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Effectiveness of agricultural wastes in soil stabilization.

Efectividad de los desechos agrícolas en la estabilización de suelos

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ABSTRACT

Many ways have been sought to improve soils, especially expansive soils which have been problematic to structures and pavements built over them and soil stabilization seems to be one of the effective ways. But soil stabilization in itself is not cost-effective hence the introduction of agricultural wastes being researched on and seen as a cheaper means to be used as stabilizing agents which helps in minimizing the cost of soil stabilization, thereby reducing the problem of waste disposal. Agricultural wastes like Rice Husk Ash, Bagasse Ash, Sugarcane Straw Ash, Saw Dust Ash, Coconut Husk Ash, Millet Husk Ash, Corn Cob Ash, Locust Bean Pod Ash, Cassava Peel Ash and Bamboo Leaf Ash have been experimented with in stabilizing soils and as well, serving as supplementary cementitious materials for cement in concrete production. The strengths of the soils and the concrete stabilized with these wastes were seen to improve significantly and their effectiveness was estimated based on an average optimum value. Agricultural waste processing Industries can be set up to help in the massive production of these natural stabilizers which would lessen the cost of soil stabilization using cement and chemicals and also generally reduce problems that are associated with waste disposal, helping in waste management.

Keywords—expansive soils, soil stabilization, agricultural wastes

RESUMEN

Se han buscado muchas formas de mejorar los suelos, especialmente los suelos expansivos que han sido problemáticos para las estructuras y pavimentos construidos sobre ellos, y la estabilización del suelo parece ser una de las formas efectivas. Pero la estabilización del suelo en sí misma no es rentable, por lo que la introducción de desechos agrícolas se está investigando y se considera un medio más barato para ser utilizado como agentes estabilizadores que ayuda a minimizar el costo de la estabilización del suelo, reduciendo así el problema de la eliminación de desechos. Residuos agrícolas como ceniza de cáscara de arroz, ceniza de bagazo, ceniza de paja de caña de azúcar, ceniza de polvo de sierra, ceniza de cáscara de coco, ceniza de cáscara de mijo, ceniza de mazorca de maíz, ceniza de vaina de algarrobo, ceniza de cáscara de yuca y ceniza de hoja de bambú se han experimentado con la estabilización de suelos y además, sirven como materiales cementantes suplementarios para el cemento en la producción de hormigón. Se observó una mejora significativa de las resistencias de los suelos y del hormigón estabilizado con estos residuos y se estimó su efectividad en base a un valor óptimo promedio. Se pueden establecer industrias de procesamiento de desechos agrícolas para ayudar en la producción masiva de estos estabilizadores naturales que reducirían el costo de la estabilización del suelo utilizando cemento y productos químicos y también reducirían en general los problemas asociados con la eliminación de desechos, lo que ayudaría en la gestión de desechos.

Palabras clave: suelos expansivos, estabilización de suelos, residuos agrícolas.

INTRODUCTION

Soil is that part of the earth’s crust that supports life (plants or organisms) and structures built above it for human habitation and works. There are different soils found on earth that are used for engineering and construction purposes and have been characterized using national codes of engineering practice, although they are also classified majorly with the American Association of State Highway and Transportation Officials (AASHTO) classification system and the Unified Soil Classification System (USCS), amongst other engineering classifications. Expansive soils have not been successfully classified under the national codes though they are found to be widely distributed in many countries of the world but mostly in tropical regions. But the USCS and AASHTO systems seem to do a fair job of classifying these soils by using criteria such as the soils’ shrinkage limit, shrinkage index, liquid limit, plastic limit, plasticity index, free swell index, etc. In their paper, [Sridharan A., and Prakash K., (2000)] discussed the procedures for classifying expansive soils and had it that parameters like liquid limit and plasticity index could predict the soil’s expansivity but not to a satisfactory level since its clay mineralogy effect could not be considered but on conducting the free swell test, these limitations were eliminated, and hence, the free swell ratio from the test results can be effectively used to acquire information on the soil's type and its degree of expansivity. These soils have been a real problem over the years to engineering structures, with a characteristic high swell-and-shrinkage capacity due to the clay mineral "montmorillonite" in them. Any treatment given to the soil, whether technical or compaction treatment, in order to reduce its vulnerability to water and to improve its strength is known as soil stabilization [Amu, O.O., Ogunniyi, S.A. and Oladeji, O.O, (2011)].

Expansive Soils: can be described as soils that expand upon wetting and shrinks upon drying. These soils are found in some countries such as India, the UK, Nigeria, Egypt, etc. Engineering structures built on this type of soil have been found to be unstable and in most cases, they have been destroyed due to the alternate swelling and shrinking of these soils. Types of these soils are clay with high plasticity, Laterite Soil, and Black Cotton Soil (BCS). Laterite soils are products of weathering (tropical or subtropical), therefore, their chemical composition depends on the degree of weathering of the mother material [Gidigasu M.D, (2012)]. Some lateritic soils could be yellowish-brown [Mohammed A.M., (2007)] or reddish-brown in colour. BCS colour can be grey-black [Amit S. K., Vishal V. S., Bhikaji S. G., and Rohankit R. D, (2014)] or dark grey in colour. They retain water when wet, and can be hard as a rock when dry.

MATERIAL AND METHODS

The following two methods can be used to accomplish soil stabilization: i) Mechanical stabilization, ii) Chemical stabilization. Mechanical soil stabilization is a physical process which can be achieved when the physical nature of the original soil particles is altered by inducing vibration in the soil, compacting of the soil or by incorporating physical barriers into it; while Chemical soil stabilization achieves its desired goal mainly depending on chemical reactions between the soil particles and the stabilizing agents which are cementitious or pozzolanic materials [Makusa, G.P., (2012)]. Drainage and compaction are the simplest processes of soil stabilization. Draining water from a wet soil strengthens the soil. Some other processes of soil stabilization are improving the soil's particle size gradation and improving weak soils by adding binders [Rogers, C. and Glendinning, S., (1996)]. Soil stabilization in itself is not cost effective hence the introduction of agricultural wastes used as stabilizing agents which help in minimizing the cost of soil stabilization and thereby reducing problem of waste disposal. The treated soil would generally be regarded as stable if it is able to withstand imposed stresses and loads on it inform of traffic as in case of roads, and superstructures as in case of foundations, and when subjected to all weather conditions, without deforming excessively.

Agricultural wastes: Wastes gotten from agricultural operations such as farms, mills, field areas, wastes from harvest, poultry houses, food processing industries etc., can be termed as agricultural wastes [19]. The agricultural wastes include, but are not limited to Bagasse, Sugarcane straw, Rice Husk, Corn cob, Cassava peel and Bamboo leaves, etc. These wastes if disposed and left unattended to, become an eyesore and as well, pollute the environment. Hence the need for managing these agricultural wastes. One of the ways of managing these wastes is to use them for heat generation, and then agricultural wastes ash become the by-product which can be useful in civil engineering and construction works (see Fig. 1) by serving as good pozzolans and stabilizers for binding concrete and stabilizing expansive soils. The use of agricultural waste ash (AWA) in concrete helps in reducing the heat of hydration, improving the properties of fresh and hardened concrete, as well as improving its durability parameters such as shrinkage and creep. Various researchers have investigated and experimented the use of some of these AWA – (some, as stand-alone stabilizers and others have some chemical stabilizers added to it) – [Amu, O.O., Ogunniyi, S.A. and Oladeji, O.O, (2011)] [Aparna R. (2014),] [Brooks R.M, (2009] [Bukhari S.S, (2017)]. This study seeks to establish the effectiveness of these AWA when used as stabilizers.

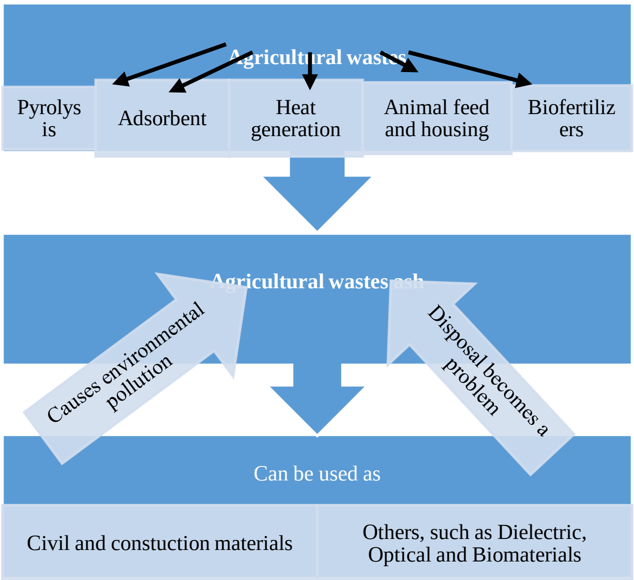

Fig. 1. Management of agricultural wastes and agricultural wastes ash (based on the model by [Sharma, Gaurav & Chhina, Manmeet & Punj, Shivani & Singh, K., (2020)]

Chemical Constituents and Composition of AWA: Table 1 gives various chemical constituents of AWA. It is majorly the siliceous and aluminous compounds in these ashes that account for them being good pozzolanas, in that, when they react with the water in soil or concrete, they form compounds having cementitious properties. The high silica content in AWA make them good cementitious materials capable of supplementing cement or other chemical stabilizers, therefore, the richer the silica content of the AWA, the more excellent pozzolana they make; and as required by ASTM C618 (2005), the summation of SiO_2, Al_2O_3 and Fe_2O_3 in cementitious or supplementary cementitious materials should be at least, 70% in order to make a good pozzolanic material.

Stabilizing soils using AWA: Table 2 gives a summary of the results obtained from various researches on the effect of agricultural wastes ash used in stabilizing soils, as well as the effect on the strength of concrete, when agricultural wastes ash are used as admixtures or partially replacing cement.

Table 1: Comparison of Chemical Constituents of Agricultural wastes

Ref	Brooks R.M, (2009)	Aparna R. (2014)	Dauda D.W and Ijimdiya T.S. (2018)	Eberemu, A. O., Omajali, D. I. and Abdulhamid, Z., (2015)	Amit S. K., Vishal V. S., Bhikaji S. G., and Rohankit R. D, (2014)	Olafusi, O.S., & Olutoge, F., (2012)	Osinubi K.J., Bafyau V., and Eberemu A.O., (20)	Fri'as and Concrete Research, 2005	Adedokun, S.I. Oluremi, J.R, (2019)						
AWA	RHA	RHA	RHA	RHA	BA	BA	BA + OPC	SCSA	SDA	CHA	MHA	CCA	RHA	BA	LBPA
Constituents						Composition %									
SiO_2	90.23	75.2	72.65	72.6	64.38	41.17	57.12 + 20	70.99	64.8-85.0	72.3	67.3-73.1	56.4-67.4	67.3-89.1	57.1-64.4	39.0-55.4
Al_2O_3	2.54	5.2	2.15	2.1	11.67	6.98	29.73 + 6	2.08	0.89-5.69	0.86-6.69	0.03-4.90	5.85-17.6	0.91-4.9	6.98-23.7	13.1-14.9
Fe_2O_3	0.21	1.02	1.65	1.6	4.56	2.75	2.75 + 3	2.25	0.85-2.57	0.18-4.65	0.95-4.2	2.95-9.07	0.52-0.95	2.75-6.98	0.28-11.5
SiO_2 + Al_2O_3 + Fe_2O_3	92.98	81.24	76.45	76.3	80.61	50.9	89.6 + 29	75.32	71.5-89.4	73.35	73.2-77.3	72.4-83.0	70.2-90.7	70.1-83.6	63.6-70.6
CaO	1.58	1.4	1.87	1.9	10.26	3.23	3.23 + 63	12.44	0.58-9.82	0.29-0.85	1.5- 36	3.50-11.8	0.11-1.36	2.51-4.52	1.08-15.7
$CaCO_3$	–	–	–	–	–	–	–	–	7.89-7.92	4.77	–	–	–	–	–
MgO	0.53	1.75	–	2.5	0.85	0.11		2.01	0.96-5.8	0.02	0.20-1.81	2.06-4.06	0.87-1.96	0.11-4.47	2.01
K_2O	–	–	–	–	3.57	8.72	8.72	3.10 1	0.11-2.43	4.77	0.5-7.5	1.98-8.42	0.85-1.98	2.41-8.72	2.00-5.62
Na_2O	–	–	–	–	1.05	–	–	0.56	0.04-0.43	–	0.1-104	0.41-1.91	0.01-1.58	–	0.18-1.21
TiO_2	–	–	–	–	–	1.10	1.10	0.02	–	–	–	–	–	–	–
P_2O_5	–	–	8.83	–	–	–	–	1.37	–	–	–	–	–	–	–

SO_3	–	–	1.67	1.7	–	0.52	0.02 + 2	–	1.06-1.33	1.4-6.38	0.04-0.72	1.06-1.41	0.14	0.02-1.48	–
LOI	–	15.43	–	8	–	17.57	17.57 + 2	–	3.67-8.40	9.34	11.0-17.8	8.55	6.06-18.3	4.38-17.6	0.63-6.00
SiO_2 + Al_2O_3 + Fe_2O_3	–	–	–	–	–	–	–	–	71.5-89.4	73.35	73.2-77.3	72.4-83.0	70.2-90.7	70.1-83.6	63.6-70.6

Table 2: Summary of Stabilized soils using Agricultural wastes ash

Reference	Type of soil	AWA + Additives (% added)	Engineering parameters considered	AWA + Additive Effect on the Engineering properties of the soils	Conclusion/Judgement
Mandeep K. and Jaspal S., (2018)	Lateritic Soil	BA + Cement BA (0, 2, 4, 6, & 8%) Cement (1, 2, 3, & 4%)	Compaction Characteristics (MDD, OMC) Shear strength Characteristics (Cohesion, Angle of Internal Friction; using BSL, WAS and BSH	Increase in OMC, Angle of Internal Friction Decrease in MDD; Cohesion, with Increasing BA & Cement content. Decrease in OMC, Increase in MDD with increasing compactive effort (i.e. in order of BSL, WAS and BSH)	Improvement at every increment of additives
Brooks R.M, (2009)	Expansive soil	RHA + FA RHA (0, 3, 6, 9, 12 & 15%) FA (0, 15, 25 & 30%)	UCS, CBR, compaction and swell-shrinkage	Improvement of UCS by 97%, improvement of CBR by 47% as RHA and FA content increased from 0 – 12%, up to 25% respectively.	12%= optimum value for RHA 25%= optimum value of FA 15% FA= optimum for swell reduction
Osinubi K.J., Bafyau V., and Eberemu A.O., (2009)	Lateritic Soil	BA	Particle size analysis, compaction (MDD & OMC), UCS, CBR and durability	MDD decreased and OMC increased with increased bagasse ash content.	BA was observed not to be effective when used as the only stabilizer for soil stabilization, but it was recommended for use in admixture stabilization.

Osinubi K.J., Ijimdiya T.S., and Nmadu I., (2009)	BCS	BA + Lime (2, 4, 6, & 8% for both BA and Lime)	Atterberg limits, MDD, CBR	Improved atterberg characteristics, slightly improvement in the bearing capacity of the soil	4% BA + 8% Lime is Optimum. Can be suitably used as a subgrade material
Amu, O.O, & Adetuberu, A.A, (2010)	Laterite soil (3 samples A, B, C)	BLA (2, 4, 6, 8 and 10%)	Atterberg limits, Compaction, CBR, Tri-axial (shear strength)	Reduction in plasticity indices and OMC, increment in MDD, CBR and Shear strength values, with higher dosage of BLA	Optimum CBR values were obtained at 6% BLA for samples A&B
Amu, O.O., Ogunniyi, S.A. and Oladeji, O.O, (2011)	Lateritic soil (3 samples A, B, & C)	SCSA (2, 4, 6, and 8%)	Compaction, CBR, unconfined compression test and triaxial)	OMC, CBR and UCS increased in each of the three samples.	An optimum of 6% SCSA content was found to be effective on lateritic soils.
Amit S. K., Vishal V. S., Bhikaji S. G., and Rohankit R. D, (2014	BCS	BA BA (0, 3, 6, 9, 12%)	Atterberg limits, compaction, CBR, UCS	MDD, CBR, UCS increased with addition of BA for up to 6% but decreased on further addition OMC optimum value is at 3% BA.	6% BA optimum for having significant improvement in BCS properties
Aparna R. (2014),	High plastic clay	RHA + Cement (RHA= 10, 15 & 20% Cement = 6%)	Atterberg limits, Compaction, UCS, CBR	OMC increases, MDD decreases, CBR and UCS improves	10% RHA + 6% Cement is the optimum for improved strength
Akinyele, J.O., Salim, R., Oikelome, K.O., & Olateju, O.T, (2015)	Lateritic Clay Soil	RHA (2, 4, 6, 8, 10%)	Particle size distribution, Index properties	Improvement in index properties of soil	Up to 10% dosage of RHA can be used for soil stabilization which would be useful as a hydraulic barrier material
Bello, A.A, Ige, J.A, & Ayodele, H., (2015)	Laterite soil (3 samples)	CPA (2, 4, 6, 8, & 10%)	Compaction, CBR, UCS	Improvement in compaction characteristics, increase in CBR values at 8%, 10% and 4% for samples 1, 2 and 3 respectively, increase in UCS values at	Improvement of soil properties with increment in CPA

				2%, 10%, 6% for samples 1, 2 and 3 respectively	
Eberemu, A. O., Omajali, D. I. and Abdulhamid, Z., (2015)	Tropical Black Clay	RHA (0, 4, 8, 12, 16%)	Index properties, compaction and consolidation characteristics. Clay compacted using BSL, WAS and BSH	A considerable improvement in index properties, compaction characteristics, and consolidation characteristic with increasing RHA content, compactive effort and curing age	8-16% dosage of RHA, with higher compactive effort and longer curing age, in order to achieve optimum results
Bukhari S.S, (2017)	BCS	RHA + FA (RHA = 0, 4.5, 9, 13.5, 18%) (FA = 0, 12, 22, 32%)	SPT, UCS	Increase in SPT & UCS which indicates strength property improvement of BCS	9% RHA & 12% FA found to be the optimum dosage in BCS stabilization
Ravinder K.S and Rafat S., (2017)	SCC	RHA (Percentages between & including 0% to 40%)	Fresh properties (slump) Strength properties (compressive, flexural, splitting tensile, modulus of elasticity) Durability properties (UPV, RCP, water absorption and porosity, Sorptivity, Electrical Resistivity, Acid Resistance, ASR)	Improvement in concrete properties with a higher curing period	10-15% RHA is suitable in SCC for improving its fresh properties and strength and durability characteristics
Mohammad B. A, and Zahid H., (2018)	Concrete	RHA (1, 2 & 3) + CFA (0, 10 & 20% each)	Mix properties of fresh concrete (slump, air content, unit weight); Mechanical properties (compressive, tensile and flexural strength, modulus of elasticity, and Poisson’s ratio of hardened concrete	High slump value for RHA 1 and low slump values for RHA 2 & RHA 3 modified concrete. Increased air contents and decreased unit weights for all RHA & CFA modified concrete. Decreased mechanical properties of concrete for RHA 1 & RHA 2, increased	10% RHA.3 best dosage for replacing cement for use in construction projects. Including 10% doze of CFA can make durable concrete being able to withstand conditions of harsh weather

				mechanical properties of concrete for RHA 3 and CFA	
Dauda D.W and Ijimdiya T.S. (2018),	Tropical Black Clay	RHA (0, 4, 8, 12,16%)	Index properties of soil	Improved index properties at all percentages of RHA treatment	16% RHA treatment was optimum for improving the index properties of the soil
Adedokun, S.I. Oluremi, J.R, (2019)	Laterite soil	SDA CHA MHA RHA CCA BA LBPA	Index and compaction properties, CBR, UCS, permeability, swell potential	Improved index and compaction properties, CBR and UCS values, reduction in swell potential	Optimum percentages of AWA were: 4% for SDA 10% for CHA 10% for MHA 8-10% for RHA 1.5% CCA 8-12% BA 8% LBPA
Dauda, D.W, Edwin, J, Wilson U.N, and Ibrahim, M.O, (2020)	BCS	BA(0, 4, 8, 12, 16%)	Atterberg limits, Compaction and Consolidation characteristics	Improvement in compaction properties (with increased BA content) and consolidation characteristics (best results obtained at 8%)	8% BA = optimum for improving the geotechnical properties of BCS

RESULTS AND DISCUSSION

From Table 2, it is seen that the AWA had positive effects on the geotechnical properties, compaction characteristics (OMC & MDD), CBR, UCS, swell-shrinkage as well as the overall engineering properties of the soils and concrete considered. The average optimum values of the agricultural wastes use in stabilizing these soils are taken to be their required replacement for effectiveness. The reason for [Osinubi K.J., Bafyau V., and Eberemu A.O., (2009)] concluding that BA cannot be used as a standalone stabilizer could be because of the low silica content of the BA, and also that the summation of SiO_2, Al_2O_3 and Fe_2O_3 was 50.9%, which could not meet up to the standard of ASTM C618 (2005), and hence it could not form compounds possessing good cementitious properties. Reference [24] had it that at 4% BA, the optimum effect was obtained on the strength properties of BCS, but with the addition of 8% Lime. The reason for the low percentage of BA needed for optimum stabilization could be as a result of the Lime added. If Lime or any other chemical stabilizers are not used, it would require a higher percentage of BA to achieve soil stabilization. Other optimum dosages obtained as reported were, 6% BA by [Amit S. K., Vishal V. S., Bhikaji S. G., and Rohankit R. D, (2014)]; 8-12% BA by [Adedokun, S.I. Oluremi, J.R, (2019)] and 8% BA by [Dauda, D.W, Edwin, J, Wilson U.N, and Ibrahim, M.O, (2020)]. Taking on the average, 8% BA can be optimally used as standalone stabilizers in engineering works, and if lesser amount is to be used, cement or chemical stabilizers can be added to make it effective. For RHA used as stabilizer: 12% RHA + 25% FA by [11]; 10% RHA + 6% cement by [9]; 10% RHA by [Akinyele, J.O., Salim, R., Oikelome, K.O., & Olateju, O.T, (2015)]; 8-16% RHA by [Eberemu, A. O., Omajali, D. I. and Abdulhamid, Z., (2015)]; 9% RHA + 12% FA [Bukhari S.S, (2017)]; 16% RHA by [Dauda D.W and Ijimdiya T.S. (2018),]; 8-10% RHA by [Adedokun, S.I. Oluremi, J.R, (2019)]. An average of 12% dosage of RHA would be optimum for use as a standalone stabilizer, in concreting works as well as soil stabilization. Optimum percentages of other agricultural wastes ash were: 6% SCSA by [8]; 4% for SDA, 10% for CHA, 10% for MHA, 1.5% CCA, 8% LBPA by [Adedokun, S.I. Oluremi, J.R, (2019)]. The very little optimal value of 1.5% CCA might be as a result of a relatively low silica content which is a major compound of the AWA.

As conclusion, it can therefore be concluded based on the report, that, agricultural wastes have positive effect on expansive soils in their stabilization. The tests conducted showed that the compaction characteristics and the bearing capacities of the expansive soils increased with increase in agricultural wastes, thereby making the expansive soils stable. The effectiveness of the agricultural wastes is obtained based on their average optimum value effect on these soils which is considered to be 12%, 8% and 6% for Rice Husk Ash, Bagasse Ash and Sugarcane straw Ash respectively. For other AWA, their effectiveness on soil stabilization might be obtained at 4% for SDA, 10% for CHA, 10% for MHA, 1.5% CCA, 8% LBPA, although before taking effectiveness into account, the condition of high silica content and SiO_2, Al_2O_3 and Fe_2O_3 summing up to 70%, according to ASTM C618 (2005) standard, needs be considered and put in place. That is to say, the chemical composition of the AWA determines their effectiveness in soil stabilization and where these are low, it is needed to combine cement or chemical additives (stabilizers) to the stabilizing process, to achieve best results in soil stabilization. And for concrete works, since cement or/and fly ash would also be in use, the optimum dosage where most effectiveness can be achieved, should be used. In addition, the disposal issue of these wastes would drastically reduce when civil engineering and construction firms incorporate them into construction works, thereby helping with waste management.

Table 3: Acronyms used in Tables 1&2

AWA	Agricultural Wastes Ashes	BA	Bagasse Ash
BCS	Black Cotton Soil	SCSA	Sugarcane Straw Ash
SCC	Self-Compacting Concrete	SDA	Saw Dust Ash
OPC	Ordinary Portland Cement	CHA	Coconut Husk Ash
RHA	Rice Husk Ash	LOI	Loss on ignition
MHA	Millet Husk Ash	CBR	California Bearing Ratio
CCA	Corn Cob Ash	SPT	Standard Proctor Test
LBPA	Locust Bean Pod Ash	BSL	British Standard Light
CPA	Cassava Peel Ash	WAS	West African Standard
BLA	Bamboo Leaf Ash	BSH	British Standard Heavy
CFA	Class C Fly Ash	UPV	Ultrasonic Pulse Velocity
FA	Fly Ash	RCP	Rapid Chloride permeability
MDD	Maximum Dry Density	ASR	Alkali Silica Reaction
OMC	Optimum Moisture Content	UCS	Unconfined Compressive Strength

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