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Integrating Wood-Ash in Cement Stabilization of Highly Expansive Soils for High-rise Building Construction Focus: Reducing Shrinkage Causing Storey Subsidence after Rains in Embakasi, Kenya

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Abstract
Soil stabilization has served various advantages ranging from roads constructions to building realizations. The amounts of loads that already stabilized soils have been subjected to have led to a need of ensuring long-term results would be achieved. However, the changes in climatic conditions like occurrence of rains have led to occurrence of an inevitable shrinkage and subsidence of highly costly structures like roads, bridges, and buildings. As a result, this research review aimed at identifying and proposing how to curb shrinkage occurrences on already stabilized soils by incorporating Wood Ash (WA) when using cement as a soil stabilizer.
The aim of achieving a plaster-like property after soil stabilization drove the idea of incorporating WA in cement soil stabilization. A 10% WA proportion has been proposed for use after its incorporation in cement did not affect the fineness properties of cement. Again, this proportion led to an improved Compressive strength after 28-days of curing and both the CBR and PI values of stabilized soils. Much importantly, the shrinkage of elements realized with a 10% incorporation of WA in cement showed a significant reduction after soaking and testing. The achievement of the properties of WA to help reduce shrinkage in highly-expansive stabilized soils leads to proposing the integration of Wood Ash in cement soil stabilization to help curb shrinkage that may lead to subsidence of high-rise buildings realized on these soils during rainy seasons.

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I. Background Information

The realization of high-rise building in modern construction industry has been recommended to accommodate the increasing population in urban centres. The availability and easy access of jobs, social amenities, and other services in urban centres has led to massive immigration of people from rural areas. However, the presence of high-expansive soils in most places, like *Embakasi in Kenya,* has created a continued subsidence of these realized high-rise buildings.

Storey building subsidence has been a recurring phenomenon in our modern construction industry. Every construction regulation has been put into practice for the realization of these storey buildings. However, with vast areas of our countries dominated by expansive soils, like black cotton, red soils, and clay soils, shrinkage that leads to subsidence of these buildings has significantly undermined the efforts employed.

Expansive soils have been described by their high shrinkage effects triggered by abrupt climatic changes. During rain seasons, these soils become weak and any structure constructed on them would collapse through subsidence processes. Again, expansive soils, like black cotton soils in Kenya (Embakasi), dry and lose absorbed water abruptly; hence leads to heaves effects on any structure realized on them. The natural changes of these soils after the rainy seasons have been uncontrollable. The changes in humidity, temperatures, and levels of moisture in construction sites where story buildings are realized lead to building subsidence. As a result, they require an effective stabilization process and continuous examination of the site plans for improvement, to curb story subsidence and heaves.

The application of different stabilization processes, like cement, lime, and pozzolanas, has not prevented the shrinkage effects these soils undergo. As a result, this review paper aims to discuss how including wood ash in cement stabilization would help reduce shrinkage effects on these soils and prevent building subsidence. The review aims to identify the various properties of wood ash that would help achieve the identified objective. First, identifying the fineness test of cement and the compressive strength of an element realized with cement-wood ash proportion would be needed. Again, with the inclusion of a proportion of wood ash in cement soil stabilization, the plasticity index (PI) and CBR of the expansive soils stabilized require being identified and compared to only the cement stabilization process.

II. Introduction

Various materials and processes have been used in the soil stabilization processes. The effectiveness of each, like cement[1], lime[2], and pozzolana materials[3], has been identified. The realization of high-rise story buildings on these soils has been carried out, however without assuredness due to the occurrence of subsidence processes[4]. Different guidelines have been offered to curb the occurrence of this menace in these buildings, like removing bushes and trees and bushes around buildings and carrying out regular inspections of the property like the piping and drainage processes around the building[5]. However, due to high presence of expansive soils at construction sites, like red soils, black cotton, clay soils, amongst others, their changes (shrinkage) caused by different weather conditions has been identified as the leading cause of building subsidence occurrence[6]. Therefore, soil stabilization processes have been required to ensure high-rise buildings would be realized.

Cement has been used as a soil stabilizer for a long period. The process has been effective in helping improve the PI index and the CBR values of weak soils. However, shrinkage effects on this stabilization have been prevented. Lime and wood ash mix has been proposed for use in wall plastering and to prevent wall-plaster cracks[7]. In the proposed use of lime and wood ash in wall plastering, the aim has been set to ensure the shrinkage effects would be curbed. Wood ash has been proposed as an agent to act against the shrinkage perspectives of the plaster. Again, wood ash has been incorporated with cement to produce building bricks with improved compressive strength[8]. However, the incorporation of wood ash in cement stabilization has not been done, and this review proposes its adoption to help lower the shrinkage levels of these soils in rainy seasons and curb building subsidence.

Field Identification of Expansive Soils

The occurrence of different types of expansive soils creates a difference in the stabilization process adopted. While each of these soils recommends an effective stabilization for laying foundations to withstand the weights of high-rise buildings for long time and even with climatic changes, Kenya has been greatly affected by the presence of black-cotton soils. As a result, the following identification would be required in the classification of these expansive soils and adopt the stabilization process of incorporating Wood Ash into cement for the effective stabilization.

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[1] Seco, A., F. Ramírez, L. Miqueleiz, and B. García. "Stabilization of expansive soils for use in construction." *Applied Clay Science* 51, no. 3 (2011): 348-352.

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Field Assessment	
Field description identification	**Detailed soil profiling required.**
Consistency with respect to moisture content	High shear strength when dry. Soft and sticky when wet.
Structure	Shrinkage fissures and cracks, Shear surfaces have a glazed or shiny appearance
Colour	May be of value on a regional or local level
Suction	Expansive soils have a high suction towards water when partly dry
Local Knowledge	Local authority engineers and builders may be a valuable source of information.

Analysis

Wood ash has been previously used in the realization of building bricks with an improved compressive strength. A 10% proportion has been adopted without both the fineness, and workability of cement being affected[9]. Again, shrinkage perspectives leading to the occurrence of cracks on the walls of buildings realized with these types of bricks have been dealt with effectively. However, the wood ash has not been integrated in the cement stabilization of highly-expansive soils for the realization of high-rise buildings. As a result, a similar proportion proposed by Wang, Ruisheng, and Peer Haller in their (2022) work would be adopted.

When wood ash has been used as a partial replacement of lime in plasters, fineness tests, and compressive strengths have been the leading objectives to achieve. Since well-stabilized soil would assume the properties of cement plaster, which would avoid shrinkage properties, a similar approach of incorporating and integrating wood ash with cement in cement-plaster mortar would be adopted. The target would be to achieve an effective stabilization that would avoid shrinkage even under climatic changes (during rains).

A 10%-90% proportion of Wood ash and cement would be adopted. Losing the already-proven clinker properties of cement should be minimized, hence the 10% wood ash proportion. Similarly, ensuring the compressive strength ensured by the cement mix would not be lost, the percentage would be adopted. Therefore, ensuring that a PI and CBR values of the stabilized soils would be achieved, the 10% wood ash proportion would be incorporated with the cement to achieve an effective stabilization.

The fineness test and compressive strength tests for a 10% replacement of cement with wood ash have given the following:

% OF WOOD ASH INCORPORATED	sand	water	cement	Wood ash
0	6.300	0.550	1.370	0
4	6.300	0.550	1.315	0.055
10	6.300	0.550	1.235	0.140
25	6.300	0.550	1.030	0.345

The Material used for Compressive Strength Test

% OF WOOD ASH INCORPORATED	sand	water	cement	Wood ash
0	0.855	0.1	0.185	0
4	0.855	0.1	0.180	0.01
10	0.855	0.1	0.170	0.02
25	0.855	0.1	0.140	0.05

The Amounts of Material Used for Shrinkage Test

Since cement has been significantly used in the soil stabilization (OPC), a test of CBR and PI values with a similar incorporation of a 10% proportion WA would be carried out after achieving positive results on both compressive strength and the fineness test of cement.

III. Results and Discussions

Compressive Strength and Shrinkage Tests

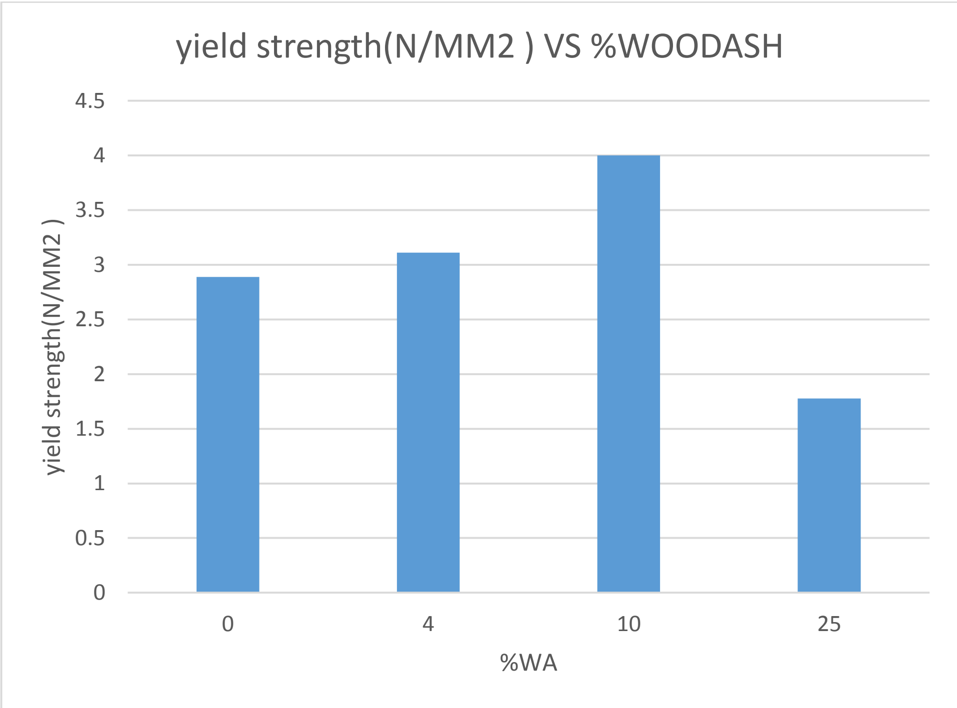
A 10% WA proportion into an OPC has showed a maintenance of the fineness properties of cement. As a result, its use in the casting of specimens to test for both compressive strength and shrinkage aspects is proposed. The

[9] Wang, Ruisheng, and Peer Haller. "Applications of wood ash as a construction material in civil engineering: a review." *Biomass Conversion and Biorefinery* (2022): 1-21.

casting of specimens into cubical and rectangular moulds for compressive and shrinkage tests adopts the 10% WA proportion with the 90% OPC for a health structural element.
The rectangular mould used for the identification of shrinkage values with the inclusion of a 10% WA proportion tested for the shrinkage everyday for 14 days of during. However, the compressive strength tested after 7, 14, and 28 days of curing. The results show as following:

% OF WA INCORPORATED	YIELD STREGTH (N/MM$^{2)}$	Area mm2	YIELD STREGTH(N/MM$^{2)}$
0	65	22500	2.88888889
4	70	22500	3.11111111
10	90	22500	4
25	40	22500	1.77777778

Table of Compressive Strength with WA incorporation in OPC

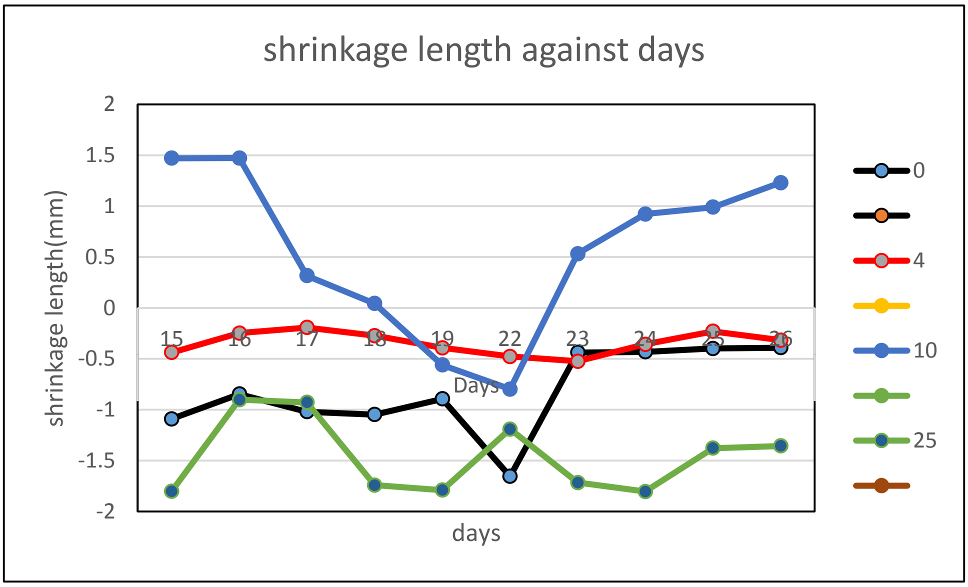


A graph of compressive yield strength against percentages of WA

The compressive strength test results show an increase in compressive strength when 4% wood ash partial replacement for cement. Further, an increase in the strength when 10% WA is incorporated with an OPC. When 25% WA is incorporated with cement, the compressive strength reduces and is lower than that of the control sample (0% WA incorporation). As a result, since a 10% WA incorporation that maintained the regulated fineness test and produces a structural element of higher compressive strength identified after 28 days of curing, a similar incorporation in the stabilization of expansive soils would help create a plaster-like layer with this compressive strength properties.

	Days									
% OF WA INCORPORATED	**15**	**16**	**17**	**18**	**19**	**22**	**23**	**24**	**25**	**26**
0	-1.090	-0.847	-1.020	-1.048	-0.894	-1.654	-0.438	-0.432	-0.398	-0.391
4	-0.438	-0.248	-0.192	-0.273	-0.392	-0.477	-0.524	-0.357	-0.231	-0.317
10	1.470	1.472	0.316	0.044	-0.560	-0.797	0.532	0.922	0.989	1.23
25	-1.801	-0.901	-0.928	-1.741	-1.790	-1.191	-1.715	-1.803	-1.377	-1.356

Shrinkage Test Data



A graph of shrinkage length against days

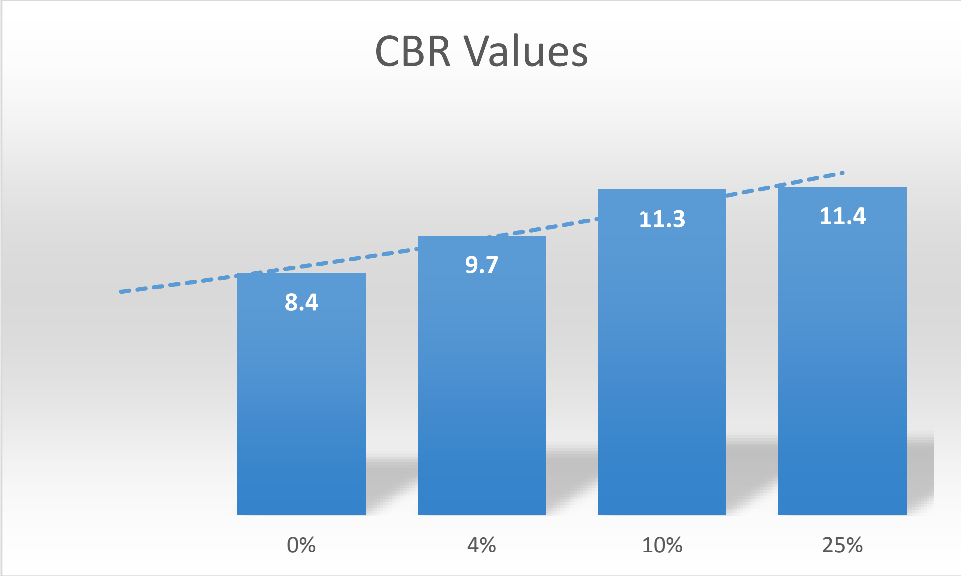
The shrinkage test results show that when 4% wood ash is incorporated with cement, shrinkage is less compared to the control sample (0% WA). Upon 10% WA incorporation, there is an even lesser shrinkage compared to that of 4% partial WA. For the 25% partial replacement, there is an increase in shrinkage length compared to the control sample. As a result, incorporating a 10% WA in the stabilization of expansive soils like Black Cotton soils would help curb the occurrence of shrinkage that occurs under climatic changes. For instance, since the shrinkage test carried out through soaking of rectangular moulds realized with a 10% WA incorporation shows a reduction, even with rainy seasons and soaking of the stabilized soils, shrinkage effects would not occur on these soils.

CBR and PI Tests

A gradual increase of WA proportions while reducing the amounts of OPC used in the soils stabilizations leads to an increase in the CBR and PI values as shown below:

CBR Values (2.5 mm Penetration)				
% WA Incorporation	0%	4%	10%	25%
CBR Values	8.4	9.7	11.3	11.4

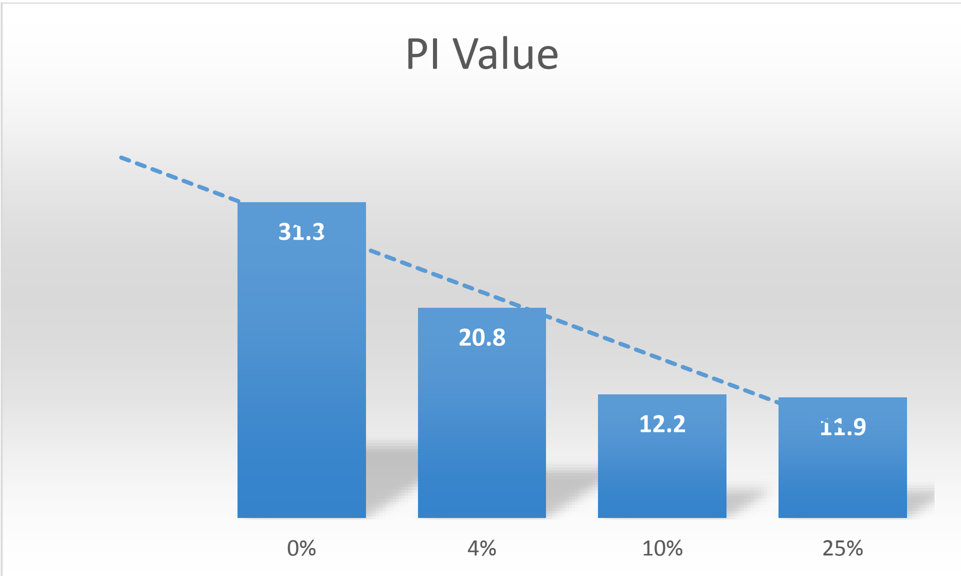
Table for CBR with WA incorporation



Graph for CBR Values with WA Incorporation

PI Index Test				
%WA Incorporation	0%	4%	10%	25%
PI Value	31.3	20.8	12.2	11.9

Table for PI Values with WA incorporation



Graph of PI Values with WA Incorporation

The CBR and PI values of soils (Black Cotton Soils) stabilized with a 10% WA integration with OPC shows improvement. While the main focus has been on incorporating WA for an improved shrinkage limitation, the proportion would also help in achieving an improved CBD and PI values of these soils.

IV. Conclusion

The realization of high-rise buildings in urban centres has been inevitable due to increasing populations. Even with the collapsing of these buildings through subsidence, stabilization has been given a significant attempt for an effective consolidated soil for the laying of effective foundations. Even the attempts of adopting pile foundations have been given trials for the increased security of these buildings under changing climatic conditions. However, the shrinkage of highly-expansive soils after rainy seasons has significantly undermined ethe stabilization routes applied. As a result, incorporating an agent to help counter the shrinkage occurrence on already stabilized soils has been required.

The incorporation of a 10% WA in a cement stabilization process of highly-expansive soils has been proposed in this research review. When a 10% WA has been integrated with a 90% OPC, the fineness properties have been maintained. Again, an increased compressive strength and reduced shrinkage properties have been recorded on structural moulds tested. Furthermore, the improvement of both CBR and PI values of these soils has been achieved with up to 10% WA integration in cement stabilization. Since cement stabilization aims at achieving a plaster-like component and incorporating a 10% WA proportion has showed improved CS without affecting the fineness properties of cement, integrating this proportion would further help to curb the shrinkage properties of these weak soils. The subsidence of storeys has been due to shrinkage of these soils after rails that has led to soaking of these already stabilized soils.

V. Recommendation

The occurrence of shrinkage on highly-expansive stabilized soils is a phenomenon that requires continuous fight to achieve durable high-rise buildings to accommodate the increasing urban population. As a result, on top of using Wood Ash (WA) in the stabilization process to curb shrinkage that may lead to building subsidence, incorporating treated fibre materials would also achieve reduced shrinkage effects. As a result, this research review also recommends identifying the percentages of fibre material incorporation that would help curb shrinkage of stabilized highly expansive soils like Black Cotton Soils.

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