Recycling and reuse of solid wastes; a hub for ecofriendly, ecoefficient and sustainable soil, concrete, wastewater and pavement reengineering

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Abstract

Ecofriendly, ecoefficient and sustainable civil engineering work has been research with emphasis on adapting the byproducts of solid waste recycling and reuse to achieving infrastructural activities with low or zero carbon emission. The direction combustion model, the solid waste incinerator caustic soda oxides of carbon entrapment model (SWI-NaOH-OCEM) developed by this research has achieved a zero carbon release. This research adopted the literature search method to put together research results of

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previous works relevant to the aim of this present work. It has been shown that CO and CO_2 emissions can be contained during the derivation of alternative or supplementary cementing materials used in the replacement of ordinary Portland cement in civil engineering works. In the overall assessment of the present review work has left the environment free of the hazards of CO and CO_2 emissions. It was shown that these supplementary cementing materials derived from solid wastes improve the engineering properties of treated soft clay and expansive soils, concrete, and asphalt. Bio-peels, another form solid waste has been established as a good detoxificant used in treating wastewater. It has been shown that solid waste recycling and reuse is a hub to achieving ecofriendly, ecoefficient and sustainable infrastructural development on the global scale.

Keywords: CO_2 emission; recycling and reuse of solid waste; ecofriendly reengineering; ecoefficient reengineering; sustainable reengineering; soil-concrete-wastewater-pavement reengineering

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1 INTRODUCTION

Solid waste handling and management around the world and more especially in the developing countries have contributed to the whooping amounts in tons of carbon dioxide (CO_2) and carbon monoxide (CO) emission and consequently on the threat of global warming [1–8]. Lots of human activities are involved in this negative contribution to environmental hazard including; construction activities that utilize Portland cement, industrial activities that release oxides of carbon and other volatile gases, agricultural activities that release biomass and biopeels, mechanical activities for example engine-fuel combustion, which releases CO/CO^2, etc. [9–12] The direct combustion or crushing, after they have been carefully sorted (see Figure 1), of agricultural, household, municipal and certain biomass materials is not left out in this list [13–20]. All these activities release CO and CO_2 into the atmosphere which contributes over 80% of the worlds volatile and hazardous emissions. More important to deal with in this present work is the recycling and reuse of solid waste materials by sorting, burning to ashes or crushing as the case may be and the utilization of the product of this process (ash or powder) in various ways in construction works (See Figures 1–5) ([13, 21–47]). A certain class of solid wastes known as bio-peels are also discharged into the landfills and they decay emitting volatile and dangerous gaseous compounds, which eventually impress on the environment and humanity in general [48, 49]. Very many others belong to the group of wastes that are also discharged on landfills and this poses a serious threat to the environment [7, 50–53]. In recent times, there have been strong calls for experts in engineering to work and exercise their expertise and practice towards ecofriendly, eco-efficient and more sustainable operations and designs to protect our planet from the dangers of global warming [8, 54]. Ordinary Portland cement as it is known, contribute equivalent amount of CO_2 emission into the atmosphere as it has found its use in almost every civil engineering construction exercise. It is also known that cement has its low ebb/performance in terms of resistance to cracking, durability issues (long-term exposure to moisture), brittleness, fire and heat resistance and sulfate resistance [55–61]. On the other hand, solid waste materials derivatives like ash (amorphous) and powder/dust (crushed) have been discovered as possessing properties that not only replace cement in parts or whole, but improve on the resistance to sulfate attacks, heat, fire, suction, capillary action, sorption, cracking, etc. of infrastructures where they are adapted (See Figures 2–4) [55, 59–63]. Further on, these materials because of their high pozzolanic properties or high aluminosilicates contents have found use in the synthesis of geopolymer cements utilized in various proportions in soft soils reengineering, asphalt and concrete modification [55, 59, 60, 62–64]. It is also important to note that bio-peels and certain solid waste ashes have found their engineering use in detoxification of wastewater and purification exercises (see Figure 3) and in the production of composite machine parts from alloys of Aluminum, Magnesium, Copper, etc. utilizing solid waste as reinforcements (see Figure 5) [65–72]. These operations are all ecofriendly and contribute nothing to the menace of global warming and the infrastructures arising from this have been shown by experimental results as eco-efficient in life service, performance and durability [26, 27, 73–78]. Also these environmental friendly binders (geopolymer cements) are derived from solid wastes under the influence of alkali activators (see Figures 2 and 4). Inasmuch as it is certain that human activity will never cease on the planet, there would always be an equivalent release of solid wastes (industrial, agricultural, household, and municipal, etc.). Hence sustaining this technology wouldn't be a problem at all. Among the numerous derivatives of solid waste that have been utilized in various civil engineering works include palm oil fuel ash, fly ash, quarry dust, rice husk ash, coffee husk ash, paper ash, waste tire ash, palm fiber, palm kernel shell ash, snail shell ash, periwinkle shell ash/powder, oyster shell powder, biomass ash, bagasse ash, egg shell ash, sawdust, crushed waste ceramics, crushed waste plastics, crushed waste glasses, bio-peels, metallurgical slag (ground granulated blast furnace slag), iron ore tailings, palm nut fiber, glass fibers, full

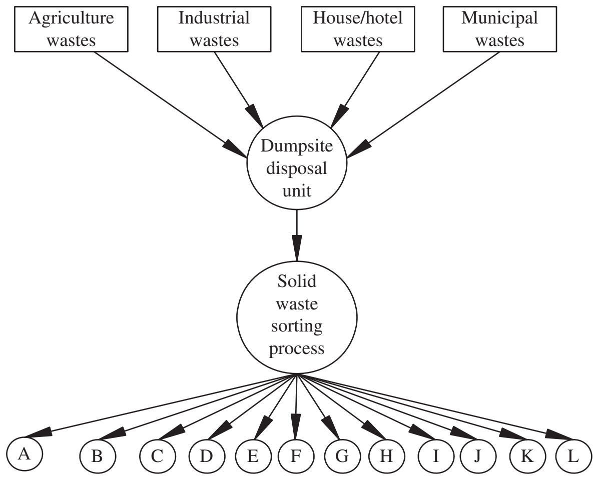

Figure 1. *Solid waste sorting process.*

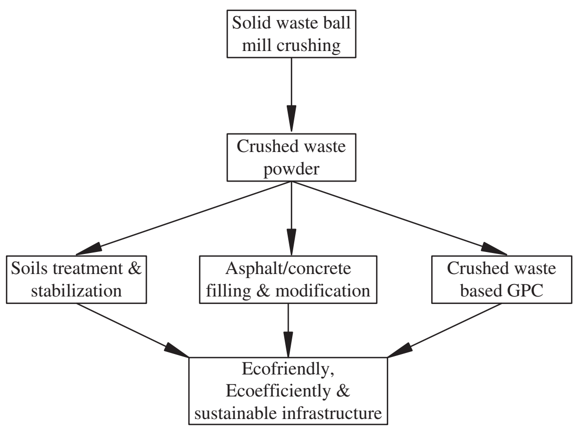

Figure 2. *Crushed solid waste production procedure and reuse for eco-friendly, ecoefficient and sustainable infrastructure.*

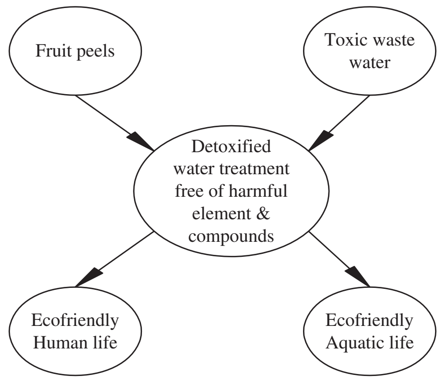

Figure 3. *Bio-peels reuse in detoxification of wastewater.*

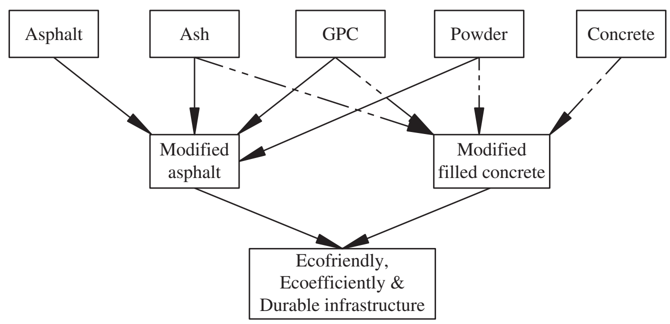

Figure 4. *Solid waste ash/powder utilization in asphalt and concrete modification process.*

depth reclaimed asphalt, etc. [13–20, 79–82]. It is important to note that this work is aimed at reviewing the recycling and reuse of solid waste as a hub to achieving ecofriendly, ecoefficient and sustainable civil and mechanical engineering infrastructure with low or zero carbon generation and emission. Our planet continues to be endangered with these emissions from agricultural, industrial, household and municipal processes and requires emergency reversal of those activities contributing to its depletion [14, 17, 83–87].

2 CONVENTIONAL SOIL, CONCRETE, WASTEWATER AND PAVEMENT ENGINEERING

Many centuries and decades ago, engineering dwelt on conventional methodologies, approaches and chemical based changes to create and solve environmental, structural, geotechnical, hydraulic, and mechanical problems [88–95]. The fundamental aim of solving an engineering problem revolves around an economy, efficient and durable design, with optimal performance and lifetime services and on the other hand changes made on an existing system that serve certain purposes and to meet certain desirable conditions for an efficient performance and overall assessment. In soil mechanics for example, the behavior of soil when exposed to various forms of forces or loads determines its acceptability in the areas of construction. It is also important to improve on those properties that have been observed to be below the minimum required standard in terms of its use in construction or production purposes. Concrete technology and designs have also being an interesting area because construction activities have found it central in most of its infrastructural activities. Wastewater management is also an important environmental problem that has attracted engineering attention in terms of handling and saving the environment from its menace. The treatment of waste water has been with certain chemical additives that eventually impress on the environment with the emission of volatile gases. Pavement engineering happens to be one of the most important infrastructural technologies that impart on every human life across the globe. The materials for its construction have been conventional and

Figure 5. *Composites of Al-, Mg-, Cu-alloys of machine parts made with solid wastes ash as reinforcements.*

known and they in the event of construction activities emit certain chemicals that affect the environmental lives of humanity. These civil engineering operations mentioned above affect our daily lives because of the release of the byproduct of those activities as highlighted. The use of ordinary Portland cement in soil and concrete engineering, certain chlorides and de-toxicants in wastewater treatment and bitumen/cement blend in pavement construction releases equivalent amount of CO and CO_2 into the environment [25, 96–102]. And the frequency with which these activities happen determines the future state of our planet. Construction and all civil engineering activities go on daily in a bid to solving man's many problems related to engineering and the environment. However, there is urgent need to reduce to zero or barest minimum the hazards introduced through these activities by moving towards ecofriendly activities and operations that would eventually solve these problems without the harms the environment is exposed to. So long as optimal operations are obtained eventually, the environment stands a chance to be healthy again in low carbon stream and imparts on global life existence.

3 RECYCLING AND REUSE OF SOLID WASTES METHODOLOGICAL REVIEW

3.1 Crushed solid wastes and powders

The utilization of various forms crushed solid waste in the reengineering of soil, concrete, wastewater and pavements has been made possible by the ball mill crushing of solid waste to obtain crushed waste plastics, crushed waste ceramics, crushed waste glasses, crushed oyster shell powder, etc. The selected solid waste materials are collected from dumpsites, sorted, washed and sundried. They are thereafter crushed with the ball mill to different sizes and texture. Characterization of these crushed powder materials is also done by particle size analysis (PSA) and UV-Vis Spectrophotometer analysis (UV-VSA). In more advanced technologies, the Canning Electron Microscopy (SEM), X-ray Fluorescent (XRF) or the X-ray Diffractometer (XRD) is used to determine through the plotted diffractograph, the micro properties and gradation behavior of the crushed materials. This also indicates the overall performance of the materials in blends with soil, concrete or asphalt. These crushed derivatives of solid waste have proven through experimentation to be good binders and fillers and modifiers in soil stabilization, concrete production and asphalt production respectively (see Figure 6) [87, 103–106]. These materials have been added in varying percentages by weight of treated homogenous mixture (soil. Concrete or asphalt) to improve their engineering properties. This has been possible because these materials were discovered to possess pozzolanic properties that enhance cementation processes [64, 107, 108]. Their ability to form compounds responsible for strengthening was as a results of high content of aluminosilicates, which makes it possible to calcium silicate hydrates (C-S-H) and calcium aluminate hydrates (C-A-H) with the treated mass or mixture.

3.2 Burnt solid wastes and ashes

The greatest amount of ash materials utilized in soil stabilization, concrete production, asphalt modification and the synthesis of geopolymer cements (GPC) are derived through direct combustion in well-designed incinerators (see Figure 6) [50, 52, 109, 110]. In most cases, this combustion exercise is uncontrolled. This by implication poses the greatest danger of CO and CO_2 emission to the environment. Like in the case of crushed solid wastes, the selected wastes are collected, sorted and burnt in an incinerator for a controlled combustion. In this case, a model of the incinerator has been designed to ensure that the CO and CO_2 released through the firing smoke is entrapped. This mechanism is to ensure that the whole essence of an ecofriendly operation in civil engineering works is not defeated. The utilization of ash or its forms in constructions and as geomaterials for the replacement of ordinary Portland cement is to reduce to zero those construction practices that release oxides of carbon into the atmosphere to ensure an environmental friendly activity. But the production of ash by combustion is against this aim. What has been done was to use the caustic soda-incinerator model to trap volatile gases released during the combustion process. The model is such that ensures that CO and CO_2 release during solid waste combustion is entrapped by caustic soda solution (prepared NaOH, 40% *w*/*v*). 100% of the CO and CO_2 released is trapped by the caustic soda solution because of the affinity caustic soda has with oxides of carbon. This entrapment produces sodium bicarbonate (baking soda, $NaHCO_3$), sodium carbonate (soda ash, Na_2CO_3) and hydrogen gas (H_2) presented in Equations (1) and (2);

$$NaOH + CO_2 \quad NaHCO_3 \tag{1}$$

$$NaOH + CO \quad Na_2CO_3 + H_2\uparrow \tag{2}$$

The caustic soda (sodium hydroxide) entrapped oxides of carbon that would been released to the environment with their dangers have been converted to household and industrial compounds. The use of baking soda ($NaHCO_3$) in households and industries cannot be overemphasized. So also is the use of soda ash (Na_2CO_3) in the synthesis of geopolymer cements; a geomaterial binder with great properties. Additionally, small amounts of the soda ash improves the flocculation properties of treated soft soils and treated wastewater by improving the binding of fine particles. Hydrogen gas is also a product of the Solid Waste Incinerator NaOH Oxides of Carbon Entrapment Model (SWI-NaOH-OCEM). This gas and its isotopes have many uses in the field of science and atomic physics. It is important to note that the products of this model; SWI-NaOH-OCEM are water soluble compounds and element and find beneficial uses to man and environment. However, ash which is the primary product of the SWI-NaOH-OCEM has been in several ways in construction works. Research results show that because of its amorphous nature and high aluminosilicates content, it acts as a binder with high pozzolanic property. It has several cases consistently improved the engineering properties of expansive soils, concrete, and asphalt.

3.3 Activated coupled solid waste derivatives and geopolymer cements

Environmental friendly Geopolymer cements are coupled binders synthesized by coupled-blending of solid waste ash or crushed waste ash under the activation influence of alkali activators. These are developed to attend to the urgent need for ecofriendly and ecoefficient binders and to totally or partially replace conventional cements (OPC) in all the civil engineering works to save our planet from the hazards of CO/CO_2 emission. The alkali activators are produced under the laboratory conditions with Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) as activators with a NaOH molar concentration of 12 M for an eco-friendly material [19, 20, 27, 59, 60, 74]. A proportion of 4.8% by weight activator is used to blend the selected ashes. Research results have shown that various forms of geopolymer cements have been synthesized from this operation which included quarry dust based geopolymer cement, crushed waste ceramics geopolymer cement, crushed waste glasses geopolymer cement, palm bunch ash based geopolymer cement, bagasse ash based geopolymer cement, etc. (see Figure 6) [13, 15, 16] These forms of GPC have shown to possess similar properties in terms of performance and behavior in their utilization as alternative or supplementary binders. The utilization of the GPC has shown to produce infrastructures with certain special properties [19, 20, 27, 59, 60, 74]. Results have shown that GPCs possess high potentials to resist sulfate attacks, moisture attacks in hydraulically bound environments, heat and high temperature, volume changes in soft clay and expansive soils, cracking in concrete structures, lateral displacement in asphalt pavement, capillary action, sorption and suction in subgrade materials and generally to improve the durability of civil infrastructures. In the run, the ecoefficiency of the facilities from these ecofriendly materials and geomaterials.

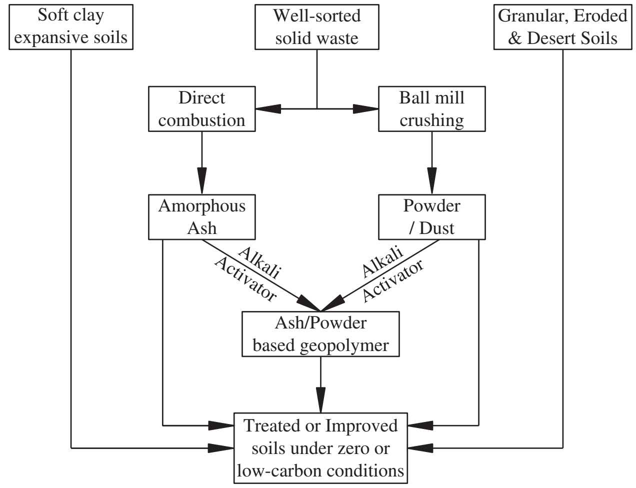

Figure 6. *Solid wastes combustion and ball milling and treatment of soft clay and granular soils.*

4 ECOFRIENDLY, ECOEFFICIENT AND SUSTAINABLE REENGINEERING AND ACHIEVEMENTS OF THE NEW TECH

For far too long, the environment has suffered the hazardous effects of CO and CO_2 emission through human and engineering activities, which deplete the ozone layer and its attendant contribution to global warming. Expert of climate change in different fora and congresses and summits have given to the world what CO/CO_2 emission is doing to our planet. Players in this menace destroying our planet have been urged to seek for ways and alternative processes to renew our planet through environmental friendly activities and practices. The utilization of Portland cement in civil engineering works seems to contribute a large amount of the oxides of carbon to the atmosphere because has shown that ordinary Portland cement (OPC) use releases equivalent of amount of CO_2 into the environment, that is to say that one ton of OPC used in any construction activity release an equivalent one ton of CO_2 into the atmosphere. This is shocking and dangerous and if these activities continue, the future of this planet seems gloomy and uncertain. OPC is used in civil engineering work for the reengineering of soils and concrete as structural and pavement foundation materials but this has failed both the ecofriendly dream environment by releasing CO_2 and eccoefficient product by failing durability tests because cemented structures are vulnerable to heat, sulfate, moisture, crack and shrinkage effects. On the other hand, ecofriendly materials that replace OPC as supplementary cementing materials are usually derived from direct combustion, another procedure that releases CO/CO_2 during the burning process. What this research has achieved among the ash derived from solid waste direct combustion, is trapping the CO/CO_2 released during solid waste combustion using the SWI-NaOH-OCEM (see Figure 7). From this model, we have the ash

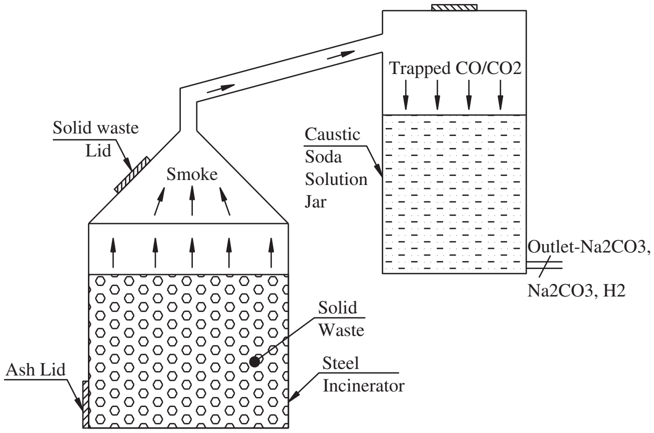

Figure 7. *SWI-NaOH-OCEM for solid waste combustion and CO/CO_2 entrapment.*

materials adapted to many different forms of geomaterials and construction materials, CO/CO2 entrapment and release of environmental friendly products ($NaHCO_3$, Na_2CO_3 and H_2) for household and industrial uses. Away from the ecofriendly disposition in handling and utilizing ash as a construction material, the treatment of soil, concrete, asphalt, etc. with ash and its products (geopolymer cements) produces structural infrastructures with high resistance to heat, temperatures, salts attacks, crack effects, punching deformations, lateral displacements, rise and fall of water tables, which give rise to volume changes (swelling and shrinkage), moisture and capillary actions and brittleness (see Figures 8 and 9) [19, 20, 27, 59, 60, 74]. These structures also possess higher durability potentials as shown by previous research results. Human, agricultural and industrial will always be parts of this environment hence the release of solid waste is a corresponding certainty. However the sustainability of the SWI-NaOH-OCEM is never in doubt and consequently the sustainability of the derivatives of solid wastes.

4.1 Consistency limits

Laboratory investigations carried out on soft clay soils treated with ash derived from solid waste and the coupled derivatives of ash; geopolymer cements and composites have shown tremendous and acceptable consistency behavior. The properties of these amorphous materials utilized in the treatment protocol promotes the pozzolanic and hydration reactions between clay minerals and dissociated ions of the additives within the activation complex interface improving on the liquid limits, plastic limits and plasticity indexes of the treated soils. Recent studies have proposed two methods through which expendable clay lattice in soft soils is identified and this procedure proves an important stage in the treatment and improvement of soils to meet engineering standards [111]. These methods are inferential testing and mineralogical identification methods. These direct methods of inferential testing are used to calibrate and standardize the consistency properties, which include the liquid limits, linear shrinkage limits, and gradation distribution. There are also indirect methods such as oedometer and free swell tests used to monitor the volume changes and consolidation settlement of these soft samples. The X-ray diffraction analysis (XRD), X-ray fluorescence (XRF), differential thermal analysis (DTA), dye adsorption, chemical oxides analysis, and scanning electron microscopy (SEM) belong to the mineralogical identification methods used to identify oxides and minerals contained in a soil specimen as to study the behavior when in contact with additives in a treatment procedure. Although the mineralogical identification methods are capable of adequately recognizing the clay minerals in soft clay soils, they are somewhat restricted in use when characterizing the swelling behavior due to various technical setbacks. The identification and characterization encourage a better understanding of the anticipated behavior of the soils when treated with ash and its derivatives as discussed above. Results have also shown that these understandings have helped in the consistent reduction in the plasticity indexes of soft clay soils treated with varying proportions of powder, ash and ash or powder based geopolymer cements. Interestingly, these achievements have been under environmental friendly activities i.e. devoid of ordinary Portland cement utilization, these test soils have improved from very high consistency ($PI > 17$) to medium consistency ($PI < 17$) and to low consistency ($PI < 7$) meeting the consistency requirements of soil materials to be used as foundation materials [112].

4.2 Compaction

Compaction behavior of soft soils treated with additives derived from solid waste, ash and powder is a density/moisture behavioral study. This translates to the densification achieved in soils during stabilization. This is a commonly used method of soft soils treatment achieving densification by mechanical methods and exerting compactive efforts and eventually reducing the voids in treated additive/soils blends [112]. This achieved to enable engineering soils withstand subsequent load without suffering immediate compression and this can be separated from those behavior characteristics initiated by long-term consolidation of soft clay soils. So it is very important to study and determine the moisture-density behavior of untreated and treated soils to establish improvements from the former. Ash materials are amorphous and contain ions dissociated when they react with clay minerals and water in a cation exchange reaction giving rise to ion combinations that support strengthening. The crushed materials (powder/dust) also act as fillers to improve on the porosity of the treated samples thereby improving the density. Results have shown significant reduction of the optimum moisture content (OMC) of treated soils more especially with the ash or powder based geopolymer cements because of the improved hydration reaction and moisture resistance of the polymers. The maximum dry density (MDD) obtained at OMC has also consistently improved in its properties under the influence of ash, powder and geopolymer cement additives in

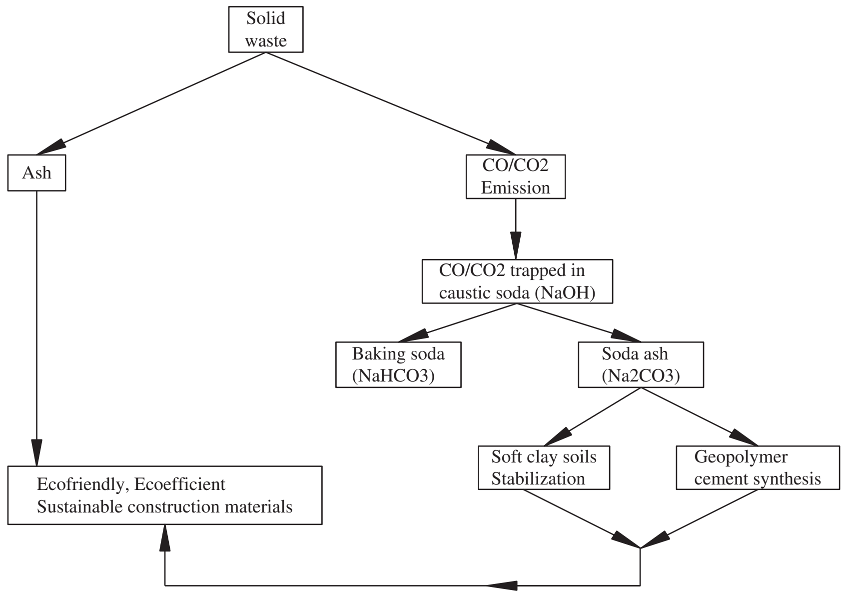

Figure 8. *Ash generation from SWI-NaOH-OCEM and the conversion of CO/CO_2 to baking soda and soda ash for use as activators and binders.*

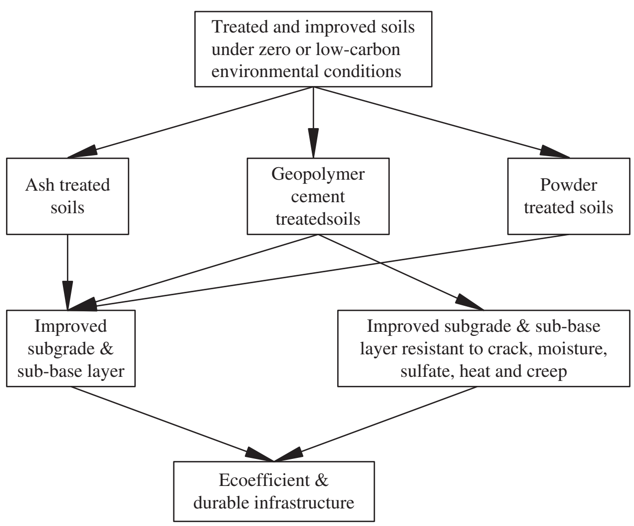

Figure 9. *Improvement of subgrade and subbase layers under low carbon conditions.*

varying proportions. The intergranular pores are improved upon by the addition of ash, powder or ash/powder based geopolymer cement, which eventually encourages densification during compaction exercises. Shape of soil grains and amount of type of clay minerals present in treated soils are soil dependent factors that influence the behavior of soft clay soils during stabilization operations. However the addition of these additives has improved the interface behavior of these factors.

4.3 Volume changes (swelling and shrinkage)

Swelling and shrinkage properties are very important factors that influence the behavior of engineering soils as foundation materials especially in hydraulically bound environments. Soils as foundation materials suffer moisture attacks through capillary action, suction, rise and fall of water table and lateral percolation [33, 35, 113, 114]. This is more prevalent in pavement structures. Volume changes cause undesirable characteristics that impair the performance and long-term service life of foundations and pavement infrastructures. Experimental results have shown that these undesirable properties of soft clay soils have been arrested by the addition of ash or powder or ash/powder based geopolymer cements in a stabilization procedure. First, the moisture resistance ability of the ash or powder materials derived from solid waste due to their composition and the hydration structure makes it possible for soils treated with them to behave within acceptable swelling limits [115]. There have been recorded reduction in swelling potentials through the addition of these additives. Conversely, these materials possess the ability to resist drying during the reverse phase of swelling, i.e. reduction of entrapped moisture. Shrinkage in soft clay soils leads to cracking and lateral deformations but the additions of solid waste derivatives has changed this undesirable behavior due to the ionic composition of aluminosilicates admixtures.

4.4 California bearing ratio

California bearing ratio (CBR) is a strength characteristic feature of soils used to determine its suitability to withstand shear deformations by punching and penetration. It establishes the overall thickness of pavements and other horizontal infrastructures. Because this has a direct relationship with the density of compacted soils, MDD is directly related to CBR. Natural and treated compacted soils are subjected to axial load and the axial strains are monitored. There are two conditions under which this is experimented. These are the soaked and unsoaked bearing ratios determined under 2.5 mm and 5.00 mm penetrations. As discussed earlier on compaction behavior of the treated soft soils, the ash materials and its derivatives improve on the density properties giving compactness that determines the California bearing ratio under axial loads [34, 36, 37]. These additives improve on the soils ability to form a densified mass and compaction completes the process of densification and strengthening.

4.5 Unconfined compressive strength and durability potential

Compressive strength of soft soils is one the strength characteristics of that has equally allowed the determination of long-term performance and behavior of treated soils more especially under hydraulic influence through loss of strength on immersion method. The failure point of a treated and compacted sample under compression is determined with respect to the sample surface area. The formation of calcium silicate hydrates and calcium aluminates hydrates with addition of ash, powder and ash/powder based geopolymer cements in soft soils promotes strengthening of treated soils. This is due to those hydrates responsible for strengthening and this improves the compressive strength of the treated samples. The innovation here is that these hydrates of strength are formed utilizing eco-friendly materials derived from solid waste hence with zero release of carbon oxides to the environment [116, 117]. The durability potential is the compression index between completely open air cured samples and partly open air cured and partly full immersion cured specimens. As has been captured previously, these amorphous materials, powder and geopolymer cements have shown to resist moisture influence by reducing its effect on soft soils and improving on the volume changes that impair the overall long-term performance and service of the infrastructures constructed with these materials.

4.6 Flexural strength

Flexural strength is the magnitude of stress and force an unreinforced concrete structure can resist when subjected to bending or transverse rupture force which is also the material property known as the stress in a material just before failure or rupture [118]. Previous experimentation in construction and mechanical materials sciences and engineering, in recent times, are involved in utilizing agricultural, household, municipal or industrial solid wastes to either partially or completely substitute conventional materials of concrete to achieve environmental friendly engineering goals. The blending of agricultural by-products as supplementary cementitious additives has been studied with positive results in the production and application of blended concrete and other coupled composites. This results not only product flexure resistant structural elements but also durable in terms moisture, sulfate, heat, and crack long-term resistance and sustainable in terms of available and workability of these additive materials [119]. The improvement recorded in this property on treated soils and concrete and asphalt has been consistent and invaluable. These materials either serve as modifiers by improving on the microstructural properties of the elements or as fillers by improving on the porosity of the compacted structural elements.

4.7 Resistance value (*R*-value) and resilient modulus

The resilient modulus and resistance value are engineering properties used to characterize materials in unbound construction environments especially in pavement construction. This measures the engineering materials stiffness (subgrade stiffness) and provides a method to analyze and study the stiffness of materials; treated and untreated under different loading and environmental conditions. Moisture, density, stress, temperature, vertical and lateral loading, etc. are some of those conditions. Most times, foundation materials subjected to vertical loading suffer lateral deformation and the ability to withstand this form of failure is known as resistance value (*R*-value). It is important to also note that these are strength properties and depend on density attained on an optimum moisture content [120]. The materials additives derived from solid waste (ash, crushed waste (powder), and coupled geopolymer cements or other composite materials) react with the minerals of soft clay soils in a treated blend to form floccs and sequestrates. Experimental results have shown that these materials improve the resistance value, deviatoric stress and resilient modulus of the treated soft soils to achieve the best performance as eco-efficient and sustainable infrastructures.

4.8 Marshall stability

This is the measure of the optimum binder content in bituminous pavements. Marshall Asphalt concrete mixtures are designed and produced to achieve standard specifications in terms of stability, flow, porosity, and density characteristics [120]. The relative impermeability of asphalt mixture depends on the quality or content of the binding materials. The asphalt concrete that meets the marshal stability requirements is always desirable and this depends on the quality of the binder. The conditions of an optimum binder content that balances different design mixtures should be taken into consideration and again the emissions released into the atmosphere is of utmost concern in this work [120–124]. The incorporation of geopolymer cement synthesized from solid waste ash materials into the production of asphalt as modifiers reduces the amount of oxides of carbon emission and produces a homogenous blend with high resistance to sulfate attack, and crack. Secondly, these materials as ash or powder have been used also as fillers to improve on the porosity and flow of the concrete. Experimental results have shown tremendous results achieved in this line.

4.9 Detoxification

There are lots of wastewater released through agricultural, industrial, municipal and household activities that are hazardous to the environment and the entire animal and human lives. The process of removing the harmful materials or compounds or elements from the wastewater before it is released is called detoxification. There are several convention methods available to achieving this process of removing wastewater ultrafiltration concentrates, which include redox reaction method, photo catalyst process using parabolic collector, alkali degradation used mainly in cassava wastewater detoxification, solar detoxification, organic soil usage as a filter, etc. apart from the organic soil usage as a filter and the solar detoxification methods, all other methods mentioned above are chemical methods and eventually release other undesirable and volatile compounds. Investigations have shown that bioremediation of wastewater can be achieved with bio-peels with evidence of acceptable results that meet wastewater detoxification requirements. Orange peels, cassava peels, pineapple peels, banana peels, etc. have been proven to be good wastewater detoxificants and achieve these results with no hazardous emissions.

5 CONCLUSIONS

Solid waste recycling and reuse as a hub to achieving a more ecofriendly, ecoefficient and sustainable civil and mechanical engineering infrastructure and a low or zero carbon emission into our planet has been reviewed. This review work among other things has developed a model for effective solid waste combustion, entrapping CO_2 and CO releasing hitherto, and the release of environmental friendly residue of baking soda ($NaHCO_3$), soda ash (Na_2CO_3) and hydrogen gas (H_2). This research has shown the efficiency of using these ecofriendly materials in;

- Soil stabilization to improve the engineering properties of soft clay and expansive soils
- Concrete modification to improve the sulfate, heat and temperature resistance, crack potentials, durability potentials, flexural potentials, compressive strength, etc. of concrete mixes.
- Asphalt modification to improve the frost susceptibility, moisture resistance, heat resistance, sulfate resistance, lateral and axial deformation potentials, and durability potentials of pavement foundations.
- Wastewater treatment to improve on the detoxification process less of CO_2 and volatile gas emissions.

And generally, the sustainability of these operations has been assured and defined by the results of the review work.

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RECOMMENDATION

It is strongly recommended to develop and research further on the proposed model, the SWI-NaOH-OCEM to ensure its workability.

CONFLICT OF INTEREST

There are no conflict of interests recorded in the cause of this research work. All illustrations in texts, tables and figures are original.

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