Scientific Journal of Engineering and Technology (2022), 1(1), 26-39
An International, Peer reviewed, Open access Journal

RESEARCH ARTICLE

Article Identifier: https://identifier.visnav.in/1.0003/sjet-21l-22001/

Stabilization of weak subgrade soil with wood ash and cement for road construction: a case study along Arba Minch town – Sille road

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ABSTRACT

Cement is one of the components of construction material which plays a significant role in the implementation of construction projects. More so, it is considered as one of the most expensive and environmentally unfriendly construction material. Therefore, the requirements for economical and environmentally-friendly cementing ingredients have given interest to other cementing compounds which is contained in other materials that can be used as partial replacement of the ordinary Portland cement. In case of Arba Minch town – Sille Road, most parts of the existing road section were heavily damaged and that is why this research study was focussed on the stabilization of subgrade soil using wood ash as partial replacement of cement in weak subgrade soil for road construction. To achieve the objectives of the study, primary data conducted directly in the field, through field observation and identifying the sections where to extract samples in the study area. The results revealed that Wood Ash found and partially can replace cement in weak subgrade soil stabilization. Plasticity index decreased slightly, maximum dry density (MDD) increased for all pits than control mix while moisture content decreased, CBR also showed a slight incremental change compared with the normal soil sample.

Keyword: Cement, Wood ash, Stabilization, Subgrade Soil

1. INTRODUCTION

The Subgrade soils are an essential component of pavement structures, and inadequate subgrade performance is the cause of many premature pavement failures. Clay subgrades in particular may provide inadequate support, particularly when saturated. Soils with significant plasticity may also shrink and swell substantially with changes in moisture conditions. These changes in volume can cause the pavement to shift or heave with changes in moisture content, and may cause a reduction in the density and strength of the subgrade, accelerating pavement deterioration. There is a substantial history of the use of soil stabilization admixtures to improve poor subgrade soil performance by controlling volume change and increasing strength. Lime and cement have been used successfully for many decades. Cement is one of the components of construction material which plays a great role in the construction industry. Nevertheless, it is the most expensive and environmentally unfriendly material. Therefore, requirements for economical and more environmentally-friendly cementing materials have extended interest in other cementing materials that can be used as partial replacement of the ordinary Portland cement [1]. These studies focused of the interest wood ash as an economical alternative to improve subgrade performance, which was checked along Arba Minch -Sille roads.

Most parts of the existing road section within the study area were heavily damaged. That is why this research study focussed on the investigation on chemically stabilized sub-grade course materials using wood ash as partial replacement of cement in weak subgrade soil stabilization along the road.

Wood ash is a residue powder that is left after combustion of wood in the home or in industries. Typically 6-10% of the mass of burnt wood result in ash as reported by WHO. The type of wood, combustion temperature and combustion time plays a vital role in the quantity of ash produced its chemical composition [2].

There are different methods practiced to improve the engineering properties of such weak soils such as stabilization, grouting, removal and replacement, removal and re-compaction, preloading and dynamic compaction and reinforcement using Geo-synthetics [3-4]. These methods, improve the physical and chemical properties of soil in such a way that the soil becomes consistent; hence, the strength is increased and deformability and permeability are reduced. Although compaction and consolidation methods work very well for granular soil, it takes a long time for the soil to consolidate (months to years) especially with the cohesive soil [5]. Replacement methods could be the possible solution for organic soil, where the organic soil to a sufficient depth is replaced with granular soil such as sand and crushed stones or preloading to improve the engineering properties [6]. Chemical stabilization is an alternative low-cost solution, where stabilizing agents such as cement, lime, fly ash, and other binders stabilize the organic soil rapidly through chemical reactions [7-8]. The usual approach when weak subgrade soil encountered is to remove the soft soil and replaces it with selected materials likes crushed rock, hard selected subgrade soil. Another way is to stabilize with different stabilizers like lime, fly ash, cement, and bottom ash etc. The method of wood ash and cement stabilization was to blend available natural subgrade soil so that, when properly compacted, it will give the desired stability in subject road sections areas.

Soil can be stabilized by adding 7-16 percent of cement by volume, the small percentage is specified to the granular soil while the high percentage is specified to the coarse soil, however, this was mistakenly being interpreted to state that any soil can be stabilized with cement, while there are types of soil that needs more than 16% of cement to be stabilized [9]. In the early of 1940, Catton noted that there are certain physical properties of soil like the surface area, grain size and the compacted density affecting the cement requirement [10].

External surface properties more strongly affect the chemical behavior of materials than any other property. This is to be expected from the surface of a solid presents to a liquid, gas or another solid actually consist of an obstacle or series of obstacles which must be pierced before chemical reactions can occur. The merit of this work lies in that it recognized by the importance of surface phenomena and an attempt was made to correlate them to the engineering behavior of soils, as displayed by density-moisture relationships, permeability, and freeze-thaw resistance [11].

Road subgrade layer fails because of weak strength. It needs an effective treatment using environmentally available materials. Cement is used as subgrade treatment material. According to researchers, the production of a tonne of Portland cement generates about one tonne of carbon dioxide (CO_2) to the atmosphere, and it is about 5% of global CO_2 emission [12]. In a developing country like Ethiopia, due to rapid urbanization and infrastructure projects, there is a vast expansion of cement industries releasing this pollutant to the surrounding. As a relief to this problem, requirements for economical and more environmentally-friendly cementing materials have extended interest in other cementing materials that can be used as partial replacement of the ordinary Portland cement [13]. These are supplementary cement replacing materials that have become a new era for construction industry sectors due to their pozzolanic properties. Out of this Blast furnace slag, silica fume, fly ash and rice husk can be cited as the example [14]. Wood ash has also been found to have such pozzolanic property.

According to the ministry of rural development in Ethiopian report, its production is increasing yearly and all 85% of rural as well as almost urban Ethiopians are using wood as their own solid biomass for heat and electricity production, which led to increase in the amount of combustion residues known as ash, which is quite large amount if it is collected from each house usage [15].

Several problems may occur in the construction of roads due to subgrade soil failure. The Bridge along Arba Minch – Sille road was failed for three times and the fourth Bridge is now in construction due to subgrade failure. Therefore, subgrade should be treated using cost saving stabilization: by replacing the cheap and environmentally available material, wood ash, to the expensive cement.

The research focused on four main objectives, it was improving the properties of the soil at the construction site so it doesn't bend under the pressure from the weight of the Vehicle wheel loading, while the other important part is how to minimize the excessive usage of the cement in this purpose and try to use other materials which can provide the same function and one of these materials is wood ash.

2. METHOD AND MATERIAL

2.1. Study Area

The study was carried out on the Arbamicnh town-sille found in the western part of the Arba Minch district in the SNNPR state.

2.2. Collecting and mixing the sample

The chemical composition of cements can be quite diverse, but by far the greatest amount of soil stabilized today is using with Portland cements which has a 28 day compressive strength of 42.5MPa and specific gravity of 3.15. Significant quantities of wood ash are currently landfilled near homes and industries that uses wood as a fuel partially or fully which poses a threat to the environment in many ways to livestock around. It was collected from neighboring areas as needed. To find out the optimum combination of admixtures materials, it was mixed by increasing the percentages of wood ash and decreasing the percentages of cement to consider the effect of WA. Estimation of blending ratio for the mechanical stabilization conducted by trial and error process. Gradation

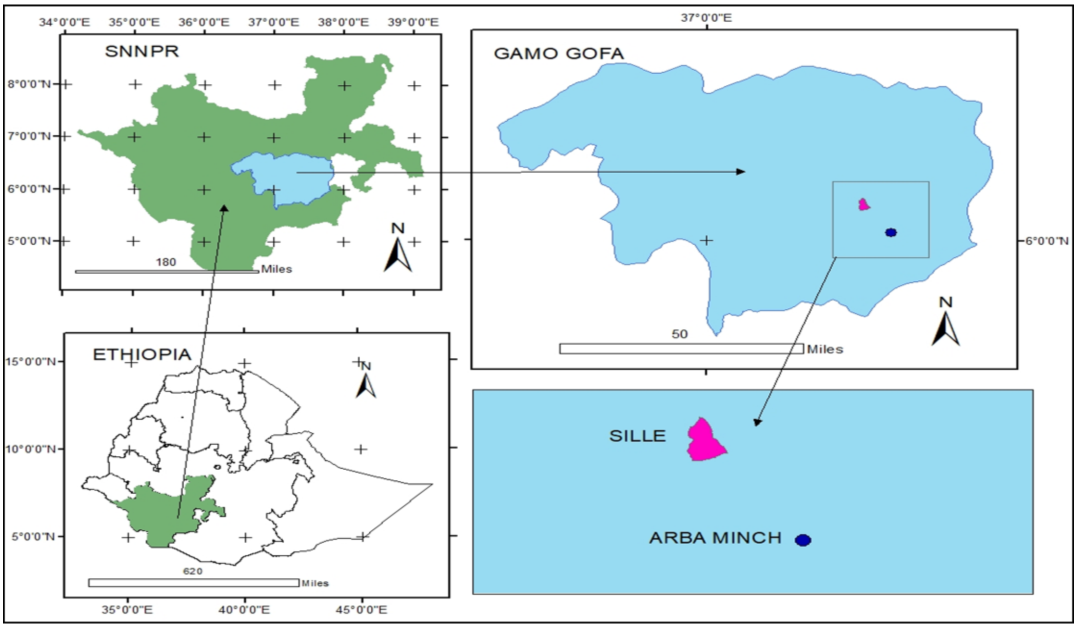

Figure 1. The area of the study

Figure 2. Sample of wood ash

Figure 3. Sample of PPC used

and plastic properties were the basic parameters in blending. Four pits were selected for the study, and four representative samples were extracted from each of these pits such as test pits 1,2, 3 & 4.

2.3. Grain size analysis

AASHTO T- 88 was used. In this test method, it was described as a procedure for the quantitative determination of the distribution of particle size in soil by grading requirements based on Standard Technical Specification – 2002. The sample passed the sieve number 200 was placed on a tray, and it was allowed to dry in an oven from 105-110 °C. Then, put set of the sieves on ascending order, starting from sieve no. 200 at the bottom to sieve no.4 on the top. The sieve stack was placed in the mechanical shaker and shaken for 10 minutes. It was removed carefully from the shaker, then the weight of each sieve with its retained soil was recorded. The calculation of Sieve analysis was done by equation 1& 2:

$$Cu = \frac{D60}{D10} \qquad \text{...eq. 1}$$

$$Cc = \frac{D30^2 * D10}{D60} \qquad \text{...eq. 2}$$

Where:

D10, D30, and D60 are the diameters corresponding to percents finer of 10%, 30%, and 60% respectively.

2.4. Atterberg's limit test

The liquid limits, plasticity limits, and plasticity index test determined in accordance with test method AASHTO T89, T90 [1]. About 0.75kg of the soil sample was weight and then it was put into the porcelain dish to mix the soil until it becomes smooth. Then the soil placed in a liquid limit machine and cut at the center of the cup using grooving tool. 15-25 drops were used until the cut surface come together. The water content is measured.

2.5. Plastic Limit Calculation

The plasticity limit is defined as the hardened state of the soil which it can be rolled by hand on a flat surface to 3.2mm diameter. The plasticity index (PI) is the measure of the plasticity in the soil. First, calculate the moisture content %w for each can after they come out from the oven. The average of the water contents was measured to determine the plastic limit by equation 3.

$$(PI) = LL - PL \qquad \text{...eq. 3}$$

2.6. Compaction test

The test was performed using the AASHTO T180: Modified compaction or Modified Proctor Test. This test method used to determine the relationship between the moisture content and density of soil when compacted in a given mold of a given size with a 4.5kg hammer dropped from a height of 457mm. The collected sample soil, was passed by 19mm sieve size, and mold with collar attached in five equal layers utilized to provide a total compacted depth 127mm. Each layer was compacted by 56 uniformly distributed blows from the hammer.

2.7. California bearing ratio (CBR) test

AASHTO T180 and AASHTO T193 methods were used to carryout the California bearing ratio test (CBR) [1]. The procedure starts from taking a representative sample of soil weighing approximately 6kg and mixed thoroughly at OMC. The CBR was calculated by equation 4:

$$\text{California Bearing Ratio} = \frac{PT \times Cf \times 100}{PS} \quad \text{...eq.4}$$

Where:

PT= corrected unit test load corresponding to the chosen penetration from the load penetration curve,
PS = total standard load for the same depth of penetration, and
Cf = proving ring correction factor

3. RESULTS AND DISCUSSION

Table 2 shows the result for the specific gravity test of wood ash in order to compare with that of specific gravity of Portland cement (3.15 g/cm^3) of 28 day compressive strength of 42.5MPa used as additives.

3.1. Sieve analysis test

From the sieve analysis it was noticed that soil particles were flown on the top indicating that the soil has coarse particles and further sieve

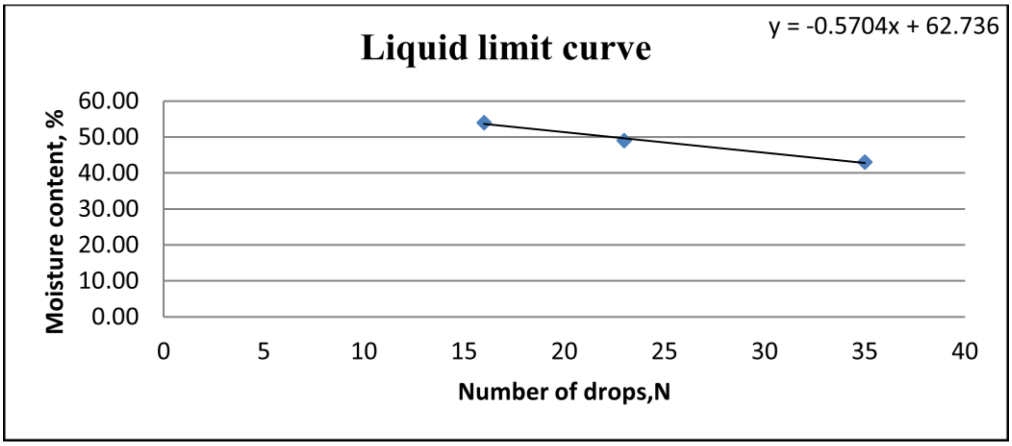

Figure 4. Water content (%) v/s Number of drops for pit one

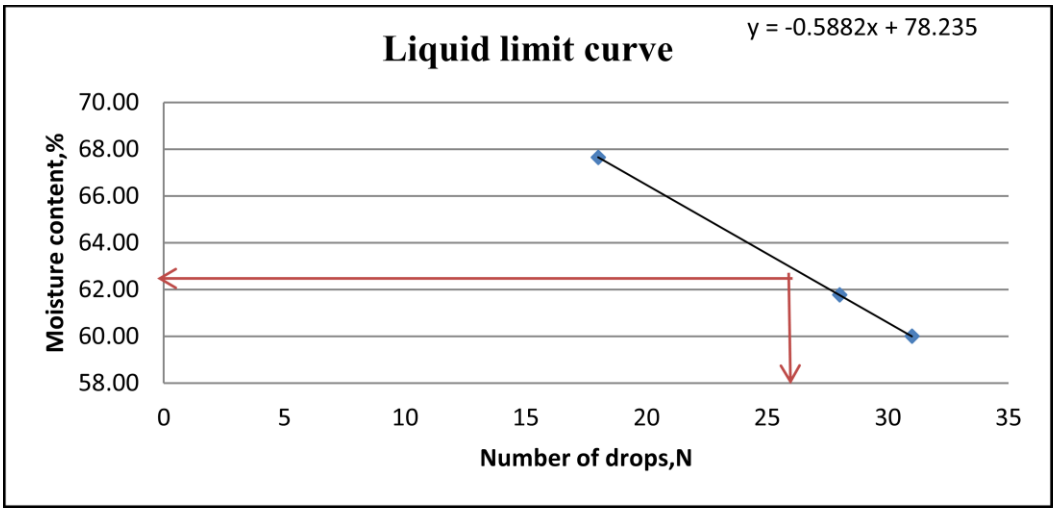

Figure 5. Water content (%) v/s Number of drops for 5% WA and 5%C

size analysis was needed to conduct.

A plot of percent passages versus particle size distribution of the normal soil. According to the result the soil classified as poorly graded soil since the values of Cu and Cc were below 4 and not in between 1 and 3 respectively. For both Cu and Cc values were determined for each pit.

The coefficient of gradation, Cu, is a parameter which indicates the range of distribution of grain sizes in a given soil specimen. If Cu is relatively large, it indicates a well graded soil. If Cu is nearly equal to one, it means that the soil grains are of approximately equal size, and the soil may be referred to as a poorly graded soil.

The parameter Cc is also referred to as the coefficient of curvature. For sand, if Cu is greater than 6 and Cc is between 1 and 3, it is considered well graded. However, for a gravel to be well-graded, Cu should be greater than 4 and Cc must be between 1 and 3. Even Cc fulfils it the Cu was not achieved, therefore it is categorized

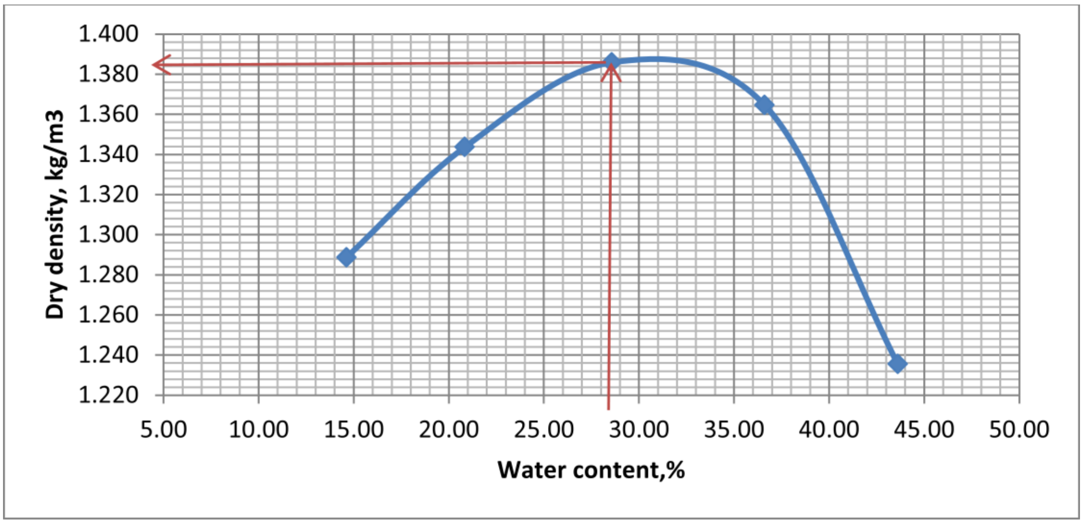

Figure 6. Compaction test for the control mix sample of pit one

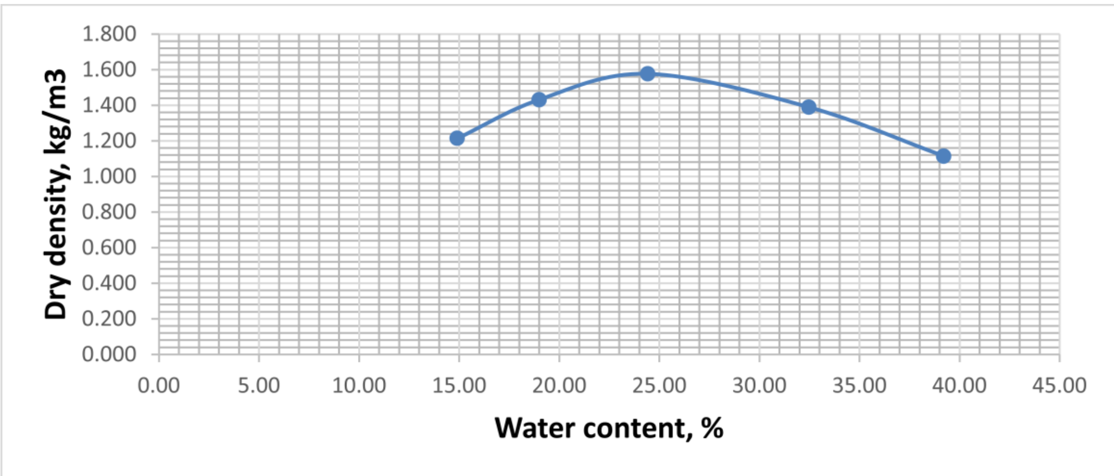

Table 7. Compaction test for the control mix sample of pit one

under the poorly graded soil.

Figure 4 shows the number of blows against the water content of the liquid limit determination test, the blue line represents the best fit line through the plotted points, and the liquid limit can be read from at 25 drops.

According to AASHTO T89 & T90, ERA test method, the soil is classified as medium plastic soil.

3.2. Comparison between the control mix and the percentages of the additives used for the atterberg limit test

Results of liquid limit and plastic limit were shown in Table 6–9. For all four pit control samples and their stabilized result were shown in the figure 4&5. according to AASHTO soil classification, the soil was classified as CH (Clayey soil with high plasticity), but the result after the increasing percentage addition of wood ash up to10% and decreasing cement to 4% the plasticity index was found in between 15% - 30%, according to AASHTO soil classification, the soil was classified as CH (Clayey soil with medium plasticity for each pit.

3.3. Compaction test for the control mix sample of pit one

Figure 6 shows the compaction test for the control mix sample of pit one, the blue color in

Figure 1. Chemical composition of wood ash [16]

Constituent	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	K_2O	Na_2O	NaO, L.O.I
Composition, %	31.8	28	10.53	9.32	2.34	10.38	6.5	27

Table 2. Physical properties of wood ash

S.NO	Property	Wood ash
1	Specific gravity	2.13
2	Water absorption	5%
3	Nature	Pozzolanic

Table 3. Combination scheme of soil sample description

Sample Id	Soil (gm)	Wood ash (gm)	Cement (gm)	Cement (%)	Wood Ash (%)
Original soil	6 000	-	-	0	0
M1	6000	300	300	5	5
M2	6000	600	240	4	10
M3	6000	900	180	3	15

Table 4. Field data sheet

No	Type of test	Size of sample from study sites (Kg)
1	Gradation/sieve analysis	4pits*3samples*10kg = 120kg
3	C.B. R	4pits*3samples*9kg = 108kg
4	Atterberg's Limit Test,	4pits*3samples*11kg = 132kg
5	Compaction	4pits*3samples*10kg = 120kg

the chart is the curve obtained by plotting the points of the average moisture content (%) versus the dry density (kg/m^3), while the orange color in the chart is for determining the optimum moisture content and maximum dry density.

When adding 10% of the water the moisture content is 14.62% and dry density is 1.389kg/m3, then when increasing the amount of water added to 13% the moisture content is increased to 20.282%, while dry density is increased to 1.344kg/m^3, when adding 16% water the moisture content is increased to 28.57% and dry density is decreased to 1.386 kg/m^3, lastly when adding 19% water, the moisture content is increased to 36.61% and the dry density is decreased to 1.365kg/m^3.

The increase of the dry density when 13% water is added is due to the increase of the cohesiveness of the soil-additive mixture, while

Figure 5. PI Classifications according to ASTMD-4318

Plasticity index	Classification
0-3	Non plastic
3-15	Slightly plastic
15-30	Medium plastic
>30	Highly plastic

Table 6. Comparison of control mix and sample with additives for pit one

S.no	Additives	Liquid limit (%)	Plastic limit, %	Plasticity index, %
1	Control mix for pit one	49.00	25.54	23.46
2	5% WA and 5% C	63.14	42.90	20.24
3	10% WA and 4%Cs	43.41	25.06	18.34
4	15 % WA and 3%C	51.00	26.60	24.40
5	20 % WA and 2%C	60.07	29.57	31.13

Table 7. Comparison of control mix and sample with additives for pit two

S.no	Additives	Liquid limit (%)	Plastic limit, %	Plasticity index, %
1	Control mix for pit one	58.50	32.81	45.79
2	5% WA and 5% C	52.59	22.86	29.72
3	10% WA and 4%Cs	53.29	31.82	21.48
4	15 % WA and 3%C	48.63	21.07	27.85
5	20 % WA and 2%C	47.34	20.45	26.89

Table 8. Comparison of control mix and sample with additives for pit three

S.no	Additives	Liquid limit, (%)	Plastic limit, %	Plasticity index, %
1	Control mix for pit one	45.64	21.20	24.44
2	5% WA and 5% C	44.91	25.06	19.37
3	10% WA and 4%Cs	49.47	28.24	21.24
4	15 % WA and 3%C	63.21	43.13	20.06
5	20 % WA and 2%C	44.50	20.76	20.74

when increasing the water added to 16% and 19%, the dry density tended to reduce due to the reduced cohesiveness of the soil – additive mixture.

From the graph the soil sample optimum moisture content is 28.57%, while the maximum dry density is 1.36 kg/m^3, which means that the cohesiveness between the particles is at its optimum.

Figure 7 shows the compaction test for the control mix sample, the blue color in the chart is the curve obtained by plotting the points of the average moisture content (%) versus the dry density (kg/m^3), while the orange color in the chart is for determining the optimum moisture content and maximum dry density.

Figure 9. Comparison of control mix and sample with additives for pit four

S.no	Additives	Liquid limit (%)	Plastic limit, %	Plasticity index, %
1	Control mix for pit one	54.90	24.06	30.85
2	5% WA and 5% C	63.14	42.90	20.24
3	10% WA and 4%Cs	53.09	30.44	22.65
4	15 % WA and 3%C	44.14	21.00	23.14
5	20 % WA and 2%C	49.93	24.76	25.17

Table 10. Comparison of the additives and control mix for soil specimen

S.no	**Additives**	**Optimum moisture content (%)**	**Maximum dry density (kg/m3)**
1	Control mix	36.61	1.365
2	5% WA and 5% C	21.59	1.438
3	10% WA and 4%Cs	29.59	1.467
4	15 % WA and 3%C	21.34	1.438
5	20 % WA and 2%C	25.25	1.53

Table 11. Comparisons of control mix and sample with additives for pit one

Sample	**CBR values**
Control mix	2.68
5%WA and 5% C	2.99
10%WA and 4% C	3.9
15%WA and 3%C	3.69
20%WA and 2% C	3.85

Table 12. Comparisons of control mix and sample with additives for pit two

Sample	**CBR values**
Control mix	2.46
5%WA and 5% C	3.12
10%WA and 4% C	4.1
15%WA and 3% C	3.84
20%WA and 2% C	2.98

When adding 10% of the water the moisture content is 14.91% and dry density is 1.214kg/m³, then when increasing the amount of water added to 13% the moisture content is increased to 19.00%, while dry density is increased to 1.432kg/m3, when adding 16% water the moisture content is increased to 24.43% and dry density is decreased to 1.577 kg/m³, lastly when adding 19% water, the moisture content is increased to 32.47% and the dry density is decreased to 1.389kg/m³.

The increase of the dry density when 13% water is added is due to the increase of the cohesiveness of the soil-additive mixture, while when increasing the water added to 16% and 19%, the dry density tended to reduce due to the reduced cohesiveness of the soil – additive mixture.

From the graph the soil sample optimum moisture content is 24.43%, while the maximum dry density is 1.577kg/m³, which means that the cohesiveness between the particles is at its optimum.

3.4. Comparison between the control mix and the percentages of the additives used

Table 10 shows the comparison of the additives and control mix for soil specimen. Almost in all cases, from pit one to four, there was a slight variation in values but in the same manner (table 10). It shows the change of the optimum moisture content and maximum dry density when using different percentages of WA and keeping cement additives constant..

For the optimum moisture content, it can be realized that the control mix sample (sample without additives) has the highest moisture content of 36.61%, then it decreases to 21.59% when 5% of WA is added, later it further decreases to 21.31% when 10% of WA is added, finally it increases to 29.59% when using 15% of WA.

The highest moisture content was found in the control mix sample, then it tended to decrease

Figure 13. Comparisons of control mix and sample with additives for pit three

Sample	CBR values
Control mix	2.47
5%WA and 5% C	2.6
10%WA and 4% C	2.93
15%WA and 3% C	2.79
20%WA and 2% C	2.37

Table 14. Comparison of control mix and sample with additives for pit four

Sample	CBR values
Control mix	3.46
5%WA and 5% C	3.47
10%WA and 4% C	3.84
15%WA and 3% C	3.75
20%WA and 2% C	3.93

when using the WA, this is due to the light weight of WA which enabled it to occupy the voids that is in the sample and prevent it from absorbing moist, thus it reduced the moisture content, then when 15% of WA is used, the moisture content increased, this is resulted from having excessive weight of WA so that weight didn't react with the soil sample and remained free, once remained free it absorbed the water and kept it inside its particles.

For the maximum dry density, it can be noticed that at the control mix sample it is 1.365kg/m^3, then it was increased to 1.438 kg/m^3, when 5% WA was added, it also increased when 10% of WA was used to 1.467 kg/m^3, later it was decreased when 15% of RHA was added to 1.38kg/m3.

The increase of the dry density when 4% and 10% of WA was added can be explained that the WA worked very well and combined with the soil particles occupying the voids in the soil preventing the water from flowing into the soil specimen and crystalline in it, however the decrease that happened later, when 15% of WA used was because of the extra WA particles that remained free and didn't combine with the soil particles, thus these extra particles absorbed more water and kept it, thus increasing the moisture content and reducing the dry density.

3.5. California bearing ratio test

Control mix sample result for pit one

The California bearing ratio of control mix of pit one was 2.68% and Highest stress for this was 0.18 at the ring reading of 16.50. This result indicates that according to AASHTO and ERA 2002 it is catagorized under the class of S1.This type of subgrade soil is weak and which needs supporting material to strengthen its properties. The California bearing ratio of control mix of pit one was 2.68% and highest stress for this was 0.25 for the ring reading of 18.40. This result indicates that according to AASHTO and ERA 2002 it is categorized under the class of S1 (subgrade class 1).This type of subgrade soil is weak and which needs supporting material to strengthen its properties. As the amount of wood ash 5% and cement 5% added the CBR from 2.68% to 2.99% increased due to the addition of the admixtures. The comparision also indicates that the subgrade class strength was increased for the 5% WA wood ash and 5% C as compared to the normal soil for each pit and, similarly, for 10% of wood ash it showed that a slight increment improving the subgrade class from S1 to S2. CBR values for the 15% of WA and 3% of cement shows the slight decrease in comparison with normal but the value is increased for 20%WA and 2%C.

Wood ash are generally discarded as waste and dumped outside of the house or landfills, which increase the volume of landfill. Significant quantities of wood ash are currently landfilled near homes and industries that use wood as a fuel partially or fully. It will be collected from a neighbouring area as needed [15].

A report by researcher suggested that the results of chemical analysis of wood ash are as follows: the total percentage composition of iron oxide (Fe_2O_3 = 2.34%), aluminium oxide (Al_2O_3 =28.0%), and silicon dioxide (SiO_2 =31.80) was found to be 62.14%. This is less than 70%, which is the minimum requirement for pozzolana [16].

This reduces the pozzolanicity of wood ash. The percentage composition of silicon dioxide (31.8%) is with the range specified by ASTM. However, the percentage composition of iron dioxide aluminium oxide were not in agreement with the work. The loss on ignition obtained was 27%. The value is more than 12% maximum as required for pozzolana. This means that wood ash contains appreciable amount of un-burnt carbon which reduces its pozzolanic activity. The un-burnt carbon is not pozzolanic and it serves as filler to the mixture.

4. CONCLUSION

Mixture of Wood ash and cement reduces the plasticity and increases maximum dry density of weak subgrade soil, while more water is required for the agglomeration and flocculation of clay particles through cation exchange reaction and coagulation with the consequent reduction in the amount of fines. (ii) Ash-cement stabilization causes an increase in subgrade class strengthen the weak subgrade soil, and 10% wood ash and 4% cement mixture optimize the results. The larger the ash-cement percentage inserted, the greater the strength for certain amount. (iii) There is a slight improvement in the CBR strength parameters with the addition of wood ash and cement. The subgrade strength class values was found in between 2-3 for the control mix (sample without additives) while for the addition of 5% – 10% wood ash and 5% cement showed a slight increment but decreased for 15% wood ash addition.

5. RECOMMENDATION

- After completing this research study, the following recommendations were suggested:
- It is recommended that using a mixture of wood ash by increasing percentage and decreasing cement amount for stabilizing weak subgrade soil could achieve the required improved different properties of soil.
- It could be possible to use the 10% of mixture wood ash and 4% cement replacement of soil in order to improve weak sub grade soil.

6. ACKNOWLEDGEMENT

NA

7. CONFLICT OF INTEREST

The authors have declared that there is no conflict of interest.

8. SOURCE/S OF FUNDING

The funds for this study were provided by Ethiopian Ministry of Education, Ethiopia.

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