STABILIZATION OF SOIL WITH PLASTIC WASTE AND LEAF ASH

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Degree of Master of Philosophy

Department of Civil Engineering

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ABSTRACT

This study aims to investigate the stabilization of three sandy soils with the addition of waste plastics, Bamboo Leaf ash (BLA), Banana Leaf ash (BALA) and a leaf ash mixture based on the enhancement in the MDD (Maximum Dry Density), OMC (Optimum Moisture Content), Soaked CBR (California Bearing Ratio), Shear strength parameters and Atterberg Limits. The soil stabilizers used in the study are the plastics strips from waste plastic file folders, BALA, BLA and a pozzolanic leaf ash mixture of five commonly available pozzolanic leaves in Sri Lanka. Plastics used in the study have 5 mm width and Aspect Ratios (ARs) of 1, 2, 3, and 4 in the weight percentages 0.5, 1, 2, 4, and 8. BALA, BLA and the leaf ash mixture used in the study are in the weight percentages 2, 4, 6, 8, and 10. The most significant improvement in MDD was achieved when 2 % of plastics with an AR 02 was mixed with soil 01. For soil 02, the best improvements in MDD with almost similar values were observed with the addition of 6 % of all the considered ashes. For soil 03, the best improvements in MDD with almost similar values were achieved with the addition of 6 % of BLA and the leaf ash mixture. The optimum improvement in soaked CBR for each soil was around (2-3) times compared to the virgin state. The optimum improvement in soaked CBR was observed with the addition of 6 % of BLA for all three soils. Shear strength parameters improved in almost all cases of the addition of plastics and ashes. A reduction of plasticity index (PI) was noted on all three soils with the addition of 2, 4 and 6 % of ashes. Soil 03 mixed with 2 % plastics of AR 03, 8 % BALA, 6 % BLA and 6 % mixture of pozzolanic ashes showed satisfactory results to be used for the upper subbase layer in flexible pavement constructions in Sri Lanka.

Keywords: Soil stabilization, Shear strength, Plastics, Leaf ashes, Geotechnical properties

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LIST OF ABBREVIATIONS

Abbreviation	Description
AR	Aspect Ratio
ASTM	American Society for Testing and Materials
BALA	Banana Leaf Ash
BLA	Bamboo Leaf Ash
CBR	California Bearing Ratio
C_c	Coefficient of gradation
C_u	Coefficient of uniformity
GSMB	Geological Survey and Mines Bureau
HDPE	High Density Polyethylene
ICTAD	Institute for Construction Training and Development
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PC	Plastic Content
PI	Plastic Index
PL	Plastic Limit
RDA	Road Development Authority
UCS	Unconfined compressive strength
USCS	Unified Soil Classification System
XRF	X-Ray Florescence

LIST OF APPENDICES

1.0 INTRODUCTION

1.1 Background

In nature, soil deposits are not homogeneous and there is considerable variation in shear strength and bearing capacity [1]. Construction of infrastructures on poor subgrade or poorly stabilized soil will lead to insufficient support to the structures and shorten their lifetime. It has been reported that due to the failures of constructed infrastructures on poorly stabilized soil, there are losses of millions of dollars worldwide [2-3]. Furthermore, with exponential population growth, rapid industrialization, and limited available lands, weak soil zones, such as agricultural land, must be selected for development work. Therefore, the need to enhance the stability of fragile soils is vital at the global level.

There are a number of techniques for improving the stability of different soils, such as drainage, pre-compression, vibration, grouting and compaction, consolidation, and so on. However, majority of them are not economically viable [4-5]. The study focuses on economic stabilization measures that are relatively new. The term stabilization refers to a method of modifying natural states of soils in order to achieve technical goals such as enhancing soil stability, bearing capacity, durability while decreasing soil permeability, compressibility, shrinkage, and swelling, and so on [6-7].

Stabilizers are primarily grouped into chemical, mechanical and polymer products based on the types of bonding that the stabilizer forms with soils [8]. The stabilization of the soil is mainly carried out for the construction of embankments, the rehabilitation of the lands, parking lots, runways, slope stabilizations and highway construction. In addition to the improvement of the quality of soil, the thickness of the soil layers can be reduced to a considerable amount with stabilization in the case of pavements. Hence the cost of construction can be reduced significantly.

There has been a drastic increase in the worldwide production of plastics from 260 million metric tons to 348 million metric tons per year in the last ten years. From the manufactured plastic, around 50 % of those are only for single usages and disposed

[9]. Only 9% of plastic garbage was recycled, with the rest being dumped in landfills and released into the natural environment, polluting the environment [10]. Therefore, it is critical to find a way to recycle plastic waste effectively to protect the environment. This research focuses on the efficacy of reusing plastic from waste plastic products with different Aspect Ratios (ARs) (1, 2, 3 and 4) and different weight percentages (0.5, 1, 2, 4 and 8) on three different types of soils.

Worldwide production of bananas is around 130 million metric tons per year, and it is considered to be the second-largest fruit crop cultivated worldwide [11]. Banana trees have been grown on 8.8 million hectares of land in subtropical and tropical regions in the world [12]. In the last decade, the contribution of banana trees towards the agricultural gross product is around 13 % in West African countries [11]. Moreover, in Malaysia, around 10 metric tons of banana trees are cut down per year to satisfy the needs of people [13]. The main intention of cultivating banana trees has been for the fruits. However, tons of unused byproducts and waste have been generated from banana farms and the farmers are facing huge problems in disposing of the wastes accumulated from the banana trees [12]. In addition to that, during the degradation process of accumulated banana tress waste, methane which is a greenhouse gas is formed as a byproduct [13]. Therefore, there is always a necessity of creating a way to manage and utilize such biowastes for better sustainability and environmental protection. Such waste can be effectively used in the process of stabilization of soils.

Bamboo usually grows much faster with a growth rate of (30-100) cm per day in forests [14-15]. However, the decomposition process of bamboo leaves is quite slow due to the presence of lignin in a higher percentage [15]. The presence of a larger amount of bamboo trees in forests affects the environment by causing changes in the nutrients of soils and the availability of the lands for the regeneration of tree seedlings in forests [16]. These adverse impacts caused by the generation of bamboo trees are required to be eliminated effectively. Therefore, leaf wastes generated from bamboo trees can be used effectively in the process of stabilization of soils.

There had been few studies conducted to stabilize soils using the ashes of banana leaves and bamboo leaves in the past. In this study, in addition to plastic, Banana leaf ash (BALA), Bamboo leaf ash (BLA) and a mixture of five different pozzolanic ashes of leaves with different weight percentages (2, 4, 6, 8 and 10) were also tested for stabilizing selected soils. Stabilizing ability of these selected agents were compared based on the improved shear strength parameters, Maximum Dry Density (MDD), Optimum Moisture Content (OMC), California Bearing Ratio (CBR) and Atterberg limits values of the stabilized soil.

1.2 Aim of the research

In the past, no studies were conducted on same soils to compare different stabilizers to gain a better understanding of their ability to stabilize soils. Therefore, the outcomes of this study will aid in better selections of the stabilizers, thereby filling an important research gap. Furthermore, only a few research have examined the ability of a specific stabilizer to stabilize different soil types. The current study will cover this research gap through the comparison of the effectiveness of four stabilizers on three sandy soil types.

1.3 Objectives of the research

i. Analyze the influence on MDD of selected soils with the addition of plastics, banana leaf ash, bamboo leaf ash and a mixture of pozzolanic ashes of leaves and compare their efficiencies.

ii. Determine the improved CBR values of selected soils with the addition of plastics, banana leaf ash, bamboo leaf ash and a mixture of pozzolanic ashes of leaves at their respective MDD obtained from proctor compaction results and compare their efficiencies.

iii. Determine the optimum plastic content and aspect ratio for improved CBR and MDD for plastics and the optimum ash weight percentage for improved CBR and MDD for selected ashes.

iv. Analyze the improvement of the shear strength parameters with the inclusion of plastics, bamboo leaf ash, banana leaf ash, and a mixture of pozzolanic ashes of leaves and compare their efficiencies.

v. Determine the optimum plastic content and aspect ratio for improved shear strength parameters for plastics and the optimum ash weight percentage for improved shear strength parameters for selected ashes.

vi. Determining the suitability of a selected soil sample with the addition of plastics, banana leaf ash, bamboo leaf ash and a mixture of pozzolanic ashes of leaves to be used as upper subbase layer in road construction in Sri Lanka as per Road Development Authority (RDA) guidelines.

1.4 Scope of the research

The current research is limited in scope to sandy types of soils. This focus is made mainly because embankments/ fills are most often made with sandy soils or mixed soils. In order to concentrate on the topic, clay type of soils and other weak types of soil like peat are excluded from this study. Additionally, the selected stabilizers are limited to plastics with four different ARs and five different weight percentages and BALA, BLA, and a mixture of five pozzolanic ashes of leaves with five different weight percentages. A further limitation of the study is that plastics used as stabilizers would be made into only rectangular shapes with different ARs, as there are economic and practical difficulties in making plastics into very fine particles to mix with soils. Consequently, Atterberg limits would not be tested for soils stabilized with plastics.

2.0 LITERATURE REVIEW

2.1 Significance of improvement of soils for civil engineering purposes

The infrastructure foundation should be able to securely transfer the load from the superstructure to the ground. At the same time, the settlement of the foundation should also fall within the permitted limits [17]. Therefore, the ground must be sturdy enough to support the load from the foundation. Structures fail when buildings are built on weak soils due to the formation of foundation fissures, a significant change in volume of soil, a displacement of the entire structure and the buckling of the roadway [18-19].

It has been recently reported that the United Kingdom and the rest of the globe spend around several million and billion dollars each year, respectively, to repair damage caused by inappropriate construction practices on inadequately stabilized expansive soils [20]. Therefore, prior to any construction of infrastructure, it should be ascertained that the engineering properties of soil are much improved and suitable for construction.

2.2 Improvement of soil by stabilization and its types

Stabilization of the soil is comparatively much cheaper than other methods of improving soil properties such as vibration method, grouting and compaction, pre-compression etc. [20]. Therefore, even small projects can adapt to it. Stabilization can simply be defined as a means of changing soil properties to meet the needs of civil engineering [20-21]. The three ways of stabilizing soils are Mechanical, Chemical and polymer or alternative stabilizations [2], [8], [21]. Mechanical soil stabilization involves the addition and compaction of two or more soils in order to change physical attributes such as particle size distribution, compressibility, shear strength characteristics etc. [22-23]. This is the oldest among the two types of soil stabilizations. During chemical stabilization, traditional stabilizers such as cement, bitumen and lime, as well as non-traditional agents that have the ability to interact physically and chemically with soils, are mixed with soils to modify soil parameters [2].

Mechanical and chemical methods of soil stabilization have prevailed in the industry for so long. However, in the last few decades with the growth of technology stabilization using innovative materials like polymers and alternative stabilizing materials have become popular. The addition of materials such as plastics and/or polymers to improve soil strength parameters are called polymer or alternative stabilizations [2]. In cases where mechanical stabilizers are not suitable for use, chemical stabilizers are currently used in industry. Cement, lime, or bituminous materials are added to soils to ensure the stability of roads especially when there is an abundance of moisture. [24].

There are several external factors that influence the effectiveness of the stabilizations of soils such as spreading and mixing of stabilizers with soils, type of roller, the thickness of the compaction layer, sequence of compaction operations and compaction efforts, method of curing and climate and environmental conditions [23].

2.3 Compulsion of this study

Although the use of stabilizing substances like cement, lime, and certain chemicals (e.g., calcium chloride, sodium chloride, and sodium silicate) has been well documented, their practical applicability is currently limited [2]. Cement is extremely costly nowadays. It requires a great deal of energy and can create environmental risks by releasing carbon dioxide. Also, the production of lime can cause climate change. In addition, applications of Geogrids and geotextiles are not a cost-effective way to strengthen soils for projects with a limited budget [21]. Consequently, it is necessary to find alternative options to stabilize weak soils. This is why, in this study, waste plastics which are available in various forms, durable and unchanged for more than centuries [22], and other materials such as BALA, BLA and a mixture of pozzolanic ashes of leaves will be examined and compared to find out their stabilizing potential on different three sandy soils.

2.4 Review of available literature on using waste plastic and innovative products as a stabilizing agent

2.4.1 Review of literature on plastics as a soil stabilizer

There were very few studies done to find the effectiveness of plastic as a soil stabilizer by considering CBR as a determining factor for deformed soil strength. The study by Thakare and Sonule [25] revealed the possibility of enhancing the soil bearing capacity with the inclusion of plastics in layers. Waste shopping bags made of polyethylene were found to contribute significantly towards improved bearing capacity and shear strength parameters of the selected soil [26]. From the study by Choudhary et.al [21], it was found out that with the AR of 3, the thickness of 0.4 mm and High-Density Polyethylene (HDPE) plastic content of 4 %, it is possible to improve soil bearing capacity and soil strength parameters.

Bhattari et al. [27] carried out experiments by altering the proportion of plastics in the weight percentages 0, 0.25, 0.5, and 1 and the ARs from 1 to 4 and achieved the best possible results with 0.5 percent HDPE plastic of AR of 03. Neopaney et.al [28] performed experiments by varying the weight percentage of plastics and ARs and found out the most significant improvement in CBR with 0.5 % plastic of AR 3.

Rather than AR, density was used as a factor together with the weight percentage of plastic by Mallikarjuna and Mani [2] to test the improved CBR of black soil. 4 % plastic was found out to be optimum with the density of 0.42gm/cc of Polypropylene in this study. Comparing to the above studies, Chebet and Kalumba [26] tested the enhanced soil strength properties reinforced by plastics having the lengths (15-45) mm and the widths (6-18) mm with a constant plastic composition of 0.3 % by weight.

According to the study by Kalliyath et al. [8], MDD was regarded as an indicator for the determination of improved soil strength parameters. By varying the weight percentage of plastic fibers as 0.25, 0.5, 1, 1.5, improved MDD was found for silt clay. 0.5 % of plastic fibers was found out to be optimum which gives optimum improved MDD. It is evident that the results found from the studies quoted above are quite different from one another for using plastic as a soil stabilizer. Therefore, this study will address this issue more effectively by investigating the improved shear strength parameters, MDD, soaked CBR values, and Atterberg limits.

2.4.2 Review of literature on ashes of leaves as a soil stabilizer

According to the study done to find the efficiency of the use of BLA for lateral soil stabilization for roads by Amu and Adetuberu [24], three different soil types were tested with the variable percentages of BLA. The addition of BLA to the soil has been found to significantly reduce OMC and plastic index (PI) while improving the MDD, CBR and shear strength parameters of soil.

Based on the study by Nnochiri and Aderinlewo [29] and Elijah [30] on enhancing soil properties, among the five various weight percentages of BALA ranging from (2-10) percentages, the addition of 4 % BALA improved CBR and unconfined compressive strength (UCS) closer to 11% and 17 %, respectively, comparing to that of the virgin states of the soil.

Reddy and Prasad [31] experimented the improved properties of stabilized soil with the combination of sugarcane straw ash and polypropylene fibers by changing their weight percentage ranging from (10-25) and (0.5-1.5) respectively. Their results show that the combination of sugarcane straw ash and polypropylene fibers with 25 % and 1 % respectively improved the CBR and UCS of soil. However, Chakraborty et.al [32] found out that the addition of 10 % of sugarcane straw ash to virgin soil will significantly improve the CBR and UCS from their experiment of addition of sugarcane straw ash ranging from (5-15) % by weight.

The results are from these limited tests done on using the ashes of bamboo leaf, banana leaf and sugarcane straws and plastics do not show uniformity or congruence. Hence this study aims to find out solutions for this problem.

2.5 Research gap that this study aims to fill

From the literature reviewed, it is quite evident that the determination of stabilizing potential of waste plastics on different types of soils is not complete. Moreover, the comparisons of the stabilizing potential of waste plastic on different soil types were not made. In addition to that, none of the past studies involved experiments using different types of stabilizing agents on the same soil. These important research gaps will be filled in this study.

3.0 MATERIALS AND METHODS

3.1 Materials

Three distinct sandy soil types were collected in the Kanthale area of Trincomalee District and brought to the University of Moratuwa for further investigations. Figures 3.1, 3.2 and 3.3 show the soil samples 01, 02 and 03 respectively.

Figure 3. 1: Soil sample 01 (Poorly graded sand)

Figure 3. 2: Soil sample 02 (Clayey sand)

Figure 3. 3: Soil sample 03 (Poorly graded sand with clay)

The plastics used in this study were obtained from new plastic files and cut into strips of 5 mm width. Aspect Ratios (ARs) of plastics used are 1, 2, 3, and 4 with the lengths 5, 10, 15, and 20 mm respectively. The plastics utilized in the study have a density of 0.915 g/cm^3. Figures 3.4, 3.5, 3.6 and 3.7 show the plastics of different ARs that were taken for the study. Previous studies revealed that the optimum plastic content for enhancing soil characteristics was between 0.5 and 4 percentage [2], [21], [26], [28]. However, the scope of this study has been widened. The samples were made by combining the plastics in weight percentages ranging from 0 to 8 (0.5 %, 1%, 2%, 4%, and 8%) with the selected air-dried soils for determining the enhancement in MDD, soaking CBR, and shear strength characteristics.

Figure 3. 4: AR 1 Plastics

Figure 3. 5: AR 2 Plastics

Figure 3. 6: AR 3 Plastics

Figure 3. 7: AR 4 Plastics

Initially, Banana, Bamboo, Teak, Glyrisidia sepium, Mango, Neem and Thespesia populnea leaves were collected and dried for a period of one month. After that, the leaves were burnt in the open atmosphere and ashes were obtained. The ashes required for the experiments were then prepared by passing the residue obtained from burning through a 0.075 mm sieve. Approximately (30-35) % by weight of ashes were obtained from the dried leaves. That means, for the 10 kg of dried leaves, around (3-3.5) kg of ashes can be produced. In addition to that BALA and BLA were also separately considered as soil stabilizers.

These ashes were subjected to X-Ray Florescence (XRF) analysis at Geological Survey and Mines Bureau (GSMB) to determine their pozzolanic properties. Pozzolana is a siliceous or aluminous substance with no cementitious characteristics found in nature; yet, when exposed to moisture in finely split form, it exhibits cementitious characteristics due to its interaction with $Ca(OH)_2$ [33-34]. A mixture of leaf ash was made by blending the ashes of all the different leaves in equal weight amounts that demonstrated pozzolanic properties in XRF experiments. The leaf ash mixture, BALA and BLA in the weight percentages of 2, 4, 6, 8 and 10 were mixed with selected air-dried soils to examine their efficacy as stabilizers of soil. Figures 3.8, 3.9 and 3.10 show BALA, BLA and a mixture of pozzolanic ashes respectively.


Figure 3. 8: Banana Leaf Ash (BALA)


Figure 3. 9: Bamboo Leaf Ash (BLA)

Figure 3. 10: Mixture of pozzolanic ashes of leaves

3.2 Experiments and explanations for the approach chosen over the alternatives

3.2.1 Particle size distribution tests and Atterberg limit tests

Particle size distribution tests were carried out in accordance with the American Society for Testing and Materials standards (ASTM) [35]. Particle size distribution tests were initially performed on the collected soil samples and particle size distribution curves were obtained. Figure 3.11 shows the sieve analysis setup. From the particle size distribution curves Coefficient of uniformity (C_u) and Coefficient of gradation (C_c) were found out. It was followed by Atterberg limit tests as per the ASTM [36]. The Atterberg Limit apparatus is shown in Figure 3.12.

Figure 3. 11: Sieve analysis apparatus setup

Figure 3. 12: Atterberg limit apparatus setup

Based on the particle size distribution and Atterberg limit tests, the soil types were classified in accordance with the Unified Soil Classification System (USCS) [37]. While experiments with ashes as stabilizers can provide satisfactory results, performing Atterberg Limit tests with longer pieces of plastics of ARs 3 and 4 and lengths 15 mm and 20 mm is impractical. Therefore, soils only with varying amounts of ashes were subjected to Atterberg limit testing.

3.2.2 Modified Proctor Compaction Tests

Modern applications have been found to require greater compaction comparing to the compaction achieved from the standard proctor compaction test. This is why in this research, the modified proctor compaction method was adopted. Soils were mixed with four different ARs and five different weight percentages of plastics, as well as a BALA, BLA, and leaf ash mixture with five different weight percentages for measuring the enhanced OMC and MDD. Modified proctor compaction tests were conducted in accordance with the ASTM. [38]. Figure 3.13 shows the modified proctor compaction equipment.

Figure 3. 13: Modified proctor hammer and mold

Initially, the bulk density and the dry density were determined. Then the graphs were plotted between the dry density and the moisture content. From that graph, OMC and MDD were found out.

3.2.3 Direct Shear Tests and CBR Tests

Conventional procedures cannot be used to create a cylindrical sample from soils that are notably cohesionless. Furthermore, preparing samples for a direct shear test is more convenient, rapid, and straightforward than preparing samples for triaxial experiments. Therefore, the direct shear test was chosen over the triaxial test in this study, which was carried out in accordance with ASTM standards. [39].

Figure 3. 14: Direct shear apparatus

Figure 3.14 shows the Direct shear apparatus. The soaked CBR test represents the worst-case scenario. Therefore, the soaked CBR test was chosen over the unsoaked CBR test and was conducted in accordance with the ASTM [40]. Figure 3.15 shows the setup for the soaked CBR experiment.

Figure 3. 15: Soaked CBR experiment setup

Direct shear and soaked CBR experiments were carried out on soils with and without the addition of stabilizers to examine the enhancement of soaked CBR and the shear strength parameters with the stabilizers. Direct shear and soaked CBR experiments were carried out at 98 % MDD and its equivalent moisture content for the AR, which demonstrates the highest improvement in MDD for each weight percentage of plastics. Direct shear and soaked CBR experiments were also carried out on soils containing all of the considered weight percentages of BALA, BLA and leaf ash mixture at 98 % MDD and its equivalent moisture content.

Graphs were generated between the load and penetration levels based on the measurements acquired from soaked CBR experiments. CBR 2.5 and CBR 5.0 that stand for CBR values at 2.5 mm penetration and 5 mm penetration respectively were determined from the generated graphs. Out of the two CBR values, higher CBR was taken for the analysis.

Based on the results of direct shear experiments for three distinct normal loads, initially, graphs were plotted between shear stress and shear displacement. Then graphs were plotted between shear stress and normal stress and from the graph, shear strength parameters were determined.

3.2.4 Unconfined compression test

Unconfined compression test was carried in accordance with ASTM [41] on soil sample 03 to determine the Unconfined Compressive Strength (UCS) with the weight percentages of plastic and ashes that satisfied the gradation, MDD and CBR requirements to be used for the upper subbase layer in road construction in Sri Lanka as per Institute for Construction Training and Development (ICTAD) specifications [42]. The specimens for the experiments were prepared using molds with 100 mm diameter and 200 mm height. Figures 3.16, 3.17 and 3.18 show the pictures relevant to the unconfined compression tests.

Figure 3. 16: Samples prepared for unconfined compression test

Figure 3. 17: Apparatus used for unconfined compression experiment

Figure 3. 18: Unconfined compression experiment on a sample prepared

4.0 RESULTS AND DISCUSSION

4.1 Experiment results on virgin soils

Figure 4.1 depicts the particle size distribution curves of the three sandy soil types used in this research. Table 4.1 shows the results of the fundamental tests (particle size distribution, Atterberg limits, and specific gravity) as well as strength tests (modified Proctor compaction, CBR, and direct shear) performed on virgin soils. According to USCS, soils 01, 02 and 03 are classified as poorly graded sand (SP), clayey sand (SC) and poorly graded sand with clay (SP-SC), respectively [37].

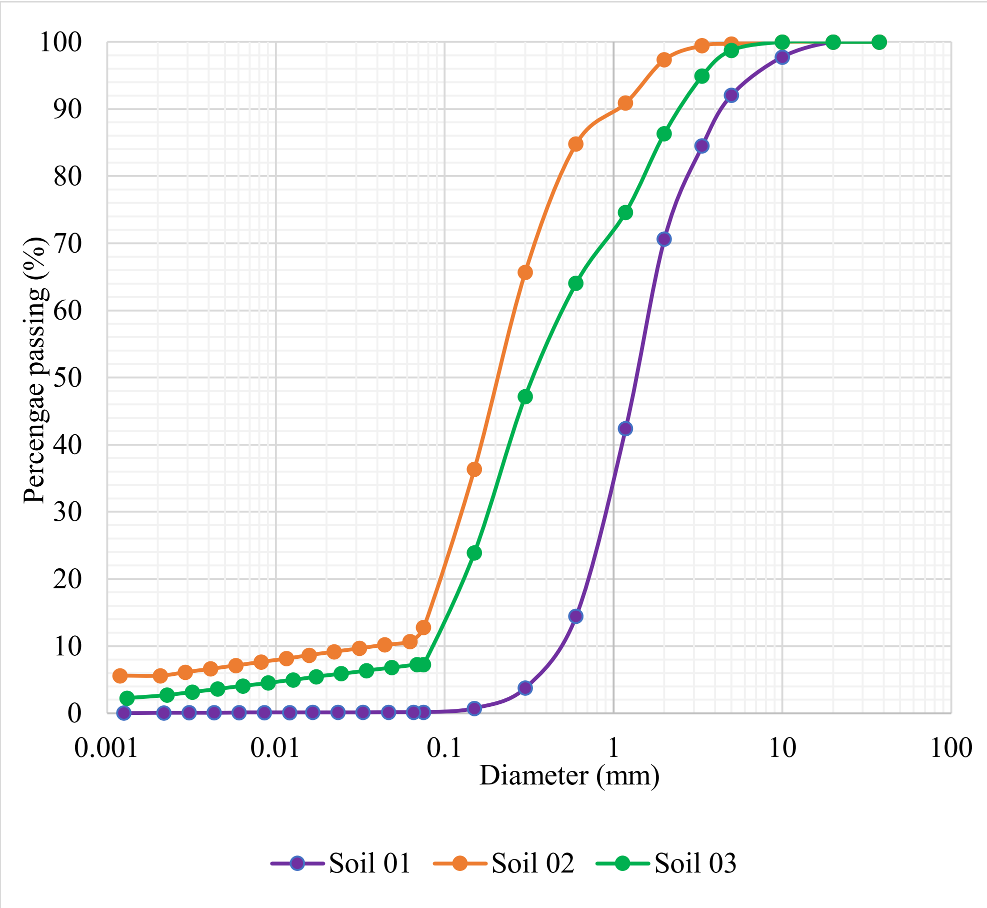

Figure 4. 1: Particles size distribution curves of three soils

Table 4. 1: Results of fundamental tests and strength tests of virgin soils

Experiments	Properties to be determined	Soil 01 (SP)	Soil 02 (SC)	Soil 03 (SP-SC)
Particle size distribution	Coefficient of gradation (C_c)	0.9	1.27	0.8
	Coefficient of uniformity (C_u)	3.4	6.5	5.9
Atterberg limits	Liquid Limit (LL)	18.7	26.4	28
	Plastic Limit (PL)	13.5	16.6	20.3
	Plastic Index (PI)	5.2	9.8	7.7
Specific gravity	Specific gravity (Gs)	2.66	2.71	2.68
Modified proctor compaction	MDD (kg/m^3)	1980.5	2014.8	1919.2
	OMC (%)	14.6	14.4	15.2
Direct shear	Cohesion (kPa)	0.8	15.9	9.5
	Internal friction angle (ϕ)	28.5	22.1	24.6
Soaked CBR	Soaked CBR (%)	18.6	11.9	13.4

4.2 Chemical compositions present in the leaf ash

Table 4. 2: Chemical compounds present in leaf ashes

Leaf ash	SiO_2 (%)	TiO_2 (%)	Al_2O_3 (%)	MnO (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)	Fe_2O_3 (%)
Banana	49.14	0.18	1.49	0.12	9.43	18.75	0.39	10.73	3.07	1.11
Bamboo	65.21	0.25	2.21	0.06	3.72	6.58	0.45	9.53	7.98	0.94
Mango	46.7	0.06	0.31	0.07	3.73	32.88	0.25	6.38	2.55	0.14
Neem	44.89	0.01	0.23	0.04	8.54	22.31	1.98	11.65	8.97	0.76
Teak	68.34	1.07	4.98	0.07	2.56	5.64	0.76	7.86	4.43	1.96
Glyrisidia sepium	51.54	0.05	2.31	0.15	5.87	15.53	0.65	10.86	7.86	0.65
Thespesia populnea	48.89	0.07	1.65	0.08	6.76	18.76	0.68	9.67	8.95	1.34

XRF tests were performed seven distinct species of leaves accessible in Sri Lanka, to establish the chemical compositions of them. Table 4.2 shows the chemical components of such ashes. According to the ASTM [43], leaf ash is pozzolanic if the total percentages of (SiO_2+Al_2O_3+Fe_2O_3) surpasses 50%. Table 2 clearly reveals that the ashes of banana leaves, bamboo, teak, sepium of Glyrisidia and Thespesia populne exhibits pozzolanic properties. However, mango leaf ash and neem leaf ash do not exhibit pozzolanic properties. Ash produced from banana, bamboo, teak, sepium of Glyrisidia, and Thespesia populnea leaves were mixed in equal quantities by weight for testing the ability of the leaf ash mixture to stabilize soils. Apart from the leaf ash mixture, BALA and BLA were investigated independently as soil stabilizers in this research.

4.3 Modified Proctor compaction experiment results with the inclusion of stabilizers

4.3.1 Modified proctor compaction experiment results with the inclusion of plastics on soil 01 (SP)

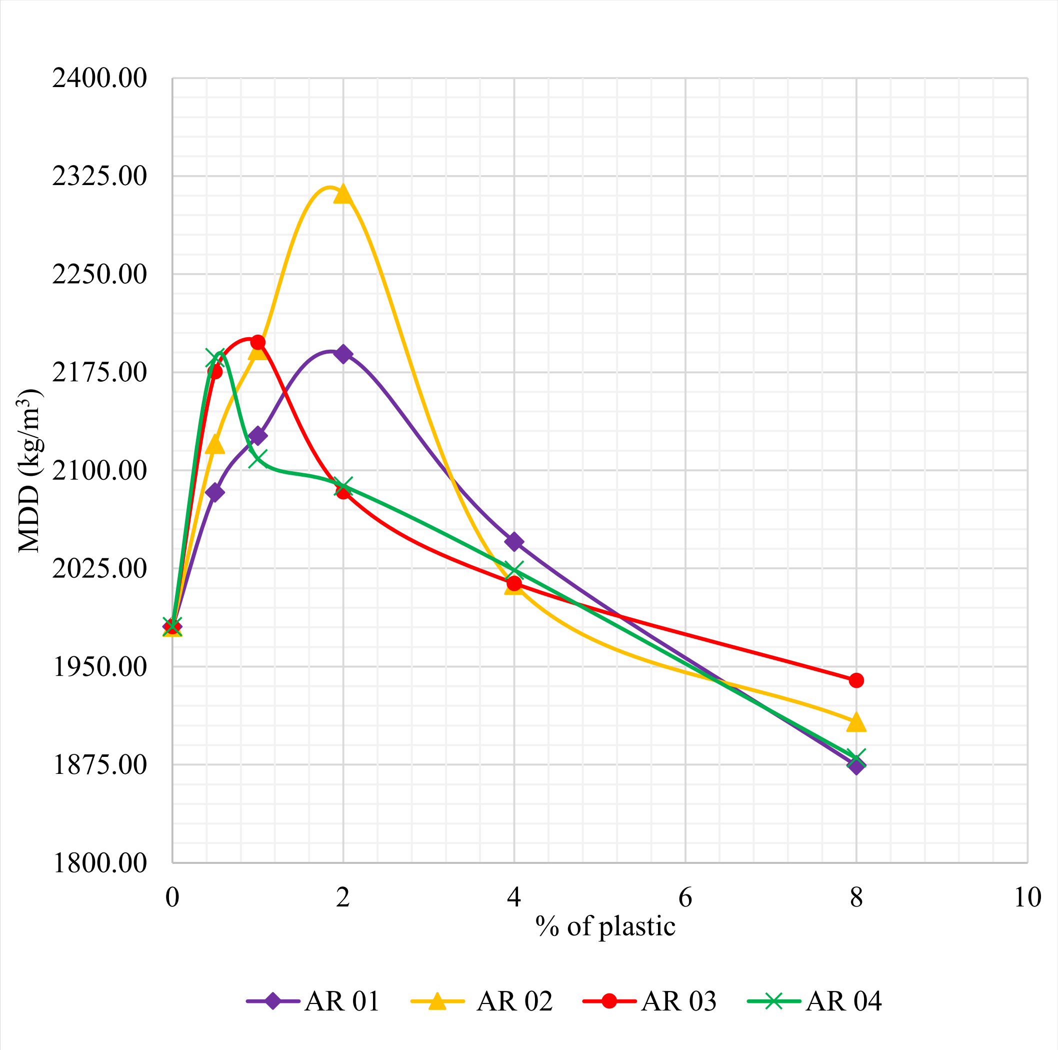

Figure 4. 2: Impact of plastics on MDD of soil 01 (SP)

Table 4. 3: Impact of plastics on OMC of soil 01(SP)

% of plastics	OMC (%) with plastics as stabilizers on soil 01 (SP)			
	AR 01	AR 02	AR 03	AR 04
0	14.6	14.6	14.6	14.6
0.5	13.2	13.2	9.8	11.2
1	13.2	12.5	12.3	12.0
2	12.5	12.1	13.7	12.3
4	13.3	13.8	13.9	13.0
8	13.4	14.1	15.5	13.2

Figure 4.2 depicts the variation of MDD of soil 01 (SP) with varied weight percentages of plastics and ARs. Table 4.3 shows the variation of OMC of soil 01 (SP) with the above-mentioned additions. Improvements in MDD comparing to the virgin state of soil 01 were noted with the addition of plastics with all the considered ARs and of 0.5, 1, 2 and 4 percentages. However, the addition of 8% of plastic with all the ARs did not show any improvements in MDD for soil 01. The most substantial improvement in MDD was achieved by combining 2% plastic of AR 2 at an OMC of 12.16 % with soil 01.

The addition of 1% plastics resulted in the second-best improvement in MDD, with an AR of 03 and an OMC of 12.38 %. However, the study by Choudhary et al. found that a plastic content of 4% resulted in the most substantial improvement in MDD [21]. Moreover, similar improvements in MDD were observed with the addition of 0.5 % of AR 04 plastic and 2 % of AR 01 plastic at the OMC of 11.26 % and 12.38 % respectively.

4.3.2 Modified proctor compaction experiment results with the inclusion of ashes on soil 01 (SP)

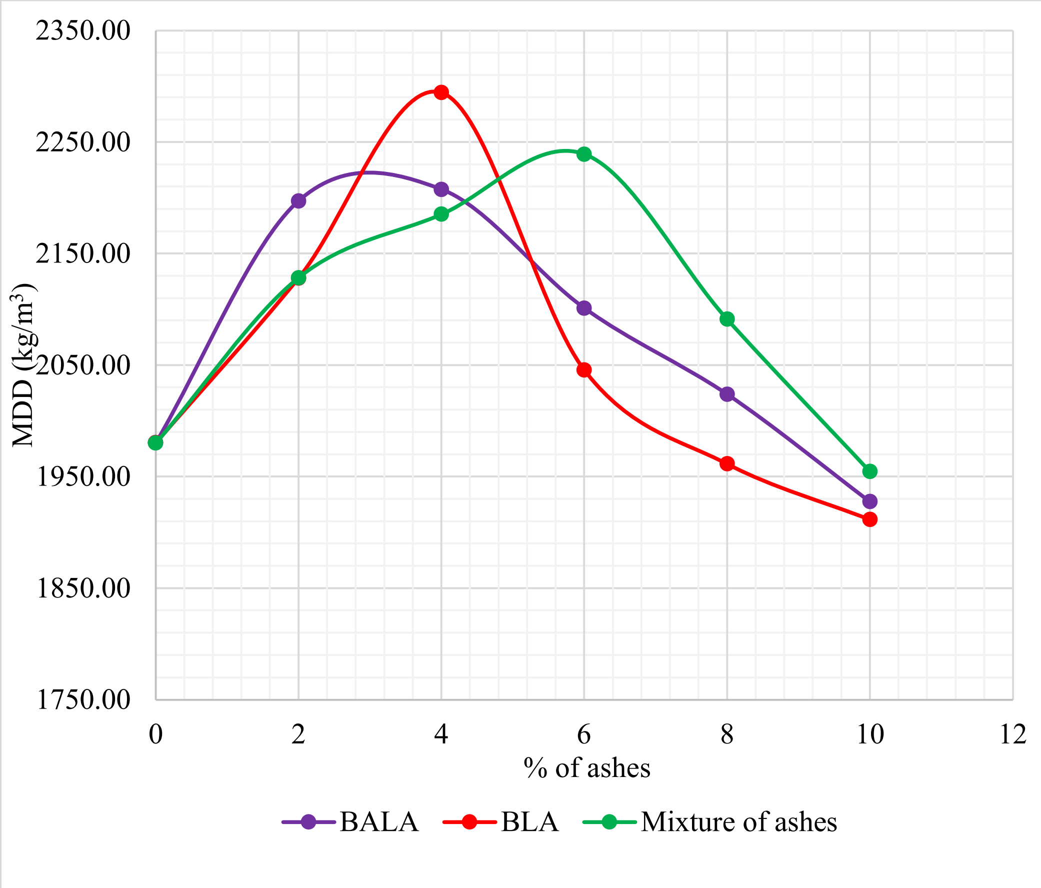

Figure 4. 3: Impact of ashes on MDD of soil 01 (SP)

Table 4. 4: Impact of ashes on OMC of soil 01(SP)

% of ashes	OMC (%) with the ashes as stabilizers on soil 01 (SP)		
	BALA	BLA	Leaf ash mixture
0	14.6	14.6	14.6
2	13.3	13.4	14.2
4	12.1	12.4	13.1
6	13.8	14.4	12.5
8	14.3	15.1	14.6
10	15.7	15.3	15.2

Figure 4.3 depicts the variation of MDD with the addition of variable weight percentages of BALA, BLA, and a leaf ash mixture on soil 01 (SP), whereas Table 4.4 shows the variation of OMC with the same additions. Improvements in MDD were noted with the addition of 2, 4, and 6 percentages of BALA, BLA and leaf ash mixture comparing to the MDD of the virgin soil 01. However, the addition of 10% of the three ash types did not result in improved MDD for soil 01.

The most significant improvement in MDD among the ashes was achieved with the addition of 4 % of BLA at the OMC of 12.4 %. Nnchiri and Aderinlewo [29] also found the most significant improvement in MDD with the addition of 4 % BALA. The addition of 6% of leaf ash mixture at 12.5 % OMC resulted in the second-best improvement in MDD among the ashes. The most substantial improvement in MDD with the addition of BALA as soil stabilizer was achieved with 4 % of BALA at the OMC of 12.1 %.

4.3.3 Modified proctor compaction experiment results with the inclusion of plastics on soil 02 (SC)

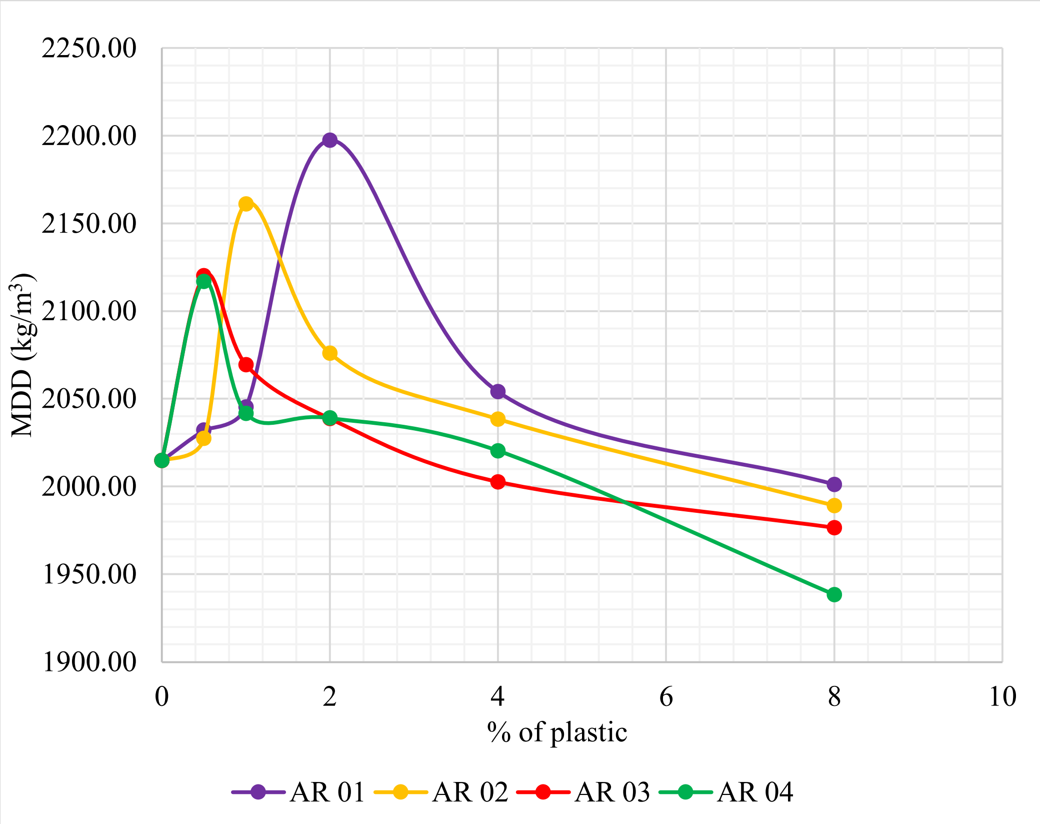

Figure 4. 4: Impact of plastics on MDD of soil 02 (SC)

Table 4. 5: Impact of plastics on OMC of soil 02 (SC)

% of plastics	OMC (%) with plastics as stabilizers on soil 02 (SC)			
	AR 01	AR 02	AR 03	AR 04
0	14.4	14.4	14.4	14.4
0.5	12.8	14.2	11.7	11.4
1	12.8	12.2	12.6	11.6
2	10.5	13.1	13.2	12.7
4	11.2	14.1	14.0	13.2
8	12.5	15.1	15.5	14.1

Figure 4.4 depicts the variation in MDD of soil 02 (SC) with the inclusion of variable weight percentages of plastics with ARs. Table 4.5 shows the change of OMC of soil 02 (SC) with the above inputs. The addition of 0.5, 1 and 2 percentages of plastics of all four ARs resulted in noticeable improvements in MDD for soil 02. At an OMC of 10.5%, the addition of 2% plastic of AR 1 resulted in the most significantly improved MDD.

The addition of 1% plastic of AR 02 to soil 02, resulted in the second-best improvement, at an OMC of 12.2 %. A similar improvement in MDD was observed when 0.5 % plastics with an AR of 3 and 0.5 % plastics with an AR of 4 were mixed at the OMC of 11.7 % and 11.4 % respectively.

4.3.4 Modified proctor compaction experiment results with the inclusion of ashes on soil 02 (SC)

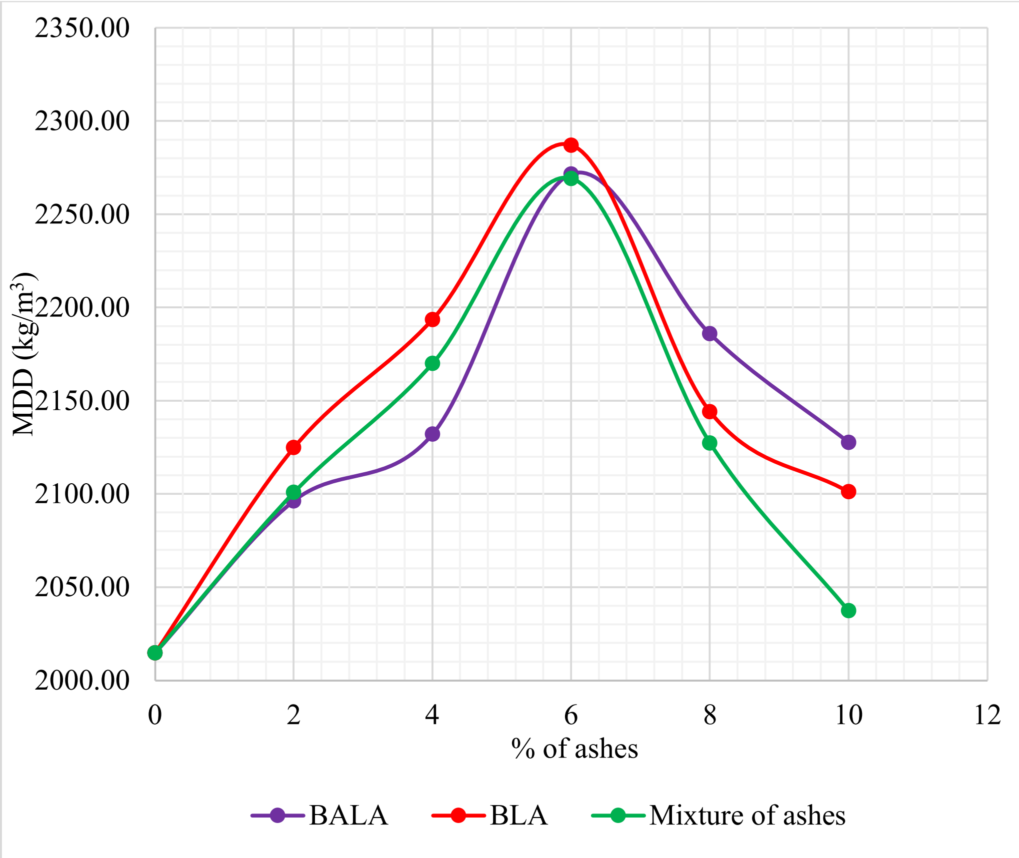

Figure 4. 5: Impact of ashes on MDD of soil 02 (SC)

Table 4. 6: Impact of ashes on OMC of soil 02 (SC)

% of ashes	OMC (%) with ashes as stabilizers on soil 02 (SC)		
	BALA	BLA	Leaf ash mixture
0	14.4	14.4	14.4
2	13.6	13.7	14.2
4	12.5	13.2	13.8
6	12.1	12.8	12.6
8	13.3	13.3	14.0
10	13.5	14.1	15.6

Figure 4.5 depicts the change in MDD of soil 02 (SC) with different weight percentages of BALA, BLA, and the leaf ash mixture, while Table 4.6 depicts the variation of OMC of soil 02 (SC) with the same additions. Improvement in MDD were noted with the addition of all relevant weight percentages of BALA, BLA and leaf ash mixture on soil 02. With the addition of 6% BLA at 12.8% OMC, the greatest substantial improvement in MDD was found. On soil 02, the addition of 6% BALA and the leaf ash mixture at the OMC of 12.1 % and 12.6 %, respectively, resulted in the second-most significant or equivalent improvement in MDD.

4.3.5 Modified proctor compaction experiment results with the inclusion of plastics on soil 03 (SP-SC)

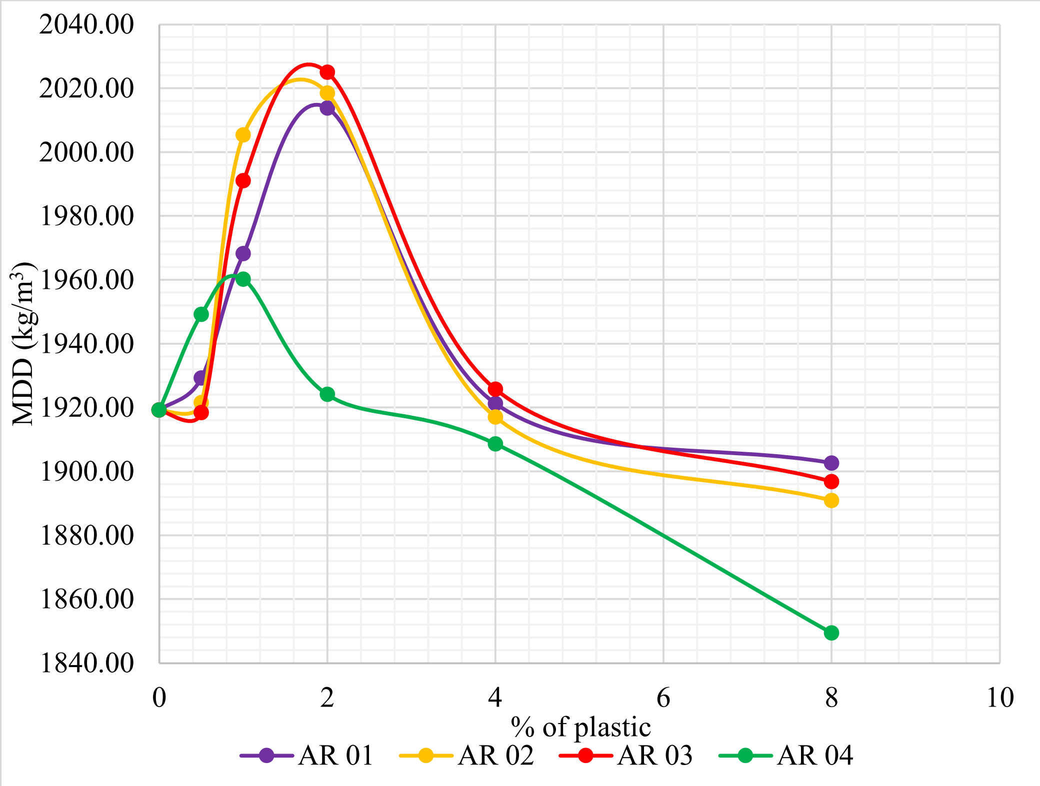

Figure 4. 6: Impact of plastics on MDD of soil 03 (SP-SC)

Table 4. 7: Impact of plastics on OMC of soil 03(SP-SC)

% of plastics	OMC (%) with plastics as stabilizers on soil 03 (SP-SC)			
	AR 01	AR 02	AR 03	AR 04
0	15.1	15.1	15.1	15.1
0.5	14.8	14.7	14.6	14.9
1	14.2	14.4	14.1	14.3
2	13.7	13.6	13.4	15.9
4	13.8	14.7	14.3	16.3
8	14.0	15.1	14.8	17.7

Figure 4.6 depicts the change in MDD of soil 03 (SP-SC) with the inclusion of various weight percentages of plastics with varying ARs. Table 4.7 shows the change of OMC of soil 03 (SP-SC) with the same inputs mentioned above. When plastics with ARs of 1, 2 and 3 and weight percentage of 2 were used, the MDD improvements were fairly similar to each other although the OMC differed. However, Neopaney et al. [28] found the most significant improvement in MDD with the addition of 0.5% plastics. No improvements in MDD were observed when plastic was mixed with the weight percentage of 8 and ARs of 1, 2, 3 and 4 compared to that of the virgin state of soil 03. Moreover, improvements in MDD were insignificant with the addition of AR 04 compared to the other ARs on soil 03.

4.3.6 Modified proctor compaction experiment results with the inclusion of ashes on soil 03 (SP-SC)

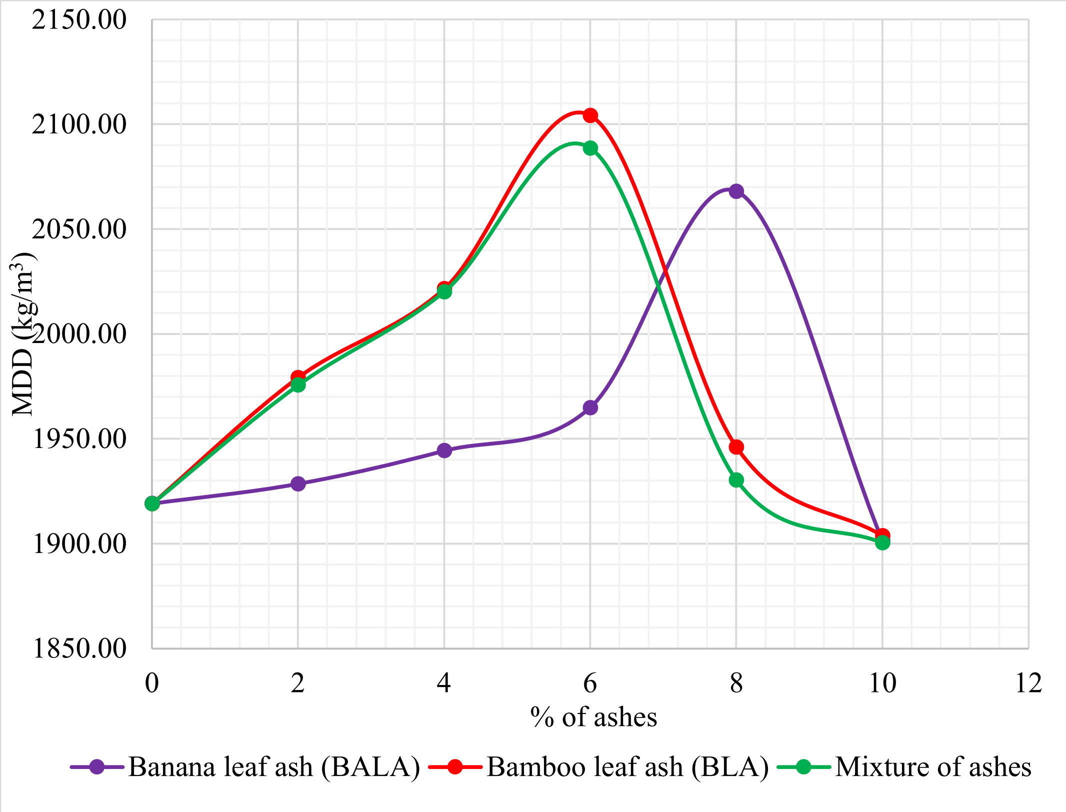

Figure 4. 7: Impact of ashes on MDD of soil 03 (SP-SC)

Table 4. 8: Impact of ashes on OMC of soil 03(SP-SC)

% of ashes	OMC (%) with ashes as stabilizers on soil 03 (SP-SC)		
	BALA	BLA	Leaf ash mixture
0	15.1	15.1	15.1
2	15.4	14.1	14.8
4	14.6	13.3	13.5
6	14.7	12.5	12.8
8	13.2	15.1	14.1
10	16.2	16.6	15.1

Figure 4.7 depicts a variation of MDD of soil 03 (SP-SC) with varied weight percentages of BALA, BLA, and the leaf ash mixture. Table 4.8 shows the change of OMC of soil 03 (SP-SC) with the same inputs mentioned above. The best improvement in MDD among the three ash additions for soil 03 was achieved with the addition of 6% BLA at 12.5% OMC, followed by 6 % leaf ash mixture at 12.8% OMC.

The most significant improvement in MDD for BALA was achieved when it was added with the weight percentage of 8 at the OMC of 13.2 %. Moreover, similar improvements in MDD were noted with the addition of 2 and 4 percentages of BLA and leaf ash mixture though the OMCs were different. However, Amu and Adetuberu [24] found that the most significant improvement in MDD was possible with the addition of 4 % of BLA.

4.3.7 Common observation on the improvement of MDD with the addition of stabilizers

Considerable improvements in MDD comparing to the virgin states of all three soils were achieved with the addition of 2, 4, 6 and 8 weight percentages of the leaf ash mixture, BALA and BLA and of 0.5, 1 and 2 weight percentages plastics of all the considered ARs. This is because the number of voids has been reduced by the addition of stabilizing agents [29]. This will improve compaction by increasing the MDD while reducing OMC, which indicates the improvement of soils. Plastic is nonabsorbent that doesn't exhibit affinity to water. Hence, reductions in OMC were noticed with additions of plastics. However, decreases in the improvement of MDD was noted mostly with the addition of 10% BALA, BLA and leaf ash mixture and 4 % and 8% of plastic. This could be due to the reduction in the specific gravity of soils with the addition of stabilizers in large quantity. [29]. In addition to that, it can be noticed that the improvement in MDD with the addition of BLA was better than that of BALA and the leaf ash mixture in all three types of soils. It shows that with an increment of pozzolanic reaction, the stabilization of soils too improves.

4.4 Soaked CBR experiment results with the inclusion of stabilizers

Soaked CBR tests were performed at 98 % MDD and its related moisture content for AR, which demonstrated the highest improvement in MDD for each weight percentage of plastics. In the case of all three types of ashes, soaked CBR tests were performed at 98 % MDD and its corresponding moisture for each weight percentage of ashes.

4.4.1 Impact of stabilizing agents on soaked CBR for soil 01 (SP)

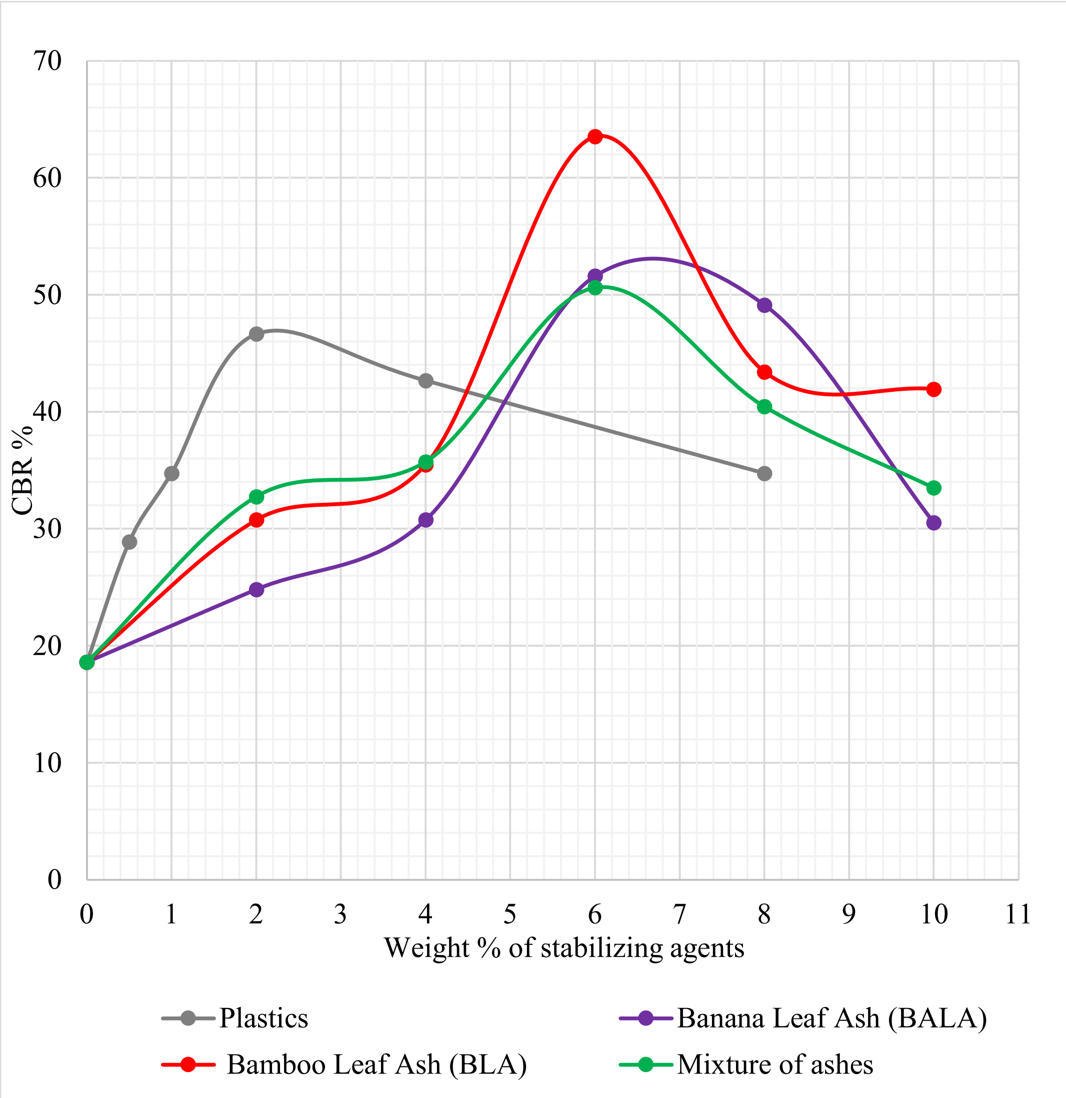

Figure 4. 8: Variation of soaked CBR of soil 01 (SP) with stabilizers

Figure 4.8 depicts the results of the soaked CBR experiments with variable weight percentages of stabilizing additives on soil 01 (SP). Considerable improvements in soaked CBR were achieved with the addition of BALA, BLA, leaf ash mixture and plastics with all the considered weight percentages. The best stabilizing agent based on improved CBR was BLA with the addition of 6 %. Amu and Adetuberu [24] also found that the best improvement in CBR was possible with the addition of 6% BLA.

Improvement in soaked CBR was almost 3.5 times that of the virgin soil 01 when BLA was mixed with 6% of BLA on soil 01. The second-best improvements/ similar improvements for soaked CBR were achieved with the addition of 6 % BALA and leaf ash mixture on soil 01 though with different OMC. However, Nnochiri and Aderinlewo [29] determined that the best improvement in CBR was observed with the addition of 4% BALA. When plastics with AR 02 was added with the weight percentage of 2, optimum improvement of soaked CBR around 2.5 times that of the virgin state of soil 01 was observed.

4.4.2 Impact of stabilizing agents on soaked CBR for soil 02 (SC)

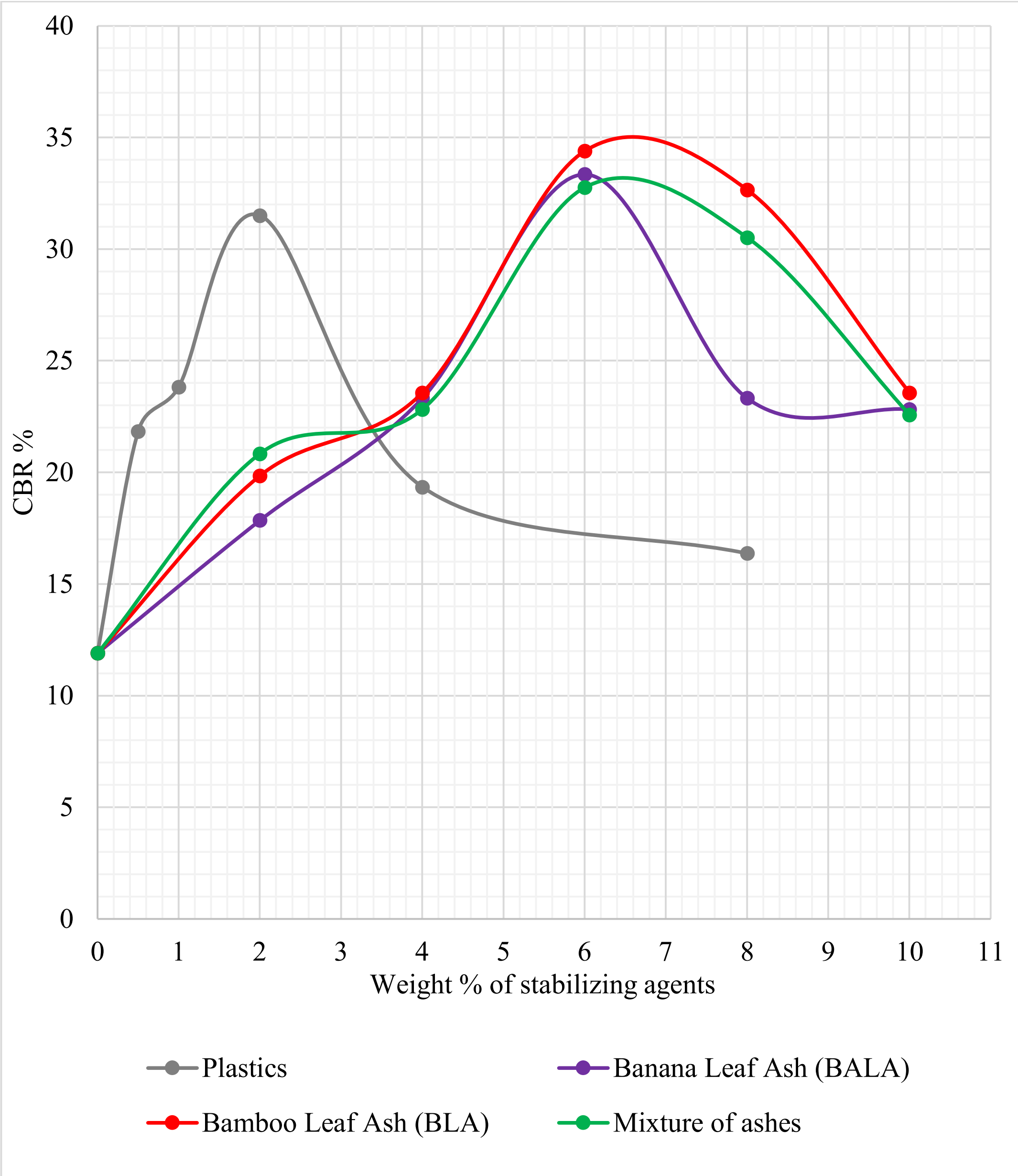

Figure 4. 9: Variation of soaked CBR of soil 02 (SC) with stabilizers

Figure 4.9 depicts the results of the soaked CBR experiments with variable weight percentages of stabilizing additives on soil 02 (SC). Considerable improvements in soaked CBR values were achieved with the addition of plastics, BALA, BLA and a leaf ash mixture with all the considered weight percentages. The best stabilizing agent based on improved soaked CBR was BLA with the addition of 6 %. However, very similar improvements in soaked CBR closer to that of the addition of 6 % of BLA were noted with the addition of 6 % of BALA and a leaf ash mixture at their respective OMC.

Improvement in soaked CBR was almost 3 times that of the virgin soil 02 when BLA, BALA and the leaf ash mixture were added with the weight percentage of six to soil 02. Furthermore, the addition of BLA and a leaf ash mixture to soil 02 resulted in almost comparable increases in soaking CBR values. The least significant improvements in soaked CBR values were noted with the addition of 10 % of BALA, BLA and the leaf ash mixture at their respective OMCs for soil 02. When plastics with AR 01 was added weight percentage of 2, optimum improvement of soaked CBR for plastics on soil 02 was observed. However, Choudhary et al. [21] found the best improvement in CBR with the addition of 4% plastics.

4.4.3 Impact of stabilizing agents on soaked CBR for soil 03 (SP-SC)

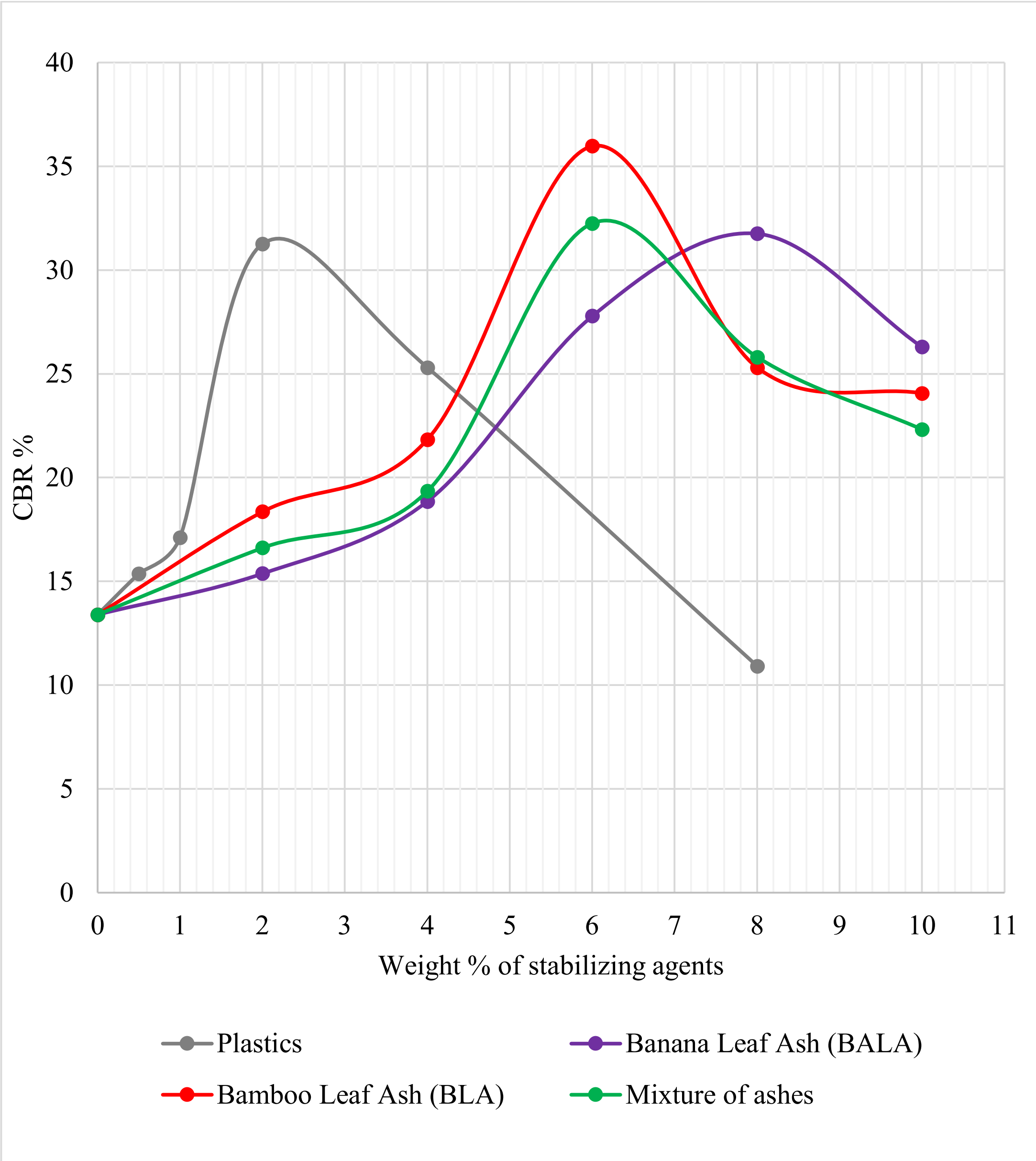

Figure 4. 10: Variation of soaked CBR of soil 03 (SP-SC) with stabilizers

Figure 4.10 depicts the results of the soaked CBR experiments with the inclusion of varying weight percentages of stabilizers on soil 03 (SP-SC). Considerable improvements in soaked CBR were achieved with the inclusion of BALA, BLA and a leaf ash mixture with all the considered weight percentages. The best stabilizing agent based on improved soaked CBR was BLA with the addition of 6 %. The specific improvement was more than 2.5 times greater than that of the virgin soil 03. Second best / similar improvements more than 2 times greater than that of the virgin state of soil 02, in soaked CBR were achieved with the addition of 2 %, 6 % and 8 % of plastics, a leaf ash mixture and BALA respectively for soil 03.

The least improvements in soaked CBR were noted with the addition of 10 % of BALA, BLA and leaf ash mixture at their respective OMCs for soil 03. Very similar improvements in soaked CBR were noted with the addition of 2% and 4 % of the leaf ash mixture and BALA and 8% and 10 % of BLA and the leaf ash mixture. When plastics of AR 03 was added with the weight percentage of 8, no improvement in soaked CBR was noticed comparing to that of the virgin state of soil 03.

4.4.4 Common observation on the improvement of soaked CBR with the addition of stabilizers

In comparison with the soaked CBR values of virgin soils, the addition of variable weight percentages of leaf ashes significantly enhances the soaked CBR values on the considered soils. The progressive development of cementitious components between $Ca(OH)_2$ contained in the pozzolanic ashes and soils would result in an enhancement of the CBR values with the inclusion of the leaf ashes [44]. A resistance might have developed because of the interaction between the soil and the plastics. Therefore, the inclusion of plastics resulted in an improvement in the soaked CBR values [45- 46].

A decrease in soaked CBR increment was noted on all three soils with the inclusion of greater leaf ash weight percentages. This might be due to surplus ashes that haven't been mobilized in the reaction, especially since the amount of calcium hydroxide normally contained in soils isn't very high and also due to not curing the soils mixed with the stabilizers for a greater number of days [47]. The addition of a higher amount of plastics may have reduced the specific gravity of the soil mixture and contributed towards a drop in the improvements of soaked CBR. In addition to that, it can be noticed that the improvement in soaked CBR with the addition of BLA was better than that of BALA and the leaf ash mixture in all three types of soils. It shows that with an increment of pozzolanic reaction, the stabilization of soils too improves.

4.4.5 Long term improvement of hardening action of natural leaf ash through soaked CBR tests

In order to understand the long-term improvement of the hardening action of natural leaf ash, a CBR test was carried out on a sample made of soil 03 (SP-SC) mixed with 6 % of the leaf ash mixture and soaked in water for 150 days. The observed CBR value of the sample was 55.5 which is around 4 times that of the CBR of virgin soil 03. This shows the pozzolanic action of the ashes with the soil improved the stabilization of soil quite vastly.

4.5 Direct shear experiment results with the inclusion of stabilizers

Direct shear experiments were performed at 98% MDD and its related moisture content for AR, which demonstrated the highest improvement in MDD for each weight percentage of plastics. In the case of all three types of ashes, direct shear tests were performed at 98 % MDD and its corresponding moisture for each weight percentage of ashes.

4.5.1 Effectiveness of stabilizers on shear strength parameters on soil 01 (SP)

Table 4. 9: Impact of plastics on shear strength parameters for soil 01 (SP)

% of plastic	Angle of internal friction (ϕ)	Cohesion (kPa)
0	28.5	0.8
0.5	32.0	1.0
1	34.3	1.2
2	35.1	1.3
4	33.3	1.1
8	30.8	0.9

Table 4. 10: Impact of BALA on shear strength parameters for soil 01 (SP)

% of BALA	Angle of internal friction (ϕ)	Cohesion (kPa)
0	28.5	0.8
2	31.6	1.7
4	34.3	1.9
6	36.0	1
8	34.0	0.9
10	32.2	0.8

Table 4. 11: Impact of BLA on shear strength parameters for soil 01 (SP)

% of BLA	Angle of internal friction (ϕ)	Cohesion (kPa)
0	28.5	0.8
2	32.7	1.9
4	36.4	1.8
6	37.3	1.3
8	36.2	1.1
10	33.6	1

Table 4. 12: Impact of leaf ash mixture on shear strength parameters for soil 01 (SP)

% of leaf ash mixture	Angle of internal friction (ϕ)	Cohesion (kPa)
0	28.5	0.8
2	33.5	2
4	34.8	1.9
6	35.6	1.8
8	34.0	1.3
10	30.2	1

Tables 4.9, 4.10, 4.11 and 4.12 present the results of the direct shear experiments with the addition of plastics, BALA, BLA and the leaf ash mixture of different weight percentages respectively on soil 01. With the inclusion of different weight percentages plastics, BALA, BLA and the leaf ash mixture, the angle of internal friction increased comparing to the angle of internal friction of virgin soil 01. The addition of 6% of BLA resulted in the most substantial improvement in the angle of internal friction. The addition of 6%, 4%, and 8% of BALA to soil 01 resulted in the second-best or equivalent improvements in the angle of internal friction. Nnochiri and Aderinlewo [29] determined that adding 4 % BALA improved shear strength parameter in the most

effective way. In the case of plastics, the addition of 2% plastics of AR 02 for soil 01 resulted in the greatest improvement in the angle of internal friction.

In the case of the leaf ash mixture, the addition of the 6 % leaf ash mixture for soil 01 resulted in the most substantial improvement in the angle of internal friction. However, when the same stabilizing agents were added, the increment of cohesion values was insignificant, because the clay content in soil 01 was insignificant. Also, values of the angle of internal friction of virgin soil 01 and as well as soil 01 mixed with the different stabilizers were quite insignificant (less than 2 kPa).

4.5.2 Effectiveness of stabilizers on shear strength parameters on soil 02 (SC)

Table 4. 13: Impact of plastics on shear strength parameters for soil 02 (SC)

% of plastic	Angle of internal friction (ϕ)	Cohesion (kPa)
0	22.1	15.9
0.5	22.5	16.4
1	23.5	16.8
2	24.6	17.3
4	25.7	17
8	21.1	15.8

Table 4. 14: Impact of BALA on shear strength parameters for soil 02 (SC)

% of BALA	Angle of internal friction (ϕ)	Cohesion (kPa)
0	22.1	15.9
2	22.6	18
4	23.1	22.1
6	25.7	24
8	22.0	20
10	18.7	17.8

Table 4. 15: Impact of BLA on shear strength parameters for soil 02 (SC)

% of BLA	Angle of internal friction (ϕ)	Cohesion (kPa)
`	22.1	15.9
2	23.4	20
4	25.5	25
6	27.1	28
8	23.1	18.8
10	16.8	17.9

Table 4. 16: Impact of leaf ash mixture on shear strength parameters for soil 02 (SC)

% of leaf ash mixture	Angle of internal friction (ϕ)	Cohesion (kPa)
0	22.1	15.9
2	23.0	17.8
4	24.1	22.5
6	27.0	25
8	22.3	19
10	18.9	17.9

Tables 4.13, 4.14, 4.15 and 4.16 present the results of the direct shear experiments with the addition of plastics, BALA, BLA and the leaf ash mixture of different weight percentages respectively on soil 02. The angle of internal friction has increased with the addition of variable percentages considered except 8 % in the case of plastics and 10 % in cases of BALA, BLA and the leaf ash mixture comparing to the angle of internal friction of virgin soil 02. The addition of 6% BLA as well as the leaf ash mixture resulted in the greatest improvement in the angle of internal friction. The addition of 4% of plastics with AR 01, 6% of BALA, and 4% of BLA for soil 02 resulted in the second best or comparable improvements in the angle of internal friction.

Improvements in cohesion values were noted with the inclusion of the variable percentages considered in the case of BALA, BLA and the leaf ash mixture comparing to that of the virgin soil 02. However, the most significant improvement in cohesion was achieved with mixing of 4 % and 6 % BLA and 6 % leaf ash mixture respectively on soil 02. In the case of plastics, insignificant improvement in cohesion on soil 02 can be noticed.

4.5.3 Effectiveness of stabilizers on shear strength parameters on soil 03 (SP-SC)

Table 4. 17: Impact of plastics on shear strength parameters for soil 03 (SP-SC)

% of plastic	Angle of internal friction (ϕ)	Cohesion (kPa)
0	24.6	9.5
0.5	25.2	10.7
1	27.5	11.4
2	30.1	12.5
4	26.9	11
8	24.8	10

Table 4. 18: Impact of BALA on shear strength parameters for soil 03 (SP-SC)

% of BALA	Angle of internal friction (ϕ)	Cohesion (kPa)
0	24.6	9.5
2	28.2	10.1
4	29.7	12
6	31.6	13.8
8	25.1	10.5
10	22.3	8

Table 4. 19: Impact of BLA on shear strength parameters for soil 03 (SP-SC)

% of BLA	Angle of internal friction (ϕ)	Cohesion (kPa)
0	24.6	9.5
2	29.0	13
4	31.1	15.9
6	29.6	15.4
8	29.0	12
10	27.8	10.2

Table 4. 20: Impact of leaf ash mixture on shear strength parameters for soil 03 (SP-SC)

% of leaf ash mixture	Angle of internal friction (ϕ)	Cohesion (kPa)
0	24.6	9.5
2	26.7	13.9
4	30.1	15.5
6	28.2	15
8	27.5	11
10	25.1	10

Tables 4.17, 4.18, 4.19 and 4.20 present the results of the direct shear experiments with the addition of plastics, BALA, BLA and the leaf ash mixture of different weight percentages respectively on soil 03. There was an increase in the angle of internal friction with the inclusion of variable weight percentages in the case of plastics, BLA and the leaf ash mixture for soil 03 comparing to the angle of internal friction of virgin soil 03. In the case of BALA, there were improvements in the shear strength parameter for all the considered weight percentages except 10 % for soil 03. The addition of 6 % BALA and 4 % BLA resulted in the greatest improvement in the angle of internal friction. The addition of 2% plastics with AR 03, and 4% of the leaf ash mixture for soil 03 resulted in the second-best or equivalent improvements in the angle of internal friction.

Except for the addition of 10% BALA, all of the weight percentages considered in the case of BALA, BLA, and leaf ash mixture resulted in improvements in cohesion values comparing to the cohesion values of the virgin soil 03. However, the optimum improvement in cohesion was observed with the addition of 4 % of BLA on soil 03. The second best or similar improvements in cohesion were observed with the addition of 6 % of BLA and 4 % of the leaf ash mixture for soil 03. In the case of plastics, not much improvement in cohesion was observed on soil 03.

4.5.4 Common observation on the improvement of shear strength parameters with the inclusion of stabilizers

Improvements in the angle of internal friction and cohesion were achieved on all three considered soils with the inclusion of 2 %, 4 %, 6 % and 8 % of BALA, BLA, and the leaf ash mixture with the OMC in the range of (12-15.5) %. With the additions of BALA, BLA and the leaf ash mixture, flocculation of the soil particles occurs. Flocculation and alteration of the angularity of the soil particles occur with the addition of finer materials such as leaf ashes [48]. It results in the improvement of the interlocking and intergranular friction of soil particles. This is the reason for the improvement in the angle of internal friction values [48].

Direct shear tests were conducted at the OMC, under conditions similar to soaked CBR tests. Though BALA, BLA and leaf ash mixture do not exhibit any cohesion in nature, when it was moist at OMC, soils mixed with BALA, BLA and leaf ash mixture may exhibit apparent cohesion. In addition to that, clay components were present in soil 02 and soil 03 and there could have been a strong bond created between soil and BALA, BLA and the leaf ash mixture due to the pozzolanic actions. Due to such reasons, there were an increase in cohesion values with the additions of BALA, BLA and the leaf ash mixture.

On all three soils, the addition of 0.5, 1, 2 percentages of plastics resulted in an improvement in the internal friction angle. This is due to the increased friction induced by the inclusion of plastics [49]. However, improvements in the internal friction angle were reduced when a higher quantity of plastic was added, such as 8%. This can be due to internal surface area of plastics may increase with the addition of the plastics in higher percentages, resulting in the shear deformation of the soils. However, since plastics are non-cementitious, no substantial changes in cohesion were noted in all three soils after their addition.

4.6 Results of Atterberg limit tests with the addition of stabilizers

4.6.1 Impact of ashes on PI and LL on soil 01 (SP)

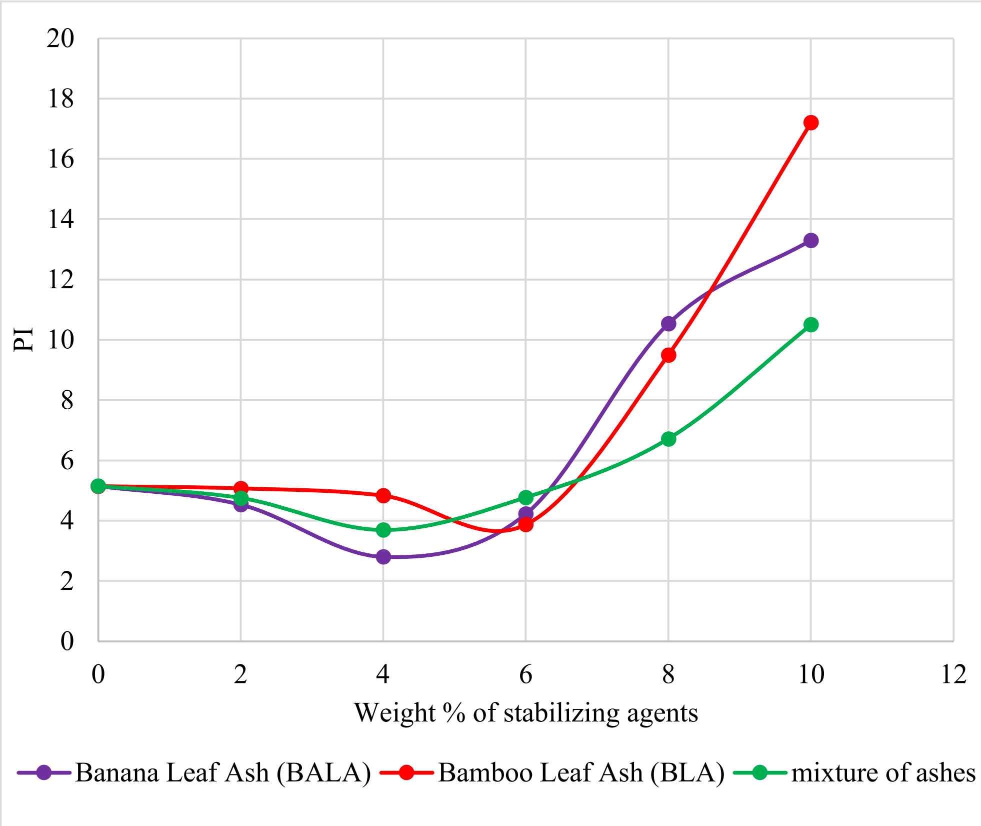

Figure 4. 11: Variation of PI with stabilizers on soil 01 (SP)

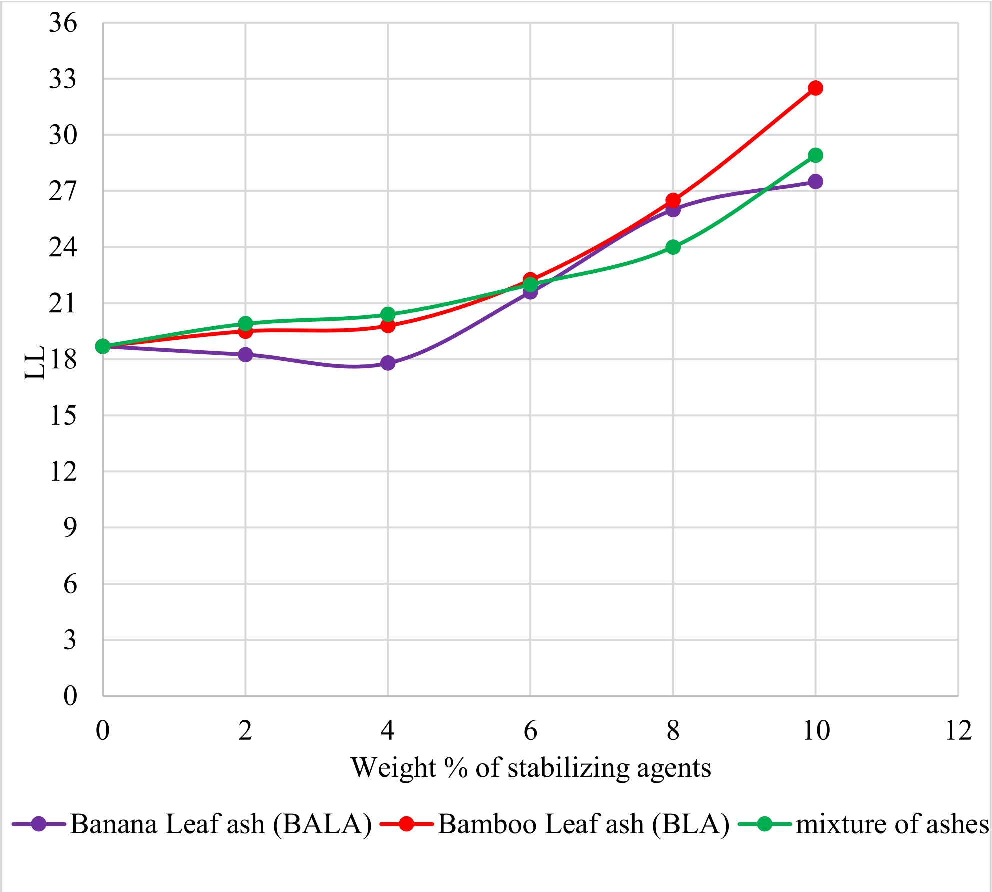

Figure 4. 12: Variation of LL with stabilizers on soil 01 (SP)

Variation of PI and LL with the addition of BALA, BLA and the leaf ash mixture on soil 01 were shown in Figures 4.11 and 4.12 respectively. The addition of variable percentages of BALA, BLA and leaf ash mixture results in a variation of LL, PL and PI on soil 01. There were improvements in PI with the addition of 2 %, 4 % and 6 % of BALA and BLA for soil 01. In the case of the leaf ash mixture, improvements in PI were noted with the addition of 2 % and 4 % for soil 01. However, the addition of 4 % of BALA resulted in the least PI on soil 01.

Variations of Atterberg limits with the addition of leaf ashes are due to the flocculation, exchange of cations, agglomeration and pozzolanic reactions [50]. With the addition of ashes to soil 01, the PI decreases, indicating a more stable soil with a significant increase in workability.

4.6.2 Impact of ashes on PI and LL on soil 02 (SC)

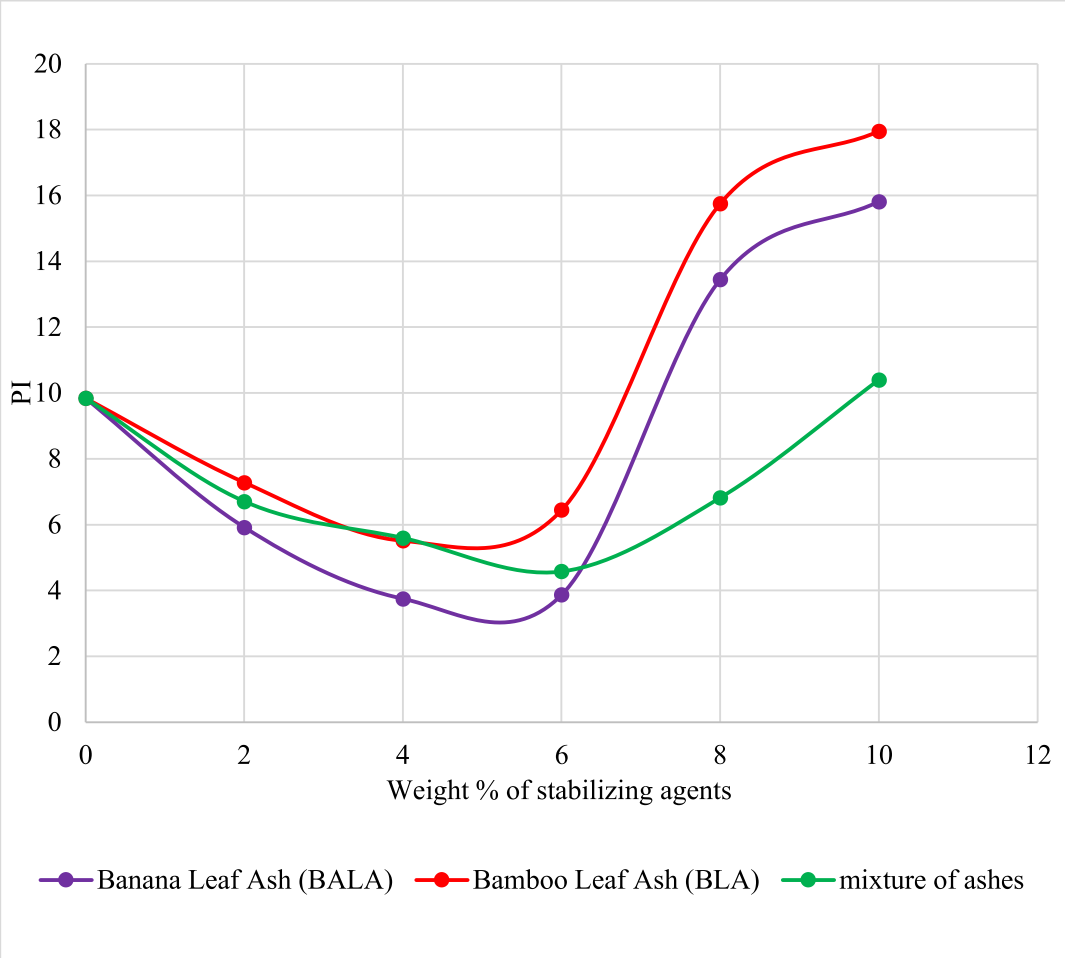

Figure 4. 13: Variation of PI with stabilizers on soil 02 (SC)

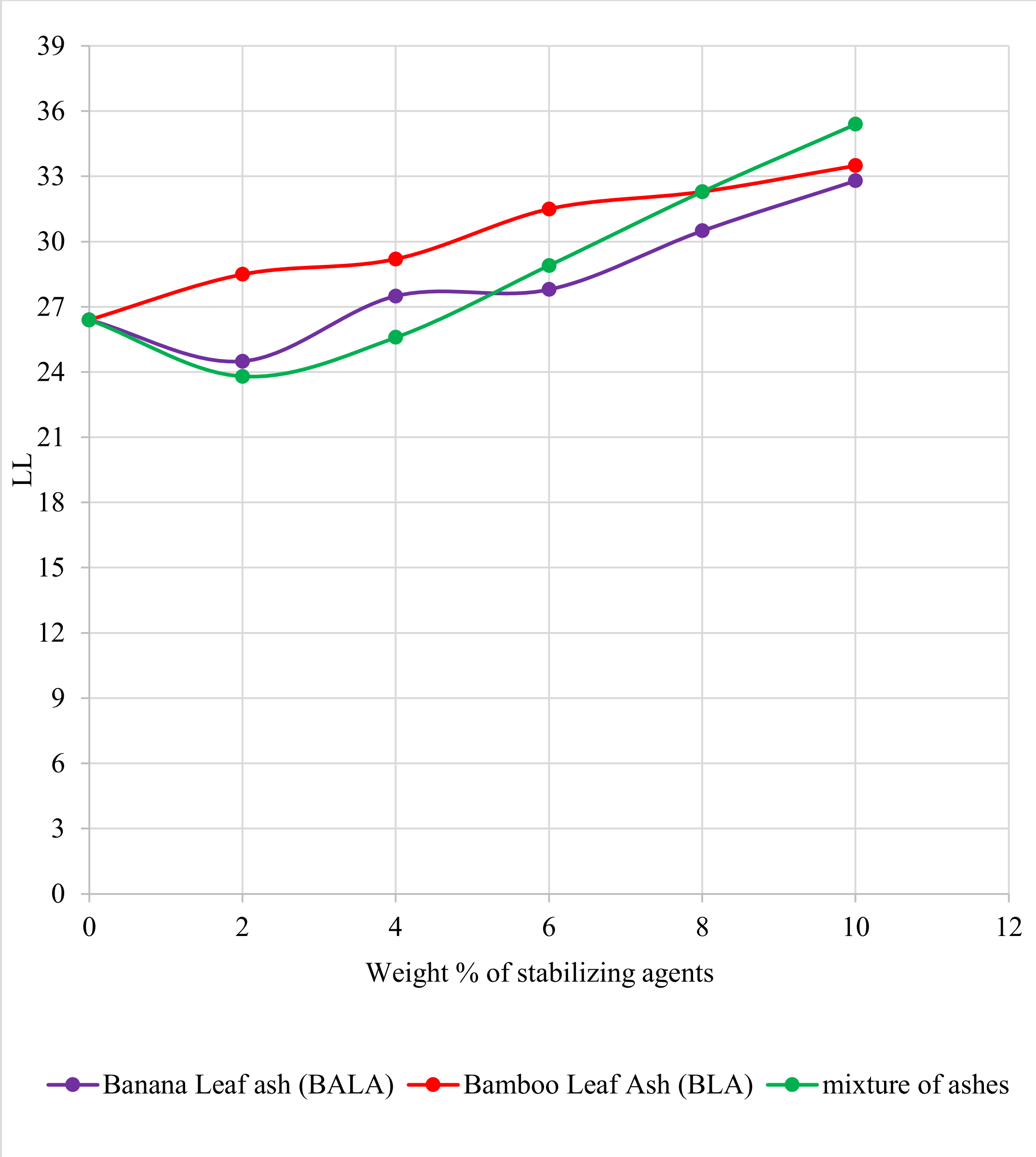

Figure 4. 14: Variation of LL with stabilizers on soil 02 (SC)

Variation of PI and LL with the addition of BALA, BLA and leaf ash mixture on soil 02 were shown in Figures 4.13 and 4.14 respectively. The addition of variable percentages of BALA, BLA and leaf ash mixture results in a variation of LL, PL and PI on soil 02. Improvements were observed in PI with the addition of 2%, 4% and 6% of BALA, BLA and leaf ash mixture for soil 02. Additionally, the addition of 8% of the leaf ash mixture to soil 02 resulted in an increase in PI. However, the addition of 4% and 6% BALA on soil 02 resulted in the least PI.

The addition of 6% of the leaf ash mixture to soil 02 resulted in the second-best PI improvement. A very similar improvements in PI was achieved with the addition of 4 % of BLA and the leaf ash mixture on soil 02. With the addition of ashes to soil 02, the PI decreases, indicating a more stable soil with a significant increase in workability.

4.6.3 Impact of ashes on PI and LL on soil 03 (SP-SC)

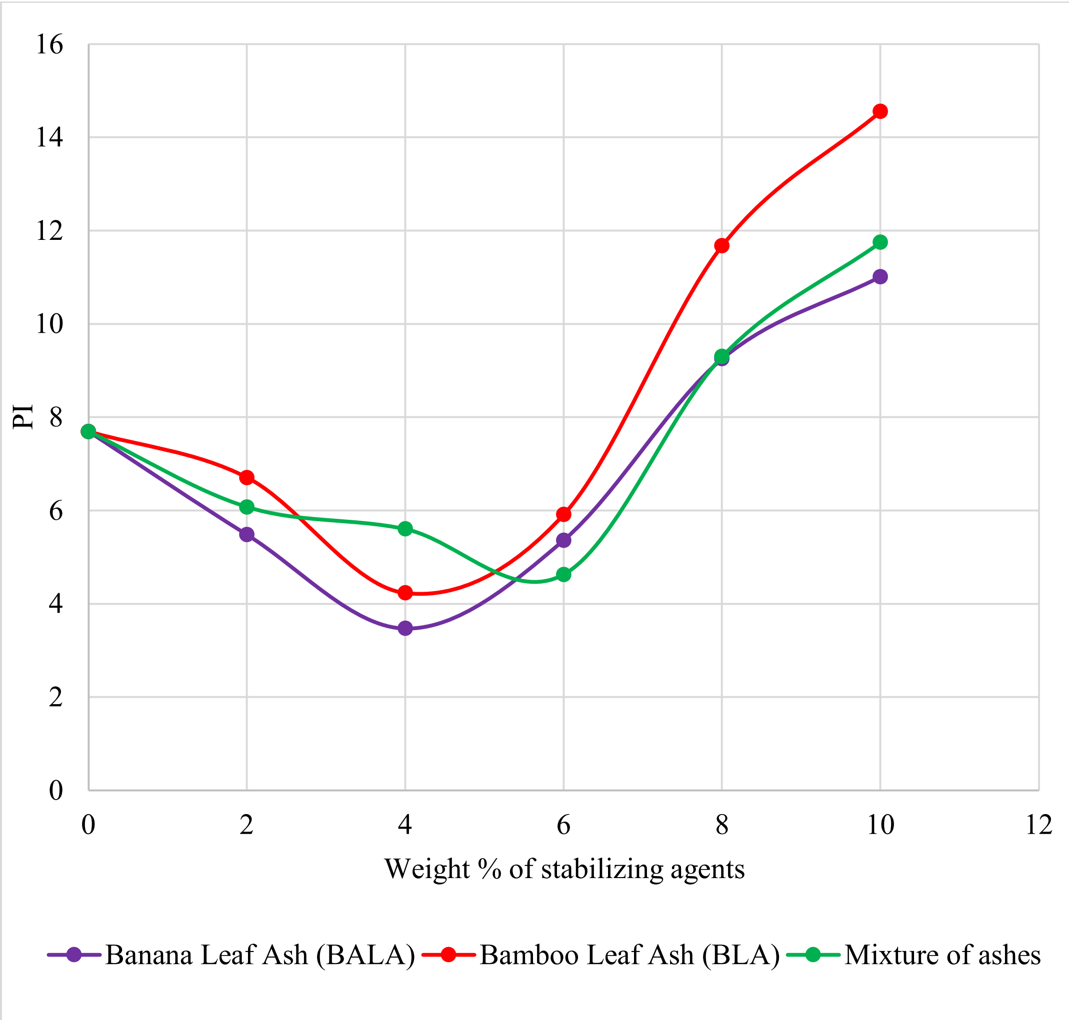

Figure 4. 15: Variation of PI with stabilizers on soil 03 (SP-SC)

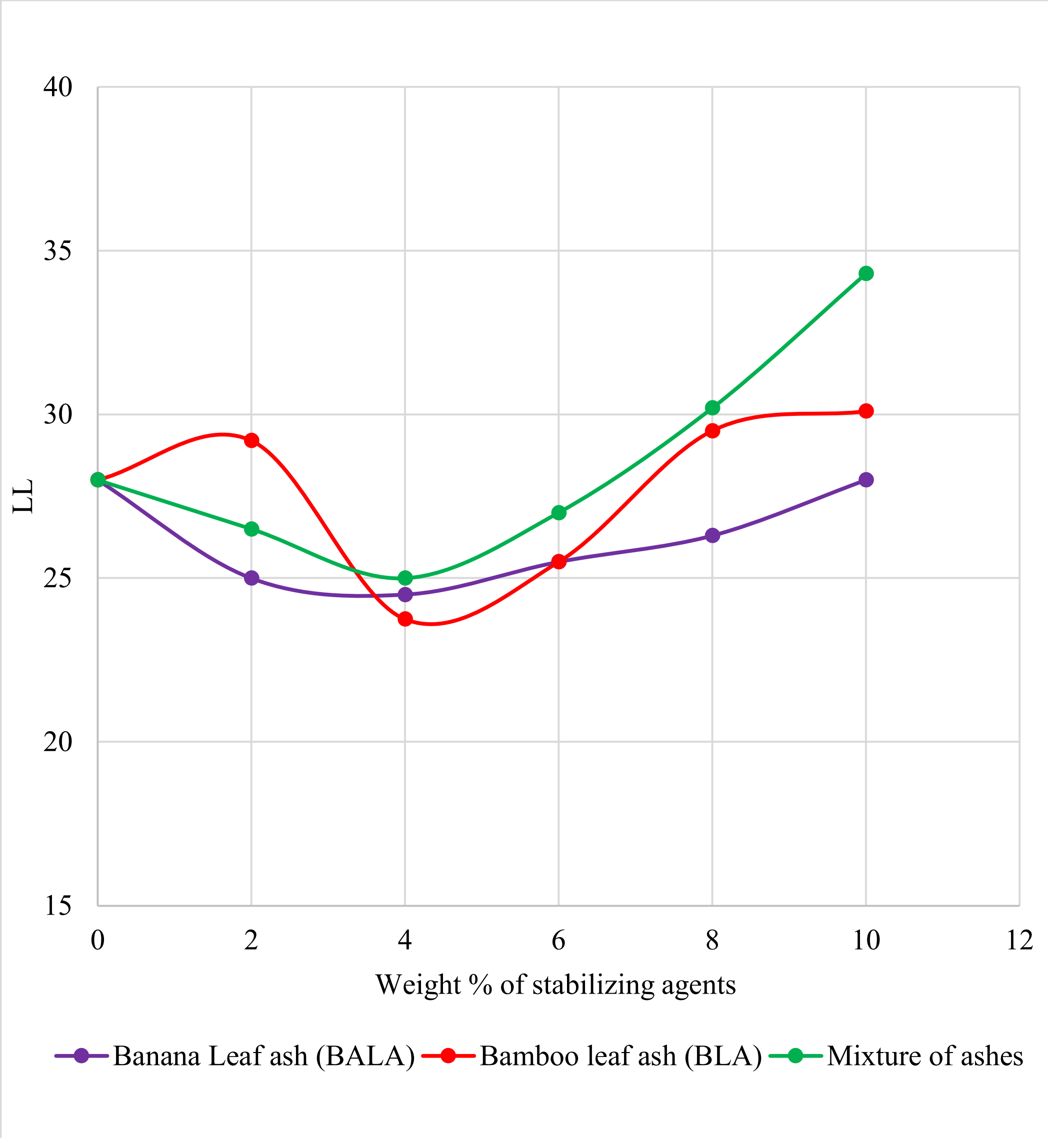

Figure 4. 16: Variation of LL with stabilizers on soil 03 (SP-SC)

Variation of PI and LL with the addition of BALA, BLA and the leaf ash mixture on soil 03 were shown in Figures 4.15 and 4.16 respectively. The addition of variable percentages of BALA, BLA and leaf ash mixture causes a variation of LL, LP and PI for soil 03. Improved PI was noted with the addition of 2%, 4% and 6% BALA, BLA and ash mix for soil 02. However, the addition of 4 % of BALA causes the least PI for soil 03. Amu and Adetuberu [24] found out the least PI at (2-4%). BLA Second best improvements / similar improvements in PI were noticed with the addition of 4 % of

BLA and 6 % of the leaf ash mixture on soil 03. With the addition of ashes to soil 03, the PI decreases, indicating a more stable soil with a significant increase in workability.

4.7 Different mechanisms of stabilization of sandy soils with plastics and leaf ashes

The mechanisms involved in the stabilization of sandy soils with plastics and leaf ashes as tested in this research are different. Both plastics and leaf ash give rise to the improvement of engineering characteristics of the types of sandy soils used in this work, which can be referred to as stabilizing the soils. The mechanism of stabilization with respect to the addition of plastics is likely to arise due to the induced friction between the solid soil particles and plastic pieces, and thus the stabilization mechanism can be categorized as mechanical in nature. The mechanism of stabilization with respect to the addition of leaf ashes is the progressive development of the cementitious components between the solid soil particles and the pozzolanic ashes, and the stabilization mechanism can be clearly identified as a chemical process.

4.8 Quantitative requirements and justifications of the stabilizers

The average bulk density of all three soils taken for the study is approximately 1950 kg/m^3 which implies that the weight of the soil per cubic meter is 1950 kg. From the study, to achieve the best possible results, soils need to be mixed with 6 % of ashes and 2 % of plastics. That implies that 117 kg of ashes and 39 kg of plastics are required to stabilize one cubic meter of soil.

The study shows that the addition of individual ashes of pozzolanic leaves such as BALA and BLA have the capability to stabilize soils. However, in cases when it is difficult to obtain a greater quantity of individual pozzolanic ashes, a mixture of pozzolanic ashes can be prepared with the addition of some additional pozzolanic ashes of leaves such as sugar cane straw ash in addition to the pozzolanic ashes of leaves used in this research. Around 91 % of manufactured plastics (317 million metric tons /year) are being dumped into landfills without recycling causing pollution to the environment [10]. Therefore, it is possible to obtain the required plastics to stabilize soils.

Preliminary calculations were carried out using the current rates for cost components of material, plant, labor, and transportation to investigate the economy of the proposed methods of stabilization of soils compared to some other methods in use. It showed that stabilization using the proposed additives would be more economical in general, as compared to other methods of stabilization using lime, cement, geotextiles, etc. Other advantages of the proposed additives are in the general fields of environmental friendliness and conservation of resources, as leaf ash is a renewable biological resource, and plastics are a waste material proposed to be re-used.

4.9 Stabilization of soil 03 with the stabilizers for upper subbase layer in flexible pavement construction as per ICTAD specifications or RDA guidelines

4.9.1 Gradation requirements of soils to be used as upper subbase layer

Table 4. 21: Gradations of soils and requirements to be used as upper subbase

Sieve size (mm)	Lower Limit	Upper Limit	Soil 01 (SP)	Soil 02 (SC)	Soil 03 (SP-SC)
50	100	100	100	100	100
37.5	80	100	100	100	100
20	60	100	100	100	100
5	30	100	92.1	99.7	98.8
1.18	17	75	42.4	90.9	74.4
0.3	9.00	50	3.8	65.7	47.2
0.075	5.00	25	0.8	12.8	7.3

Table 4.21 shows the gradation requirements of soils to be used as upper subbase layer as per RDA or ICTAD requirements and the percentages of soil passed through each sieve for all three soil samples. For soil 01, percentages passed through the sieves 0.3 mm and 0.075 mm do not satisfy the gradation requirements whereas for soil 02, percentages passed through the sieves 1.18 mm, 0.3 mm and 0.075 mm do not satisfy the gradation requirements. It is impossible to satisfy the gradation requirement by mixing the soils with the selected stabilizing agents. Hence soils 01 and 02 were not taken for further analysis to be used as upper subbase layer. On the other hand, gradation requirements were satisfied by all the sieves for soil 03. Therefore, from this point onwards, further requirements for investigating the potential of soil 03 with the stabilizers to be used as upper subbase was done.

4.9.2 Atterberg limit requirements for soils to be used as upper subbase layer

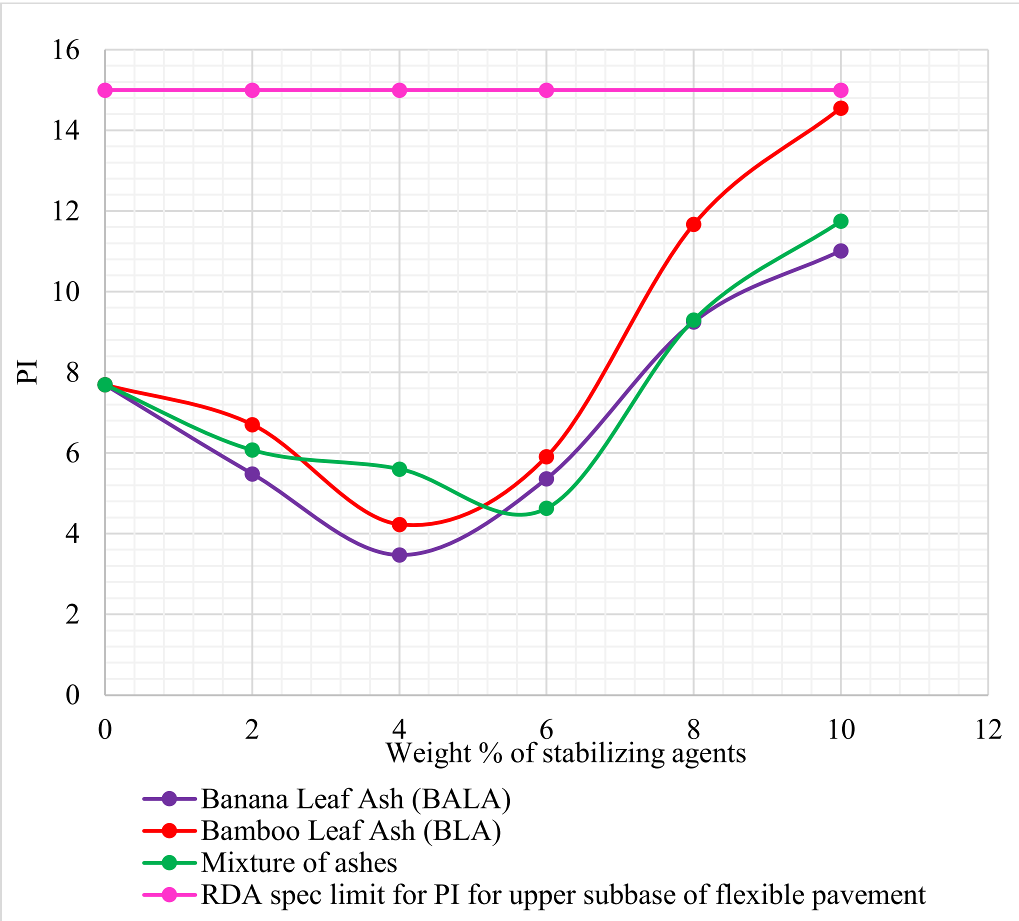

Figure 4. 17: PI requirements and impact of stabilizers on PI for soil 03

Figure 4.17 shows the comparison between the impact of the ashes on PI and the actual requirement of PI of a soil to be used as the upper subbase layer of a flexible pavement. PI of soil is required to be less than 15 in order to be used as an upper subbase layer. From Figure 4.17, it is clear that PI of soil 03 with and without the stabilizing agents of all the considered weight percentages satisfy the RDA or ICTAD requirements to be used as upper subbase layer in flexible pavements.

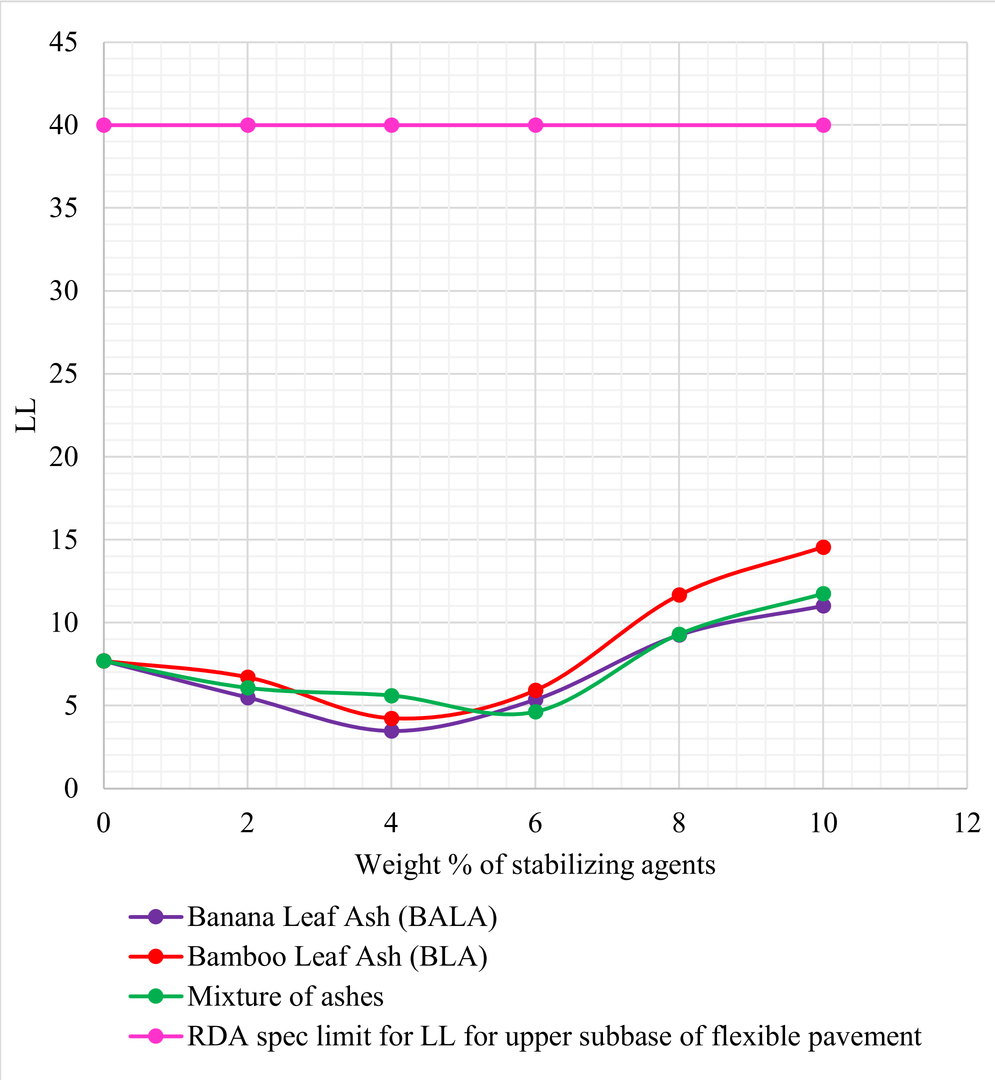

Figure 4. 18: LL requirements and impact of stabilizers on LL for soil 03

Figure 4.18 shows the comparison between the impact of the ashes on LL and the actual requirement of LL of soil to be used as the upper subbase layer of flexible pavement. LL of soil is required to be less than 40 in order to be used as an upper subbase layer. From Figure 4.18, it is clear that LL of soil 03 with and without the stabilizing agents of all the considered weight percentages satisfy the RDA or ICTAD requirements to be used as upper subbase layer in flexible pavements.

4.9.3 MDD requirements for soils to be used as upper subbase layer

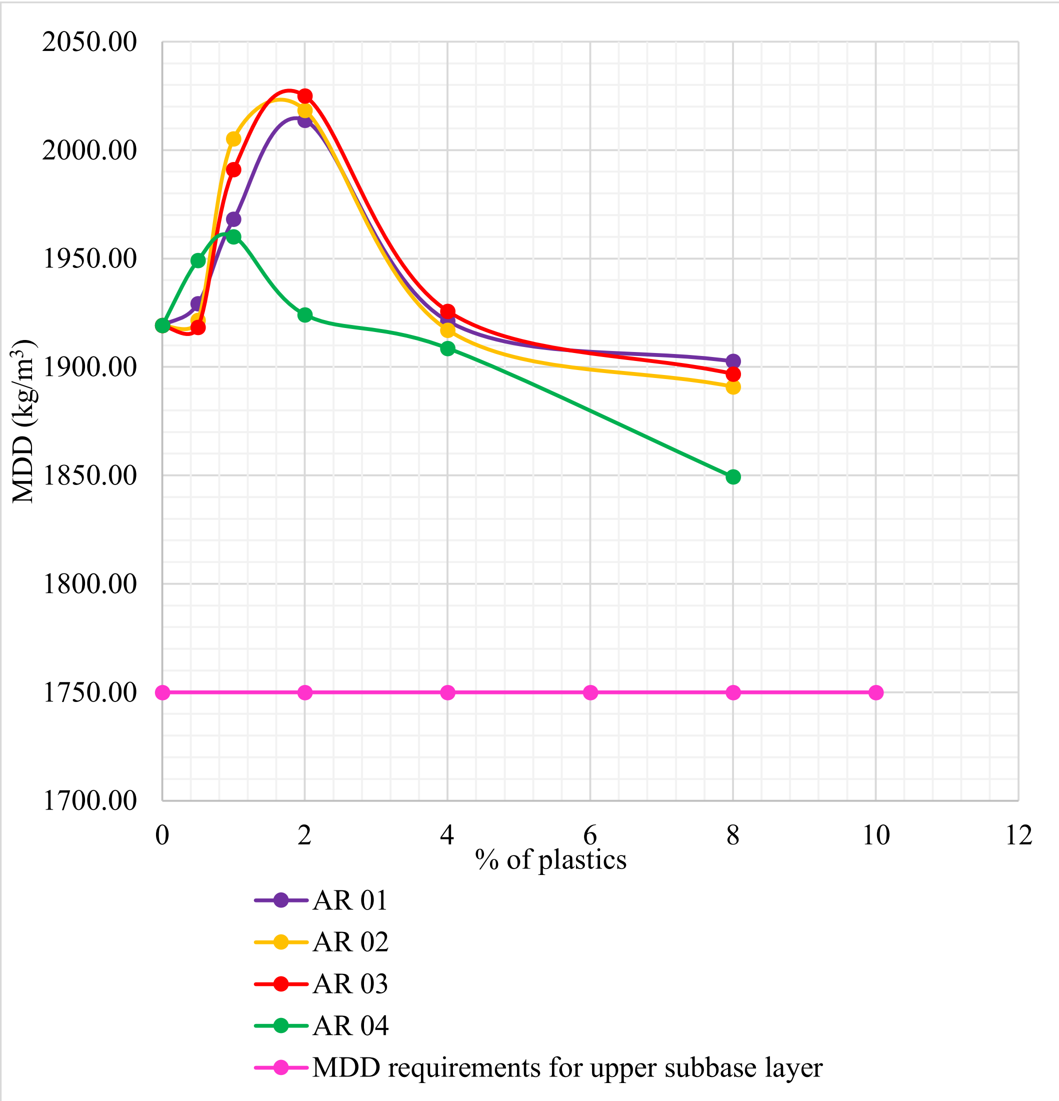

Figure 4. 19: MDD requirements and impact of plastics on MDD for soil 03

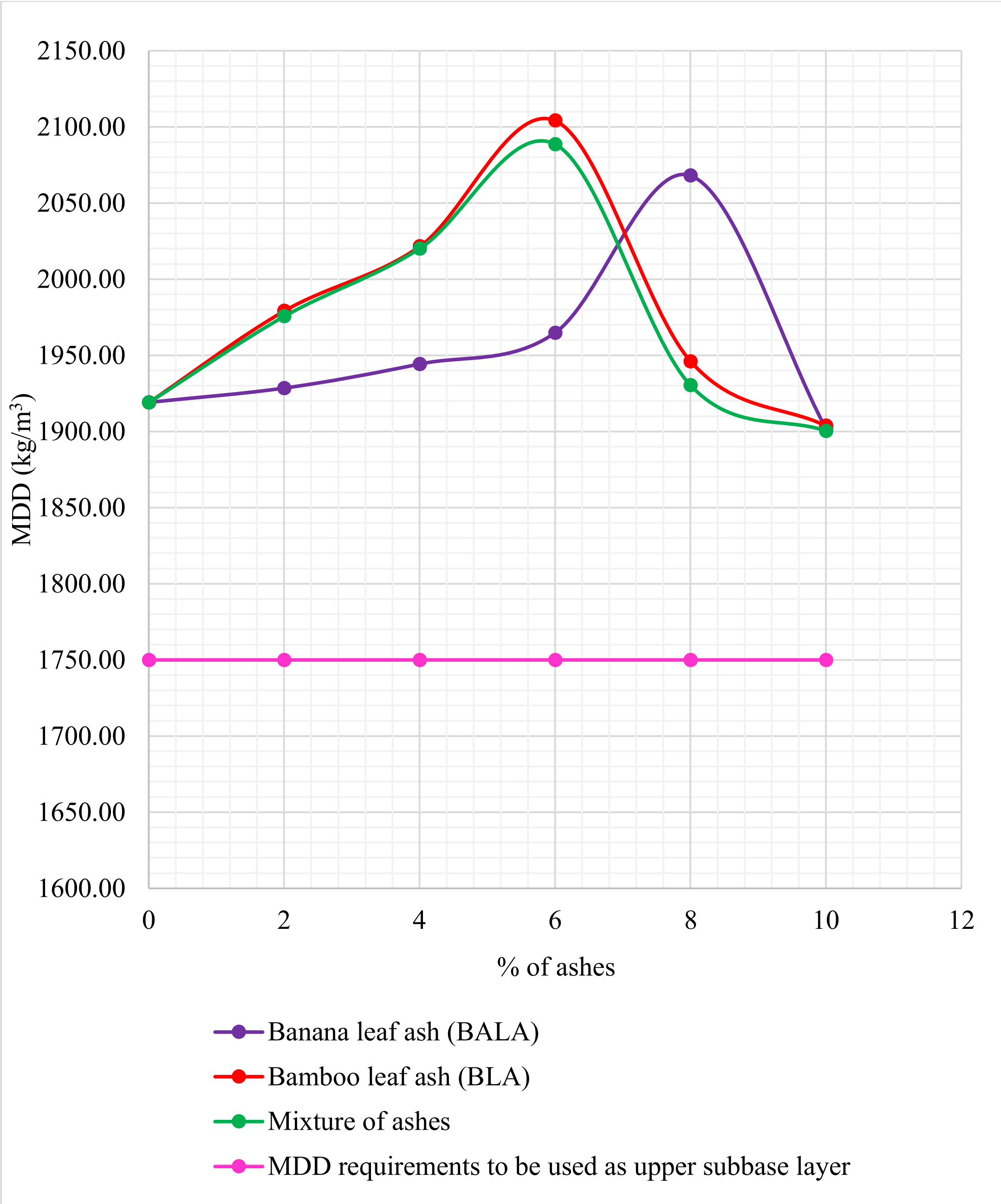

Figure 4. 20: MDD requirements and impact of ashes on MDD for soil 03

Figures 4.19 and 4.20 show the comparisons between the impact of the plastics with different ARs and weight percentages and ashes with different weight percentages respectively on MDD and the actual requirement of MDD to be used as the upper subbase layer of flexible pavement. MDD of a soil is required to be more than 1750 kg/m3 in order to be used as an upper subbase layer. From Figures 4.19 and 4.20, it is clear that MDD of soil 03 with and without the plastics and ashes of all the considered weight percentages satisfy the RDA or ICTAD requirements to be used as upper subbase layer in flexible pavements.

4.9.4 CBR requirements for soils to be used as upper subbase layer

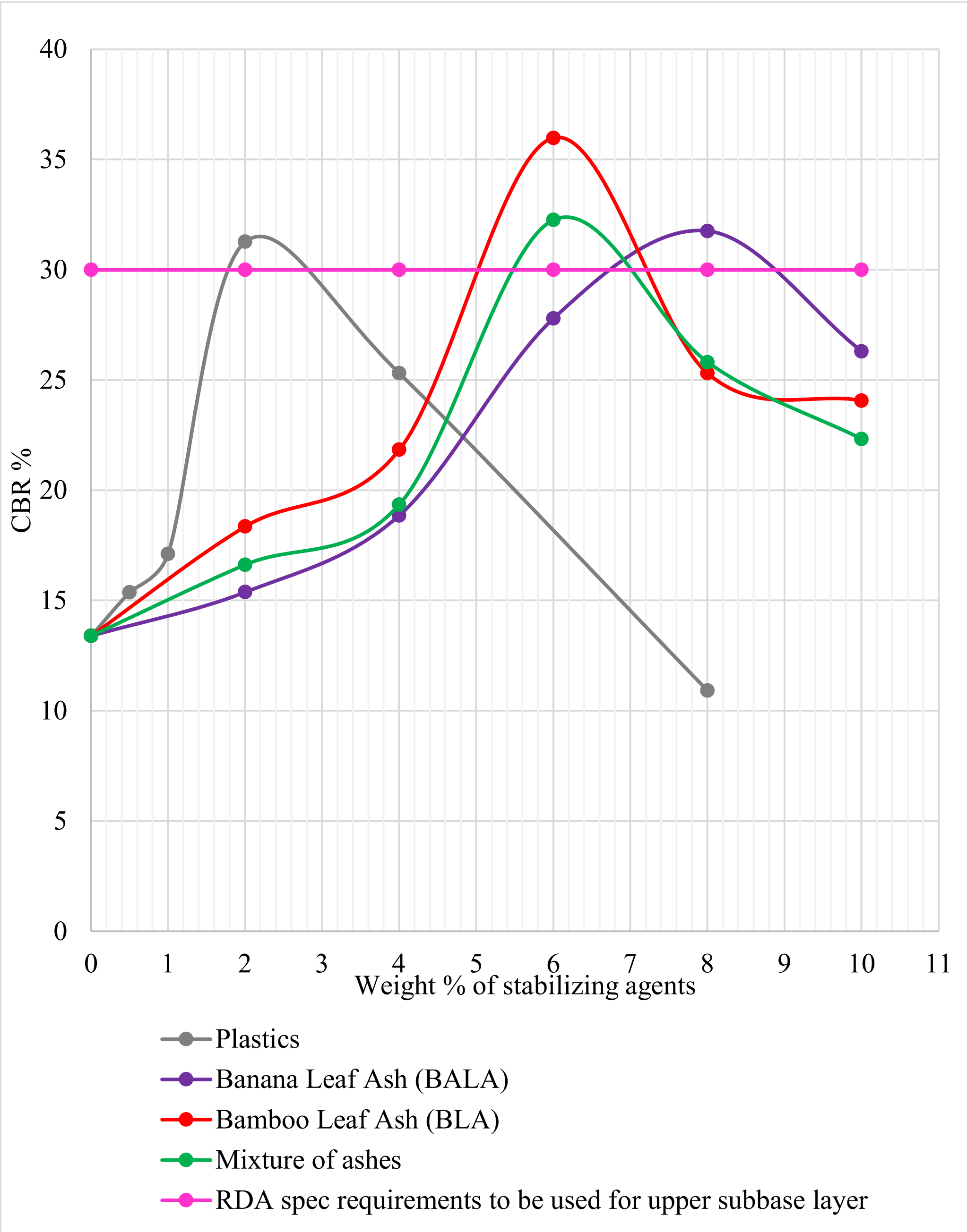

Figure 4. 21: CBR requirements and impact of ashes on CBR for soil 03

Figure 4.21 shows the comparisons between the impact of the plastics and ashes with different weight percentages on 4 days soaked CBR values and the actual requirement of 4 days soaked CBR value to be used as the upper subbase layer of flexible pavement. As per the specification by RDA or ICTAD, 4 days soaked CBR should be more than 30 to be used as upper subbase layer in flexible pavement construction. 4 days soaked CBR value of the virgin soil 03 is 18.6 which is less than the required value of 30. Hence soil 03 cannot be used as the upper subbase layer in the flexible pavement in its virgin state. However, when soil 03 was mixed with plastics of AR 03 with the weight % of 2, BLA and leaf ash mixture with the weight % of 6 and BALA with the weight % of 8, observed 4 days soaked CBR values were more than 30. Hence soil 03 withthe addition of 2 % plastics of AR 03 or 6 % of BLA or 6 % of the leaf ash mixture or 8 % of BALA satisfy the CBR requirements of the upper subbase layer in flexible pavement construction.

4.9.5 UCS requirements for soils to be used as upper subbase layer

Table 4. 22: Impact of plastics on UCS on soil 03 (SP-SC)

% of Plastic	UCS (kPa)			
	Sample 01	Sample 02	Sample 03	Average
0.0	749.3	749.3	624.4	707.7
2.0	999.1	999.1	1124.0	1040.7

Table 4. 23: Impact of BALA on UCS on soil 03 (SP-SC)

% of BALA	UCS (kPa)			
	Sample 01	Sample 02	Sample 03	Average
0.0	749.3	749.3	624.4	707.7
8.0	1124.0	1124.0	1248.8	1165.6

Table 4. 24: Impact of BLA on UCS on soil 03 (SP-SC)

% of BLA	UCS (kPa)			
	Sample 01	Sample 02	Sample 03	Average
0.0	749.3	749.3	624.4	707.7
6.0	1373.7	1373.7	1498.6	1415.4

Table 4. 25: Impact of leaf ash mixture on UCS on soil 03 (SP-SC)

% of leaf ash mixture	UCS (kPa)			
	Sample 01	Sample 02	Sample 03	Average
0.0	749.3	749.3	624.4	707.7
6.0	1248.8	1248.8	1248.8	1248.8

Tables 4.22, 4.23, 4.24 and 4.25 show the results of UCS tests on soil 03 with the addition of plastics of AR 03, BALA, BLA and leaf ash mixture respectively. UCS tests were conducted with the addition of 2 % plastics of AR 03, 8 % BALA, 6 % BLA and 6 % leaf ash mixture since these additions satisfied the Atterberg limits, MDD and 4 days soaked CBR requirements as specified by RDA or ICTAD for upper subbase layer in flexible pavements in Sri Lanka. As per the specification requirements by RDA, 28 days UCS strength should be in the range of (750-1500) kPa. From the UCS tests, it was found out that the additions of 2 % of plastics of AR 03, 8 % BALA, 6 % BLA and 6 % leaf ash mixture on soil 03 satisfied the UCS requirements as specified by RDA or ICTAD for upper subbase layer.

4.9.6 Applicability of using soil 03 (SP-SC) with the stabilizers as upper subbase layer in flexible pavement construction

Soil 03 (SP-SC) with the additions of 2 % of plastics of AR 03, 8 % BALA, 6 % BLA and 6 % leaf ash mixture satisfied the gradation, PI, LL, MDD and 4 days soaked CBR requirements as specified by RDA or ICTAD for upper subbase layer in flexible pavement construction. Therefore, soil 03 (SP-SC) with the inclusion of particularly above-mentioned weight percentages of stabilizers can be used for the upper subbase layer in flexible pavement constructions in Sri Lanka.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The goal of the study was to determine the stabilizing potential of different stabilizing agents on the same soil as well as the stabilizing potential of a single stabilizing agent on diverse sandy soils. Three different soil types, plastics with four aspect ratios and five weight percentages, and three different types of natural leaf ashes having pozzolanic characteristics with five weight percentages were used in the study. Stabilization of soils was evaluated in terms of MDD (maximum Dry Density), OMC (Optimum moisture Content), shear strength parameters (cohesion and angle of internal friction), CBR (California Bearing Ratio) and Atterberg limits where applicable.

Following findings can be drawn from the research.

1. A considerable range of sandy soil types can be stabilized by the addition of 2 % of plastics though with different ARs.
2. A considerable range of sandy soil types can be stabilized by the addition of 6% of natural leaf ashes showing pozzolanic characteristics.

Following points can also be highlighted:

1. Assuming the bulk density of soil to be 1950 kg /m^3 (based on the soils used in the study), around 40 kg of plastics and 120 kg of ashes are required to stabilize 1 m^3 of sandy soil in the best possible way.
2. Soils that satisfy the gradation, Atterberg limits and MDD requirements but not satisfy the CBR requirements in their virgin states can be stabilized with the addition of 6 % of leaf ash mixture and 2 % of plastics in order to use for flexible pavement constructions.
3. Bamboo leaf ash is more pozzolanic than banana leaf ash and the leaf ash mixture used in the study. In almost all the cases, stabilization of soils is better with the bamboo leaf ash than the other two ashes. Therefore, it can be concluded that with an increment of pozzolanic reaction, the stabilization of soils too improves.

4. Clearly, the mechanisms of stabilization involved with additives of plastics and leaf ashes are different. In the case of plastics, the mechanism is likely the induced friction between solid soil particles and pieces of plastics, which is a mechanical process, while in the case of leaf ashes, the improvements in soils are due to the progressive development of cementitious components between the solid soil particles and the leaf ashes, which is a chemical stabilization process.

5.2 Recommendations

1. Though the addition of plastics other than 2 % by weight and ashes other than 6 % showed optimum improvements in soils in some instances, additions of 2 % and 6 % plastics showed improvements almost very closer to the optimum amount. It is also noted that there may be some experimental and man-made errors. Therefore, it is recommended to use 2 % plastics and 6 % of leaf ashes.

2. In future, it is recommended to use ashes of other leaves that show pozzolanic characteristics in order to prepare other suitable mixtures of ashes for stabilizing soils. Sugarcane straw ash is a possible example.

3. For future studies, it can be recommended to use plastics with different shapes like circles or triangles to investigate their stabilizing potential.

4. It can be recommended to conduct investigations with additional different types of soils in future studies to analyze the stabilizing potentials of the plastics and pozzolanic ashes on those soils too.

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APPENDIX A: DETAILED RESULTS OF MODIFIED PROCTOR COMPACTION TESTS

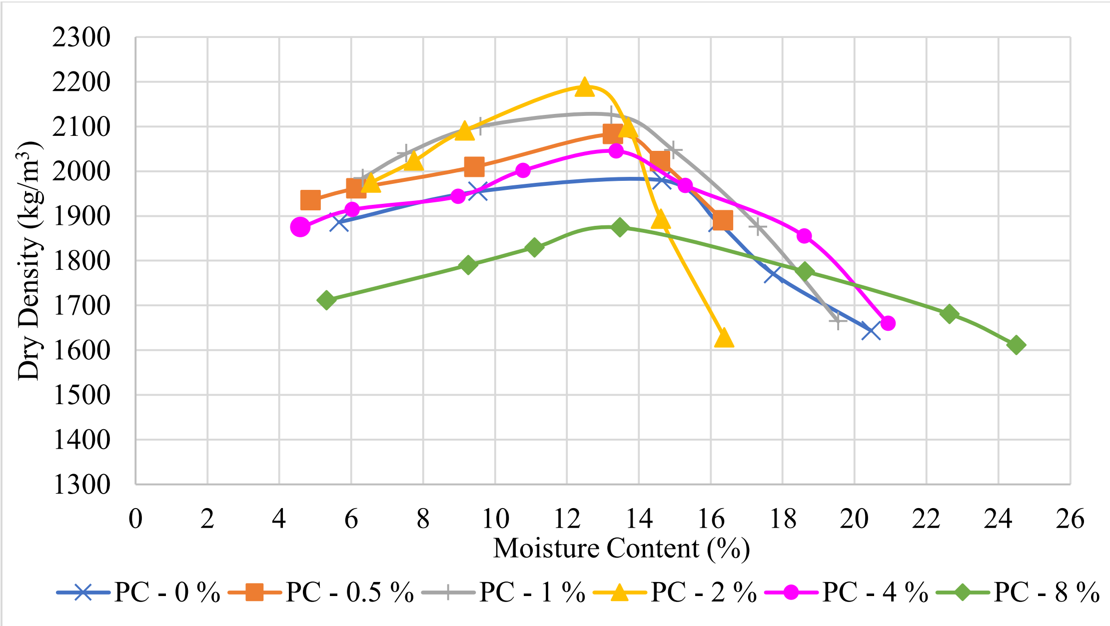

Figure A- 1: Variation of dry density with AR 01 on soil 01

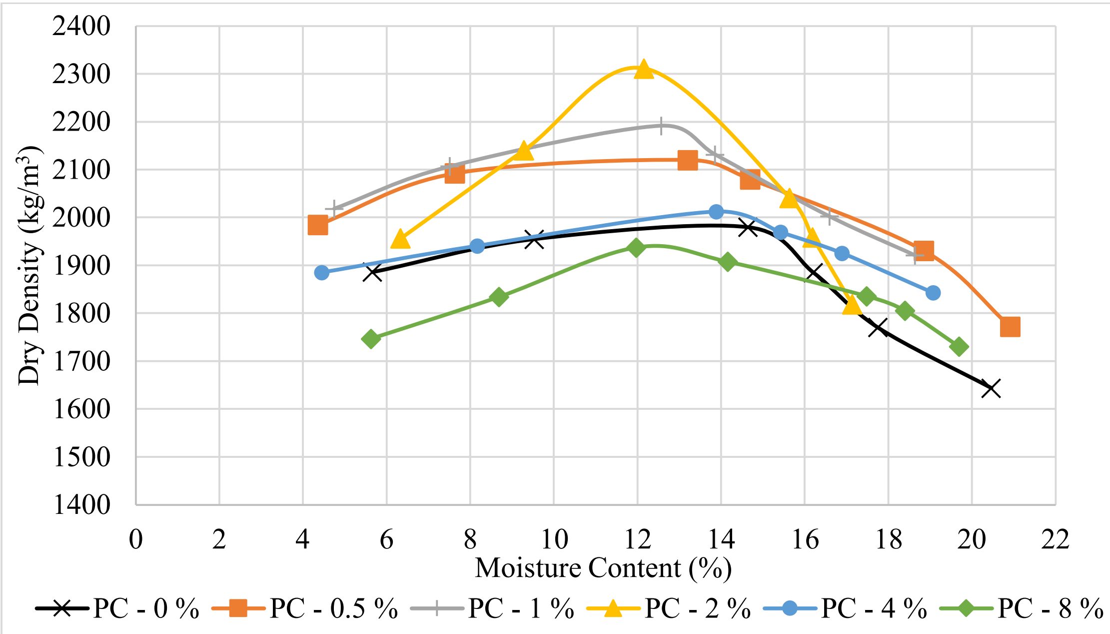

Figure A- 2: Variation of dry density with AR 02 on soil 01

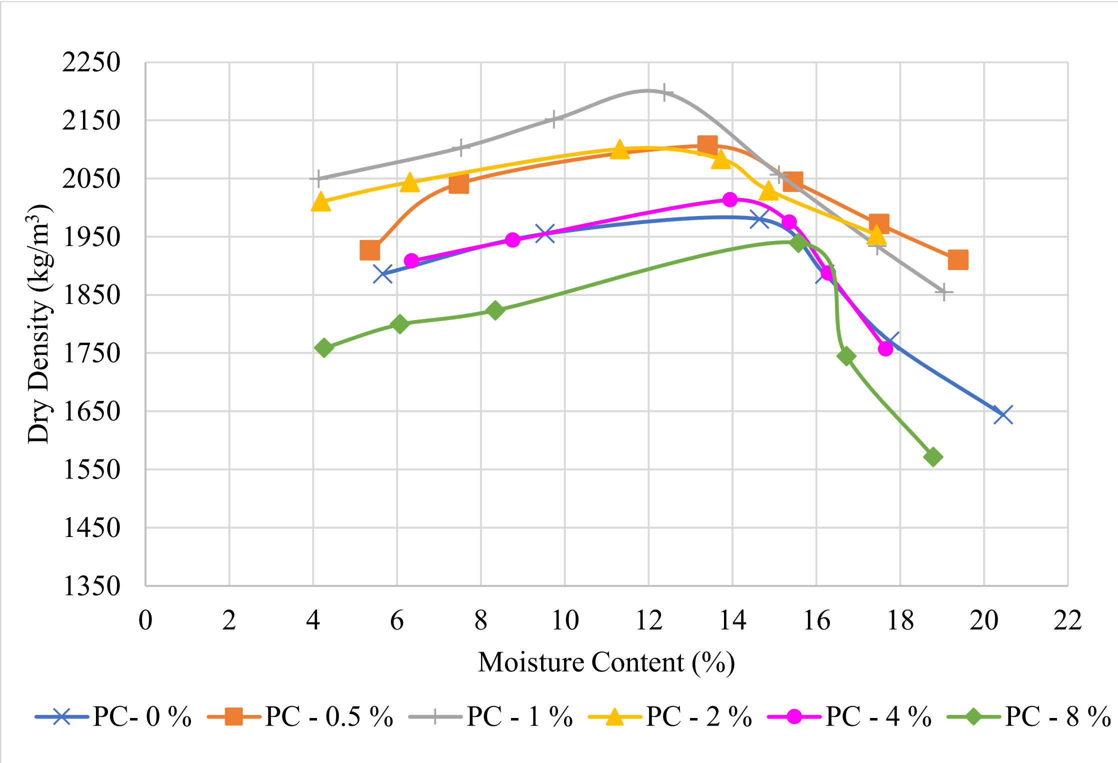

Figure A- 3: Variation of dry density with AR 03 on soil 01

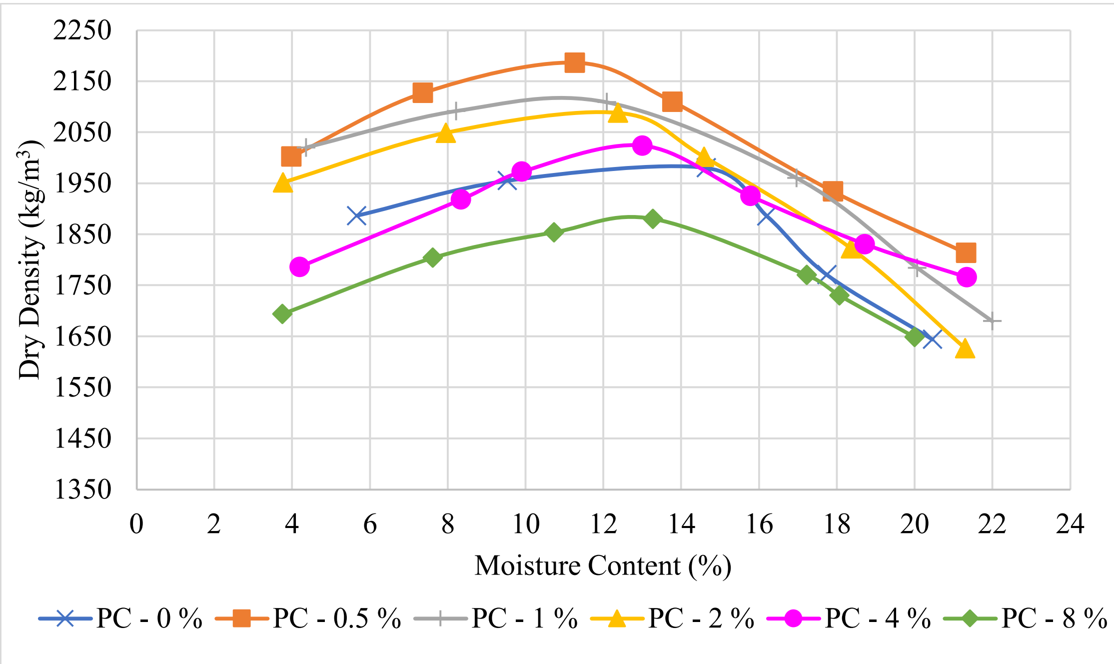

Figure A- 4: Variation of dry density with AR 04 on soil 01

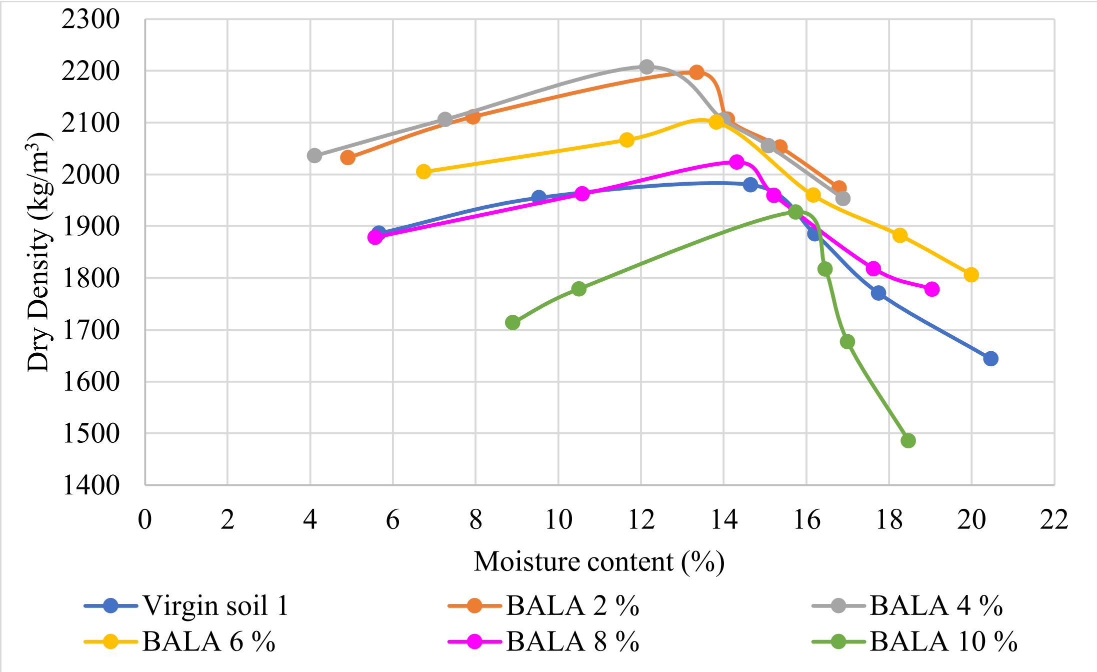

Figure A- 5: Variation of dry density with BALA on soil 01

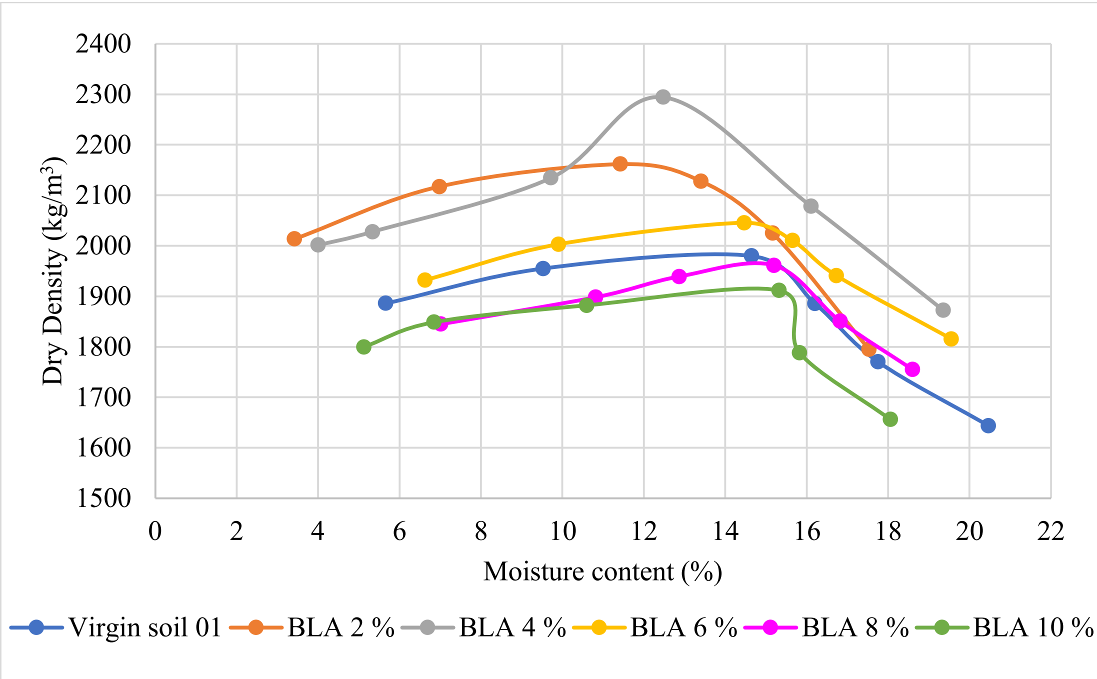

Figure A- 6: Variation of dry density with BLA on soil 01

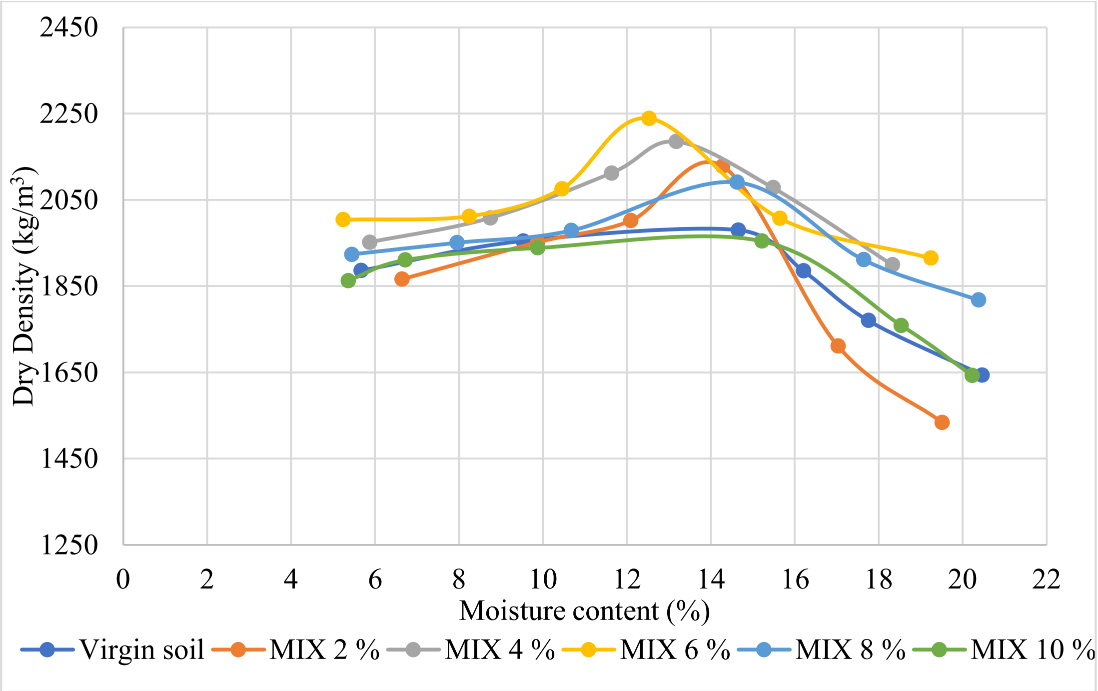

Figure A- 7: Variation of dry density with leaf ash mixture on soil 01

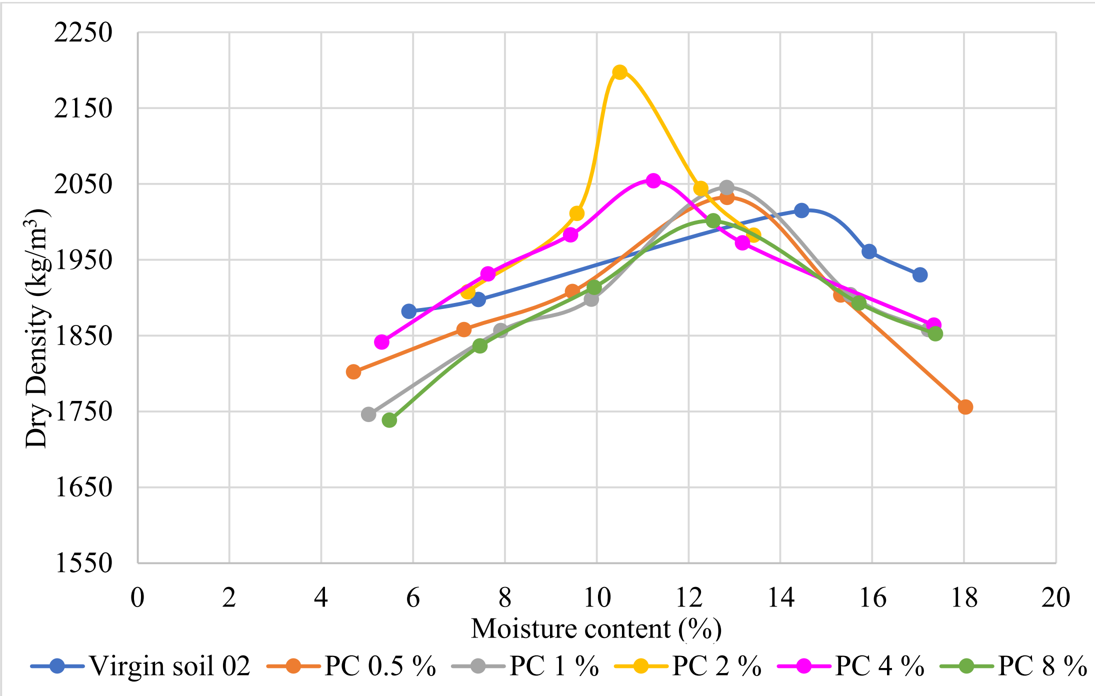

Figure A- 8: Variation of dry density with AR 01 on soil 02

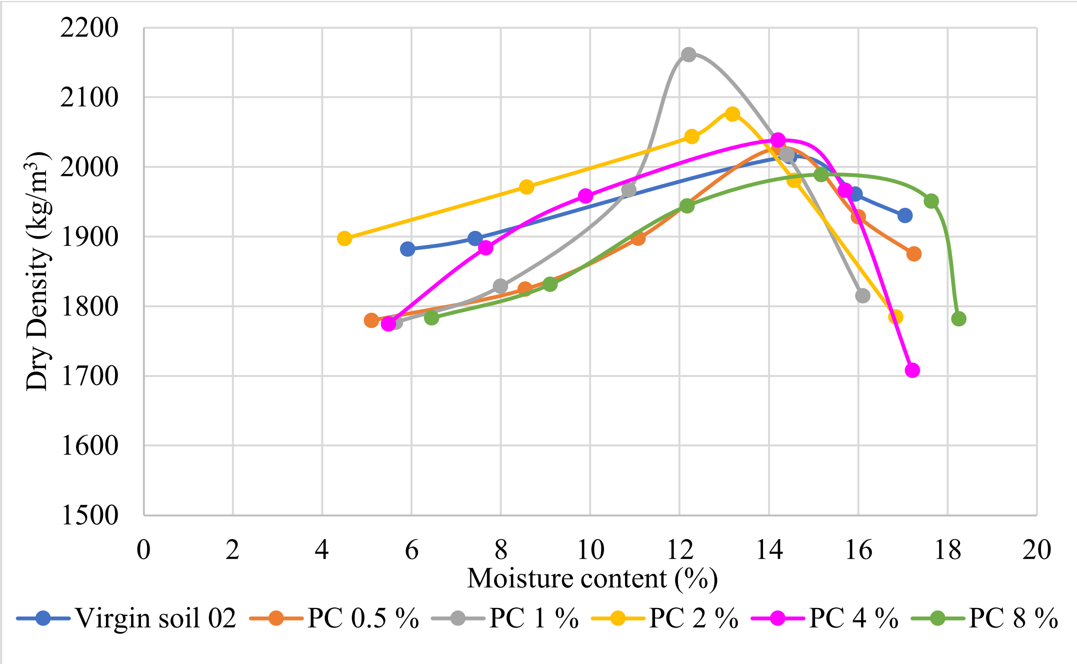

Figure A- 9: Variation of dry density with AR 02 on soil 02

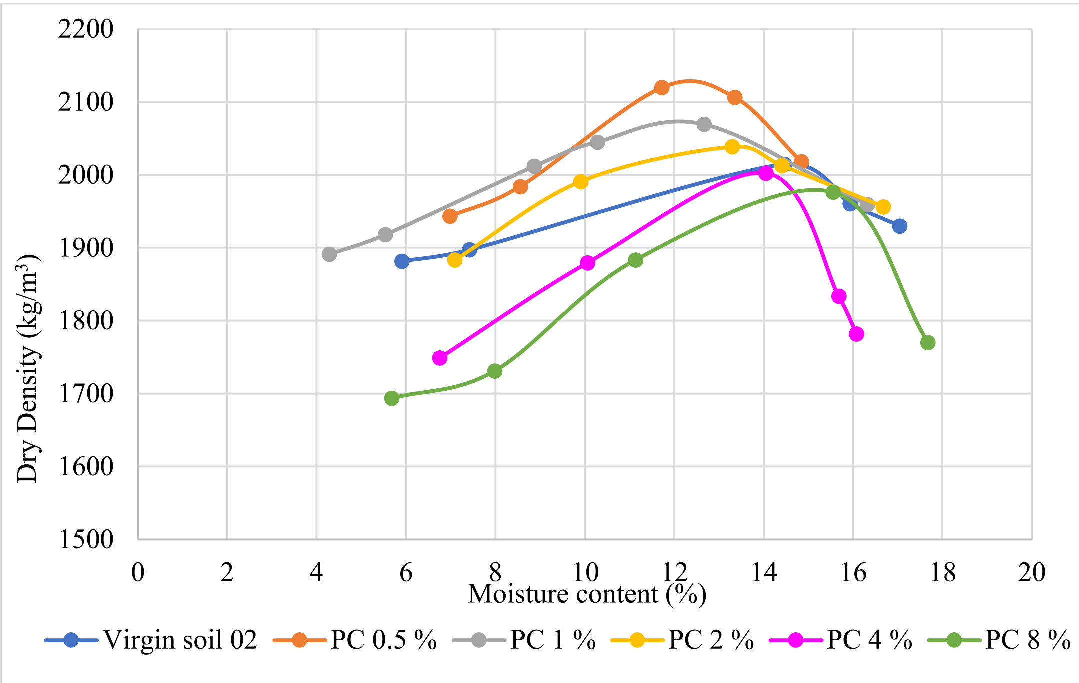

Figure A- 10: Variation of dry density with AR 03 on soil 02

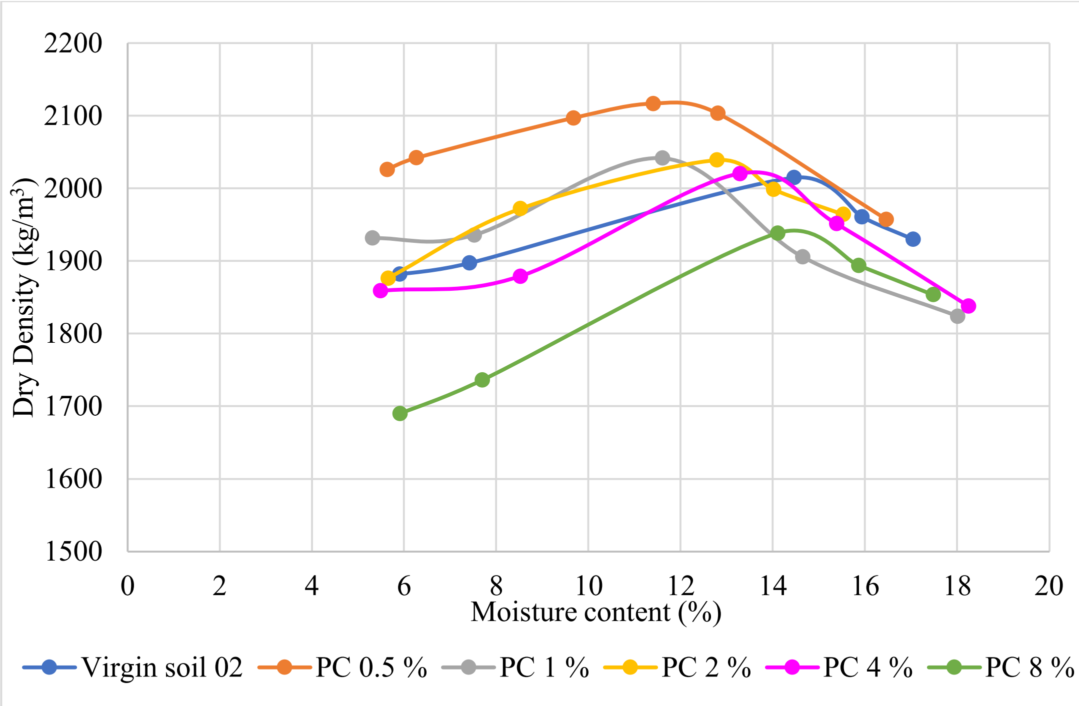

Figure A- 11: Variation of dry density with AR 04 on soil 02

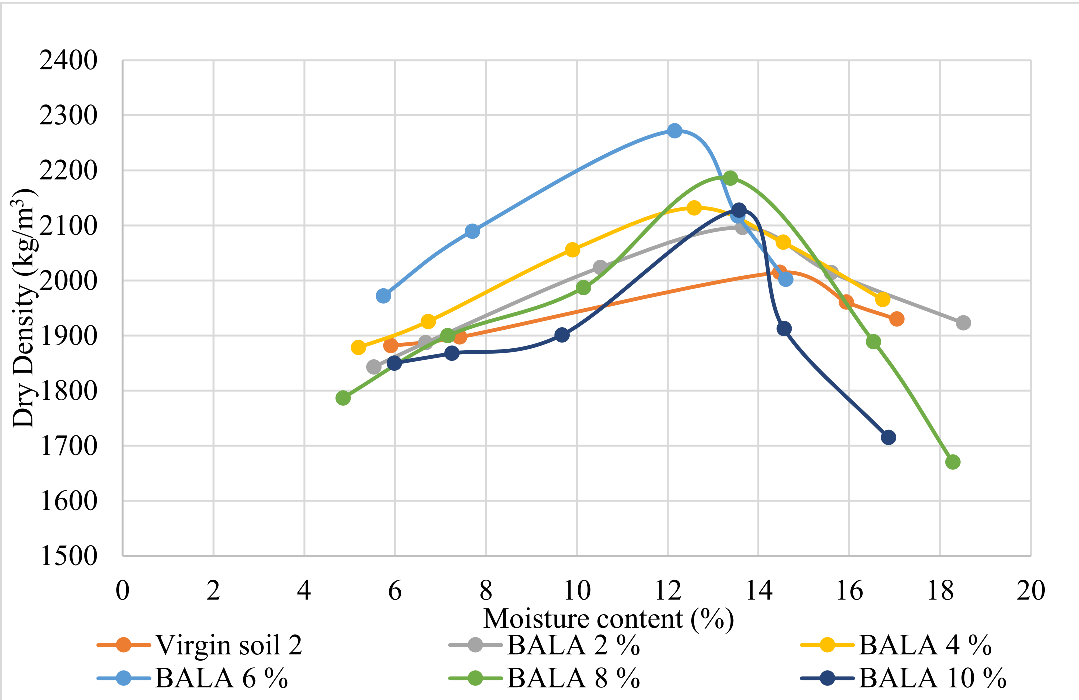

Figure A- 12: Variation of dry density with BALA on soil 02

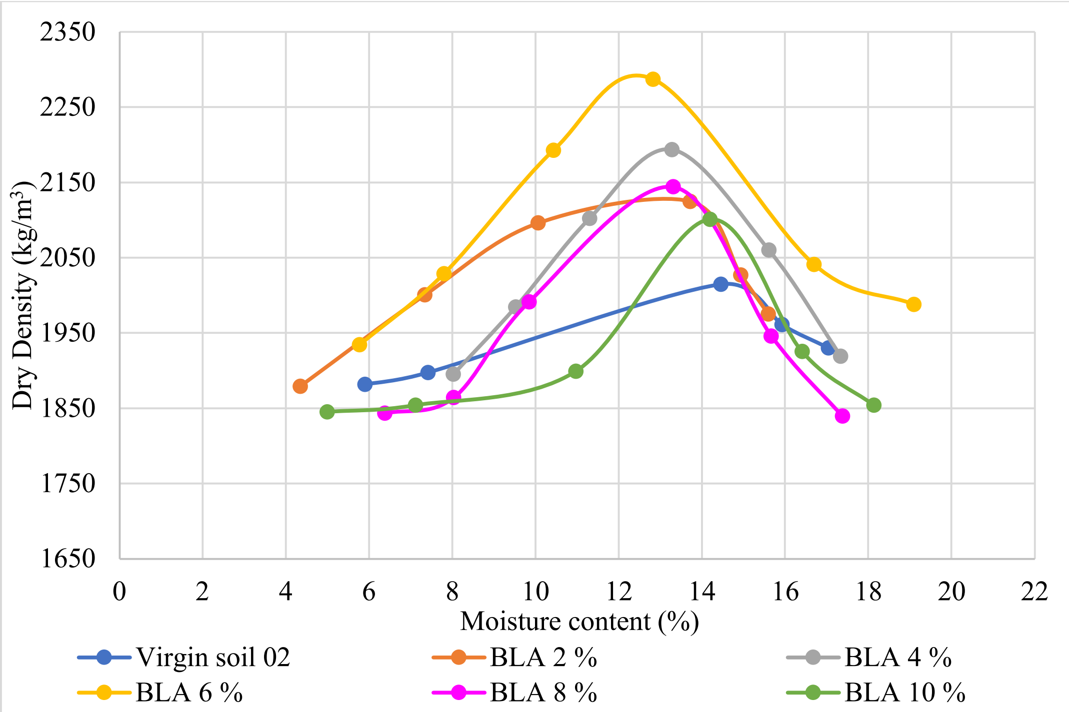

Figure A- 13: Variation of dry density with BLA on soil 02

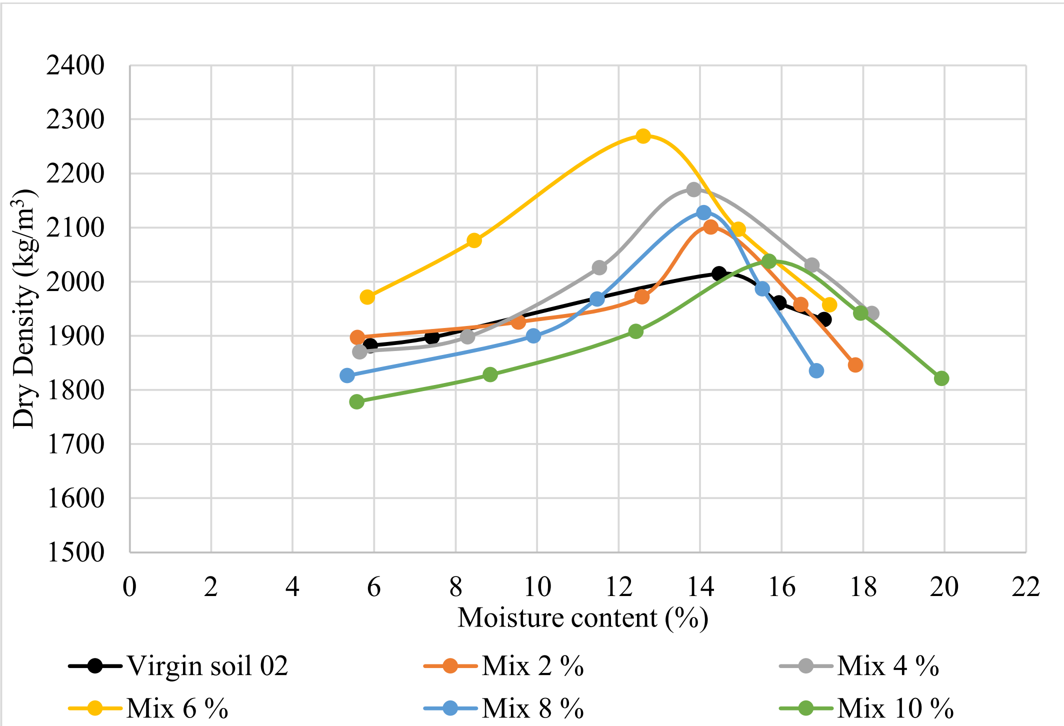

Figure A- 14: Variation of dry density with leaf ash mixture on soil 02

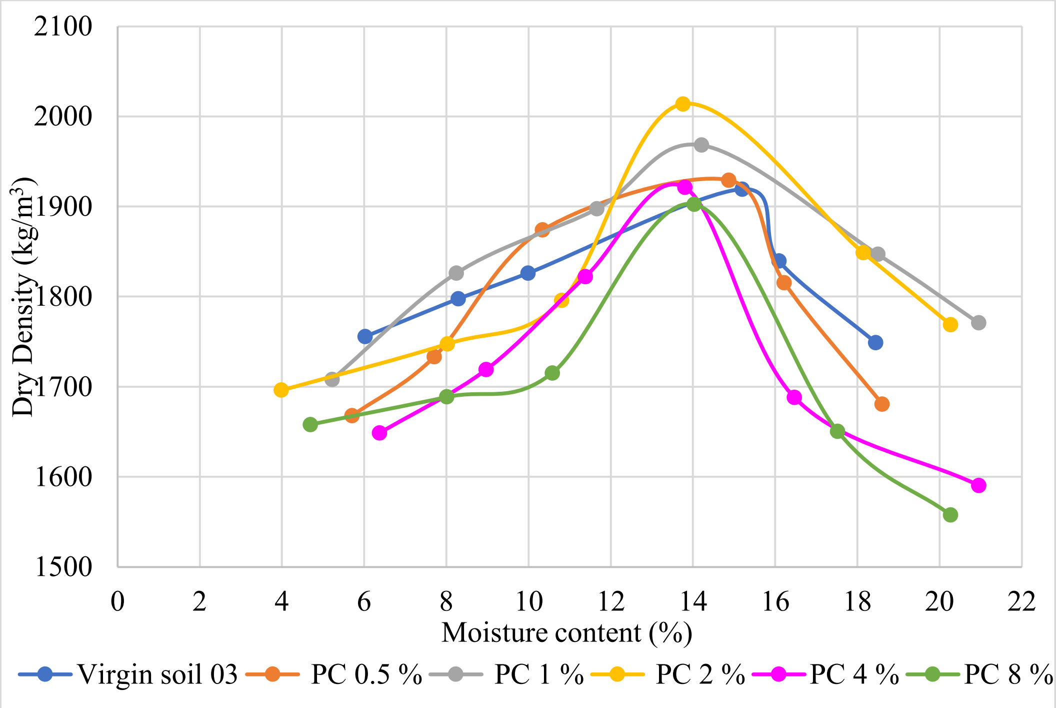

Figure A- 15: Variation of dry density with AR 01 on soil 03

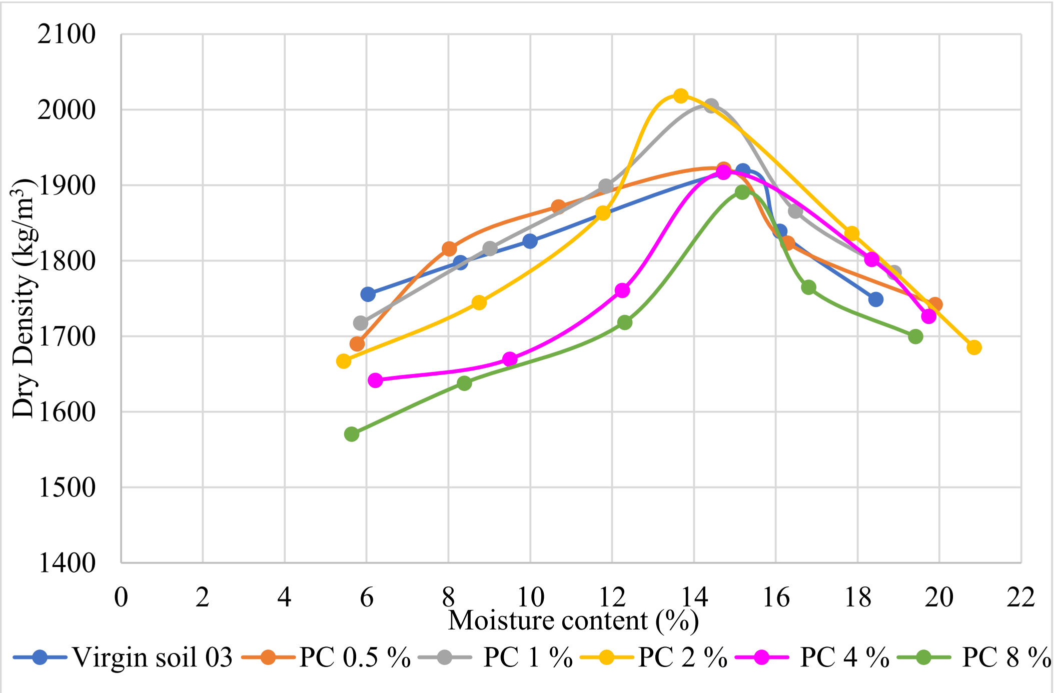

Figure A- 16: Variation of dry density with AR 02 on soil 03

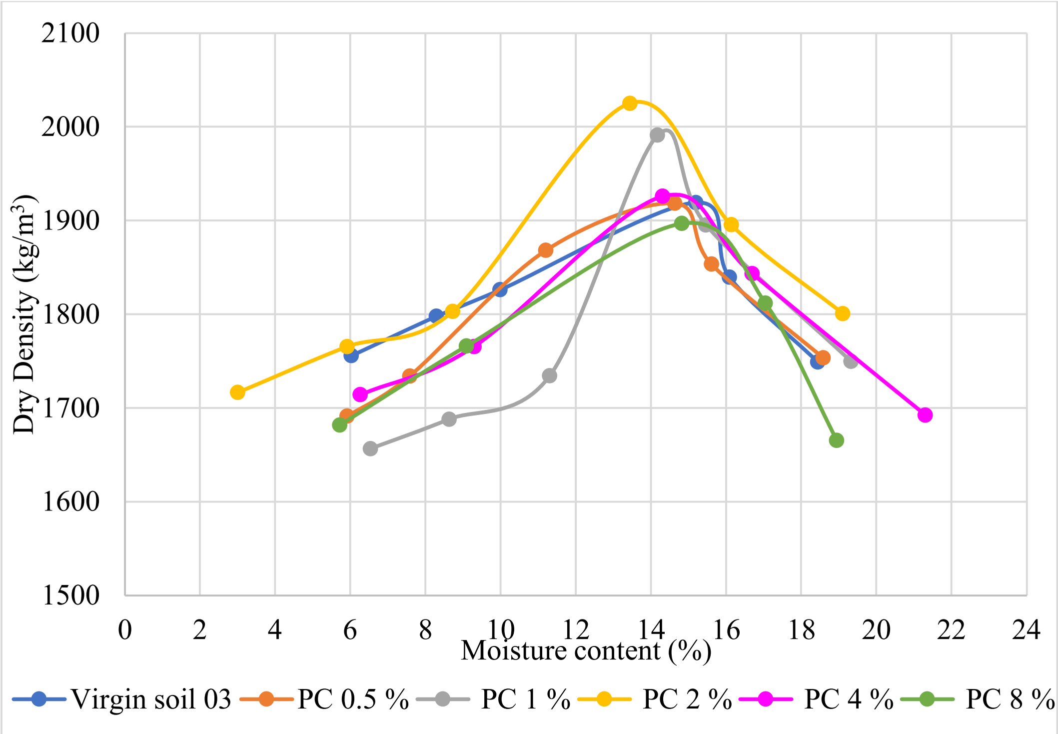

Figure A- 17: Variation of dry density with AR 03 on soil 03

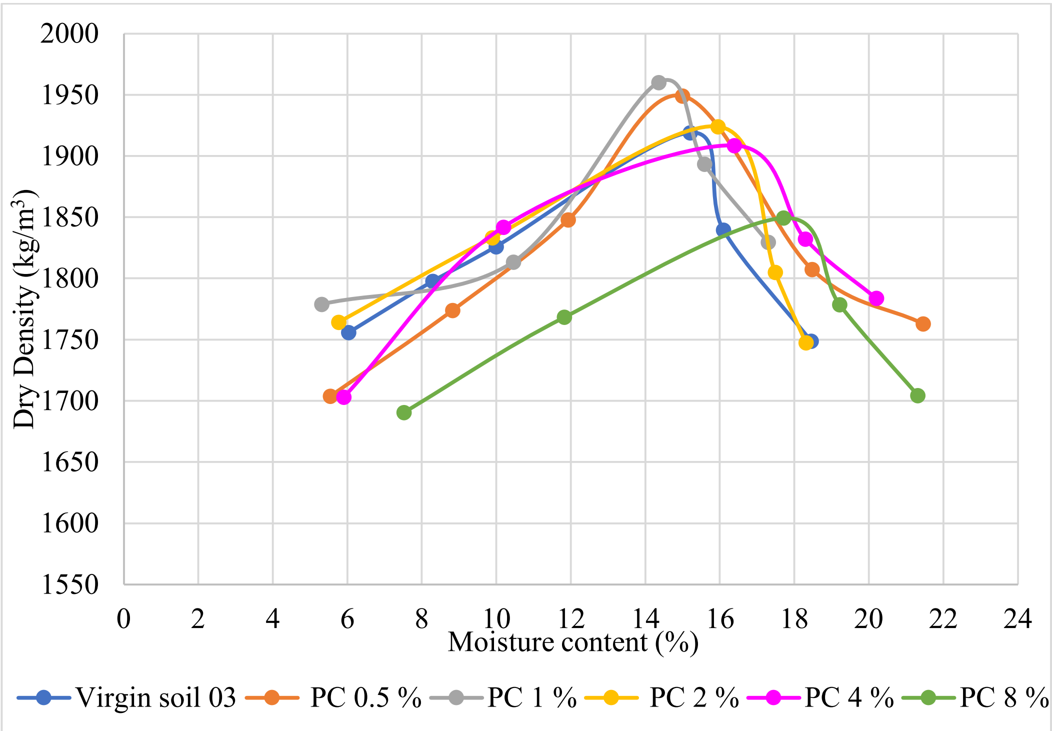

Figure A- 18: Variation of dry density with AR 04 on soil 03

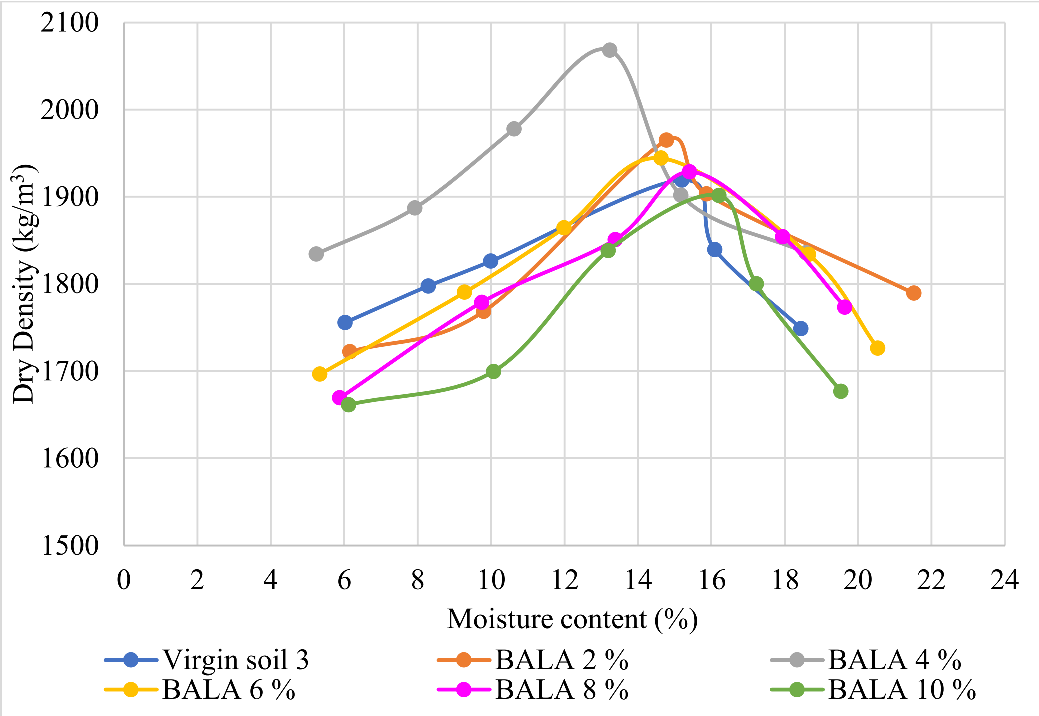

Figure A- 19: Variation of dry density with BALA on soil 03

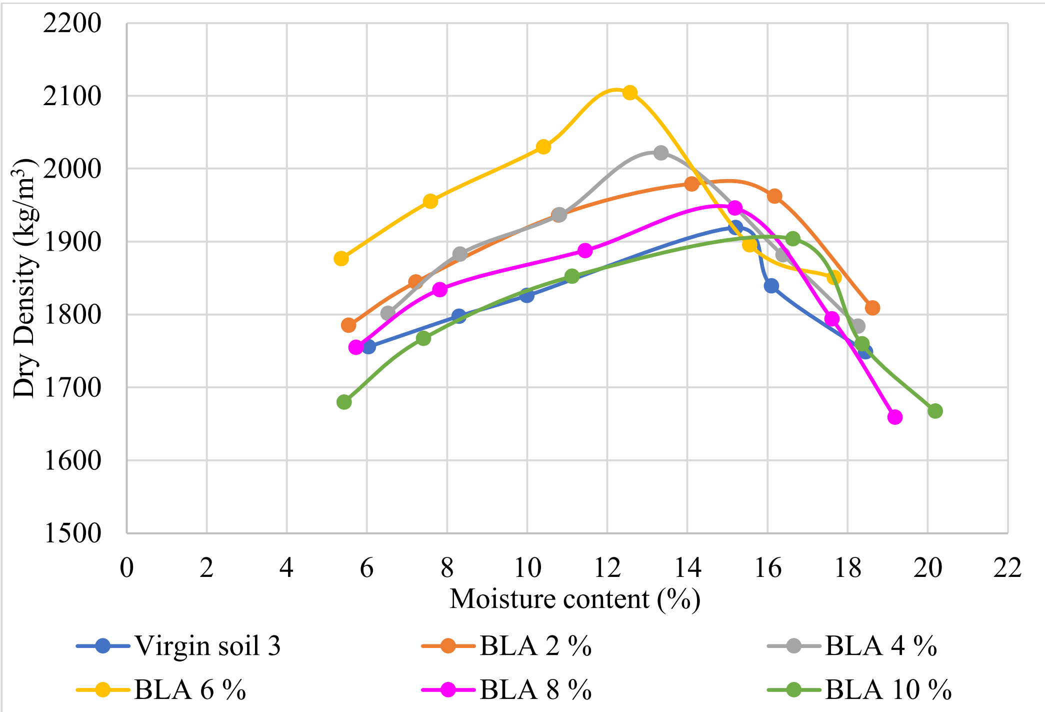

Figure A- 20: Variation of dry density with BALA on soil 03

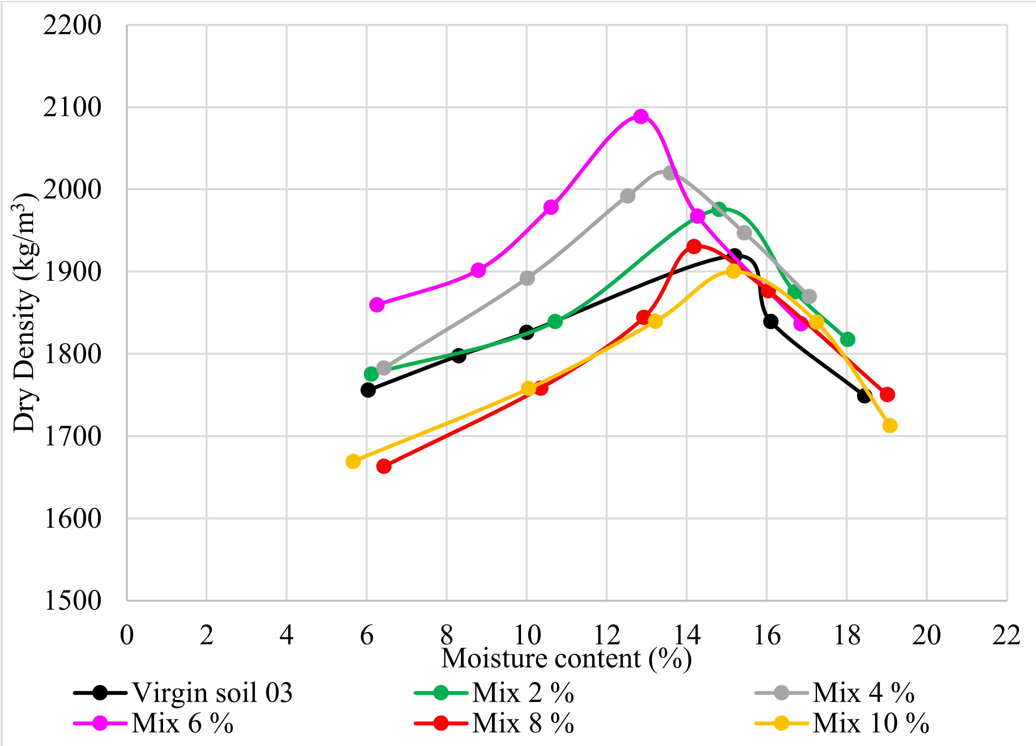

Figure A- 21: Variation of dry density with leaf ash mixture on soil 03

APPENDIX B: ADDITIONAL RESULTS OF ATTERBERG LIMITS EXPERIMENTS

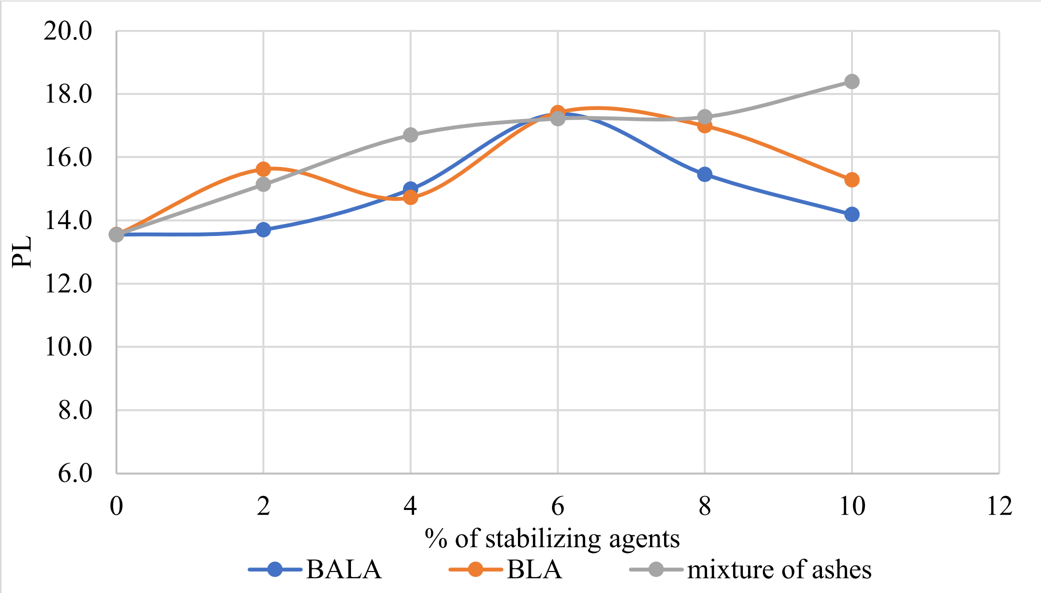

Figure B- 1: Variation of PI with ashes on soil 01

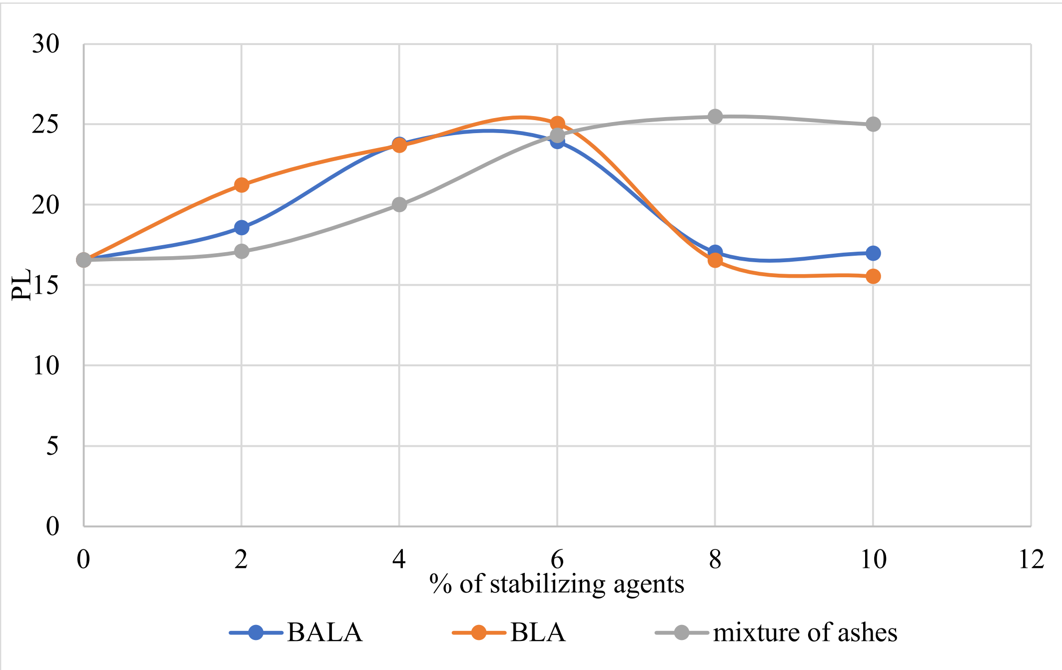

Figure B- 2: Variation of PI with ashes on soil 02

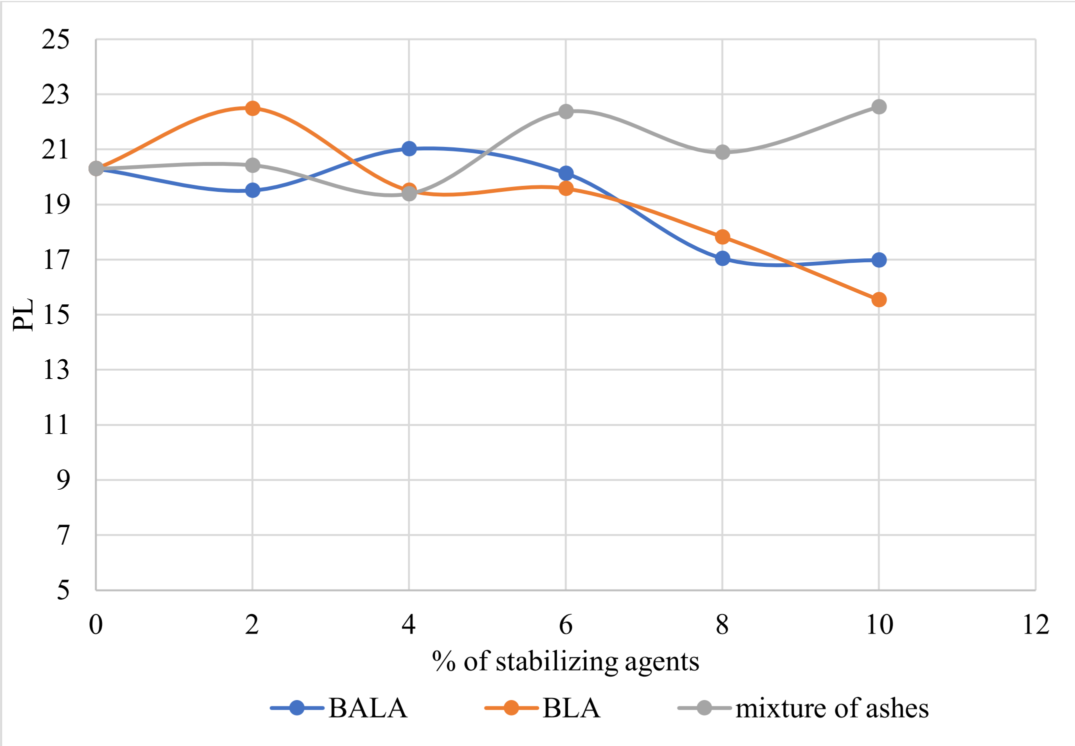

Figure B- 3: Variation of PI with ashes on soil 03

APPENDIX C: ADDITIONAL INFORMATION ON UCS TESTS

Table C- 1: Impact of plastics on UCS

% of Plastic	Area (m2)	Units (1=0.1962 kN)			UCS (kPa)			
		Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Average
0.00	0.001571	6.0	6.0	5.0	749.3	749.3	624.4	707.7
2.00	0.001571	8.0	8.0	9.0	999.1	999.1	1124.0	1040.7

Table C- 2: Impact of BALA on UCS

% of BALA	Area (m2)	Units (1=0.1962 kN)			UCS (kPa)			
		Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Average
0.00	0.001571	6.0	6.0	5.0	749.3	749.3	624.4	707.7
8.00	0.001571	9.0	9.0	10.0	1124.0	1124.0	1248.8	1165.6

Table C- 3: Impact of BLA on UCS

% of BLA	Area (m2)	Units (1=0.1962 kN)			UCS (kPa)			
		Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Average
0.00	0.001571	6.0	6.0	5.0	749.3	749.3	624.4	707.7
6.00	0.001571	11.0	11.0	12.0	1373.7	1373.7	1498.6	1415.4

Table C- 4: Impact of leaf ash mixture on UCS

% of mix	Area (m2)	Units (1=0.1962 kN)			UCS (kPa)			
		Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Average
0.00	0.001571	6.0	6.0	5.0	749.3	749.3	624.4	707.7
6.00	0.001571	10.0	10.0	10.0	1248.8	1248.8	1248.8	1248.

APPENDIX D: ADDITIONAL INFORMATION OF SOAKED CBR TEST RESULTS

Table D- 1: Impact on CBR with plastics on soil 01

% of Plastic	CBR Top (%)	CBR Bottom (%)
0.0	17.6	18.6
0.5	25.8	28.8
1.0	33.7	34.7
2.0	46.6	38.7
4.0	42.6	38.7
8.0	32.7	34.7

Table D- 2: Impact on CBR with BALA on soil 01

% of BALA	CBR Top (%)	CBR Bottom (%)
0.0	17.6	18.6
2.0	24.8	22.8
4.0	29.7	30.7
6.0	48.6	51.6
8.0	43.1	49.1
10.0	30.5	30.0

Table D- 3: Impact on CBR with BLA on soil 01

% of BLA	CBR Top	CBR Bottom
0.0	17.6	18.6
2.0	30.7	30.5
4.0	35.4	31.2
6.0	63.5	46.6
8.0	40.2	43.4
10.0	41.6	41.9

Table D- 4: Impact on CBR with leaf ash mixture on soil 01

% of Mix	CBR Top (%)	CBR Bottom (%)
0.0	17.6	18.6
2.0	32.7	31.7
4.0	35.7	25.5
6.0	43.6	50.6
8.0	40.4	31.7
10.0	33.5	26.8

Table D- 5: Impact on CBR with plastics on soil 02

% of Plastic	CBR Top (%)	CBR Bottom (%)
0.0	11.9	11.9
0.5	18.3	21.8
1.0	23.8	21.3
2.0	19.3	31.5
4.0	13.6	19.3
8.0	15.6	16.3

Table D- 6: Impact on CBR with BALA on soil 02

% of BALA	CBR Top	CBR Bottom
0.0	11.9	11.9
2.0	17.8	16.8
4.0	21.5	23.3
6.0	33.3	32.2
8.0	21.5	23.3
10.0	21.8	22.8

Table D- 7: Impact on CBR with BLA on soil 02

% of BLA	CBR Top (%)	CBR Bottom (%)
0.0	11.9	11.9
2.0	19.8	18.6
4.0	22.8	23.5
6.0	31.2	34.3
8.0	32.6	31.7
10.0	23.0	23.5

Table D- 8: Impact on CBR with leaf ash mixture on soil 02

% of Mix	CBR Top (%)	CBR Bottom (%)
0.0	11.9	11.9
2.0	20.8	18.1
4.0	22.8	21.8
6.0	30.5	32.7
8.0	30.5	29.7
10.0	22.0	22.5

Table D- 9: Impact on CBR with plastics on soil 03

% of Plastic	CBR Top (%)	CBR Bottom (%)
0.0	13.4	12.6
0.5	15.0	15.3
1.0	17.1	17.1
2.0	24.5	29.6
4.0	25.3	24.8
8.0	10.9	10.5

Table D- 10: Impact on CBR with BALA on soil 03

% of BALA	CBR Top (%)	CBR Bottom (%)
0.0	13.4	12.6
2.0	15.3	14.8
4.0	17.8	18.8
6.0	27.7	25.3
8.0	25.8	31.7
10.0	26.3	26.0

Table D- 11: Impact on CBR with BLA on soil 03

% of BLA	CBR Top (%)	CBR Bottom (%)
0.0	13.4	12.6
2.0	18.3	13.0
4.0	17.8	21.8
6.0	34.2	35.9
8.0	20.8	25.3
10.0	24.0	21.8

Table D- 12: Impact on CBR with leaf ash mixture on soil 03

% of Mix	CBR Top (%)	CBR Bottom (%)
0.0	13.4	12.6
2.0	16.6	15.3
4.0	15.6	19.3
6.0	28.7	32.2
8.0	24.8	25.8
10.0	16.8	22.3