Nigerian General Specification, 1997). The consistent increase in the CBR value with the addition of derivatives of solid waste was due to the presence of adequate amount of calcium required in the formation of Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrate (CAH), which are the major compounds responsible for strength development [72]. The soil + additive blends passed to meet the minimum CBR value of 20–30% specified by Gidigasu and Dogbey [73], for materials suitable for use as base course materials when determined at MDD and OMC. Increase in CBR is an indication of the increase in MDD which is attributed to the compatibility of the grains of soils due to the increased reactive complex created by the additives and the high pozzolanic properties of the additives such that greater polycondensation and flocculation were achieved [7,33–45].

3.4.2. Unconfined compressive strength

UCS is the measure of the ability of test materials to withstand compression. It is part of the stiffness measurement of construction materials like soils. During the treatment tests, the treated test specimens are cured for 7, 14 and 28 days. The test for durability was a modified form of the UCS test but in this case, the specimens were cured for 14 days and immersed for 14 days. The results of the additives effect on the UCS showed a consistent pattern of improvement in compressive strength. The presence of the admixture derived from solid waste materials in the soft soils increased the strength properties of the stabilized mixture. This is attributed to the physicochemical and highly pozzolanic properties of the admixtures from recycled solid wastes and to its ability to reduce adsorbed water thereby making soils with higher clay content to behave like granular soil. The addition of these additives derived from solid waste also improved the durability of the treated soft soils

3.4.3. Resilient modulus

This is one of the major stiffness determination factors that is a function of lateral pressure and deviatoric stress. The applied deviator stress and the recoverable strain techniques of the modified triaxial test on the treated specimens were used [7]. The tested soils behaved in almost the same pattern with similar reactions with increased additives of solid waste base. The deviatoric stress consistently increased with increase in the proportion of the admixtures for the test soils. It is important to note at this point that the additives are highly aluminosilicate compounds with a crystal texture prior to its utilization in the stabilization procedure [40–45]. These compounds are responsible for pozzolanic reaction, and strengthening by forming silicates of calcium hydrates and aluminates. Test soils had shown an improvement index of above 20. The highest improvement index recorded with test soils 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 additives and the dissociated soil ions in contact with moisture had caused the improvement on both deviatoric stress and resilient modulus of the test treated soils. 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 admixtures derived from solid waste, hence improving the strength behaviour of the treated soils.

3.4.4. Resistance value

Resistance value test conducted on solid waste base geomaterials treated soft soils showed a consistent improvement in the r-value of the soft soils increasing its resistance to lateral deformation [7]. This improvement was recorded with increased proportions of the geomaterials. This improvement was due to formation of CAH and CSH from the adsorbed complex reaction between clay and the additives [24]. These compounds form the building block of strength gain and density development in treated soils thereby increasing its ability to withstand lateral deformation. This behaviour is due to molecular rearrangement between the dissociated ions from softs clay soils and the additives at optimum moisture within the DDL.

4. Summary remarks

Geomaterials derived from solid waste, soft soil reengineering, and results of the effect of solid waste derivatives on soft clay soils used as foundation materials have been reviewed. This article has outlined the methods of derivation of amorphous ash and powder from solid waste and the procedure through which these materials are utilized in the improvement of the mechanical and strength properties of soft soils. This being aimed at making the soft soils or problem soils or expansive soils usable as foundation materials in a stabilization process. This procedure not only improves on the properties of the soils to meet certain minimum standards for soils to be used as subgrade materials but also reduced to almost zero or zero the CO_2 emission into the atmosphere and also created an avenue for proper disposal of solid wastes through recycling.

Conflict of interest

There are no conflict of interest recorded in this paper.

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