Stabilization of Deficient Soils in Ethiopia - A Review

Fitsum Markos Deboch
MSc, Department of civil Engineering, Wolaita Sodo University, Wolaita sodo, Ethiopia

Abstract
In Ethiopia the construction of road is increasing from time to time. Likewise, there is increasing demand of naturally occurring construction materials. Unfortunately, not all the natural materials along the vicinity of road projects are suitable for the proposed construction because these materials fail to fulfill the standard quality requirements. The best alternative in those areas, where there is scarcity of suitable construction materials, is upgrading the locally available materials so that they can be used for the proposed construction. There is an increasing effort around the world towards introducing innovative and unconventional road construction approaches that aim at reducing costs of construction by enabling use of this construction materials found with in the road route. One of proven technologies in connection to this effort is stabilization of soil. Soil stabilization is the alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of a soil. This paper present the review of studies on the stabilization of deficient soils in Ethiopia.
Keywords: Expansive soil, Lateritic soil, Subbase, Subgrade, Stabilization

1. Introduction

Deficient soils are regarded as soils which do not meet some or all the criteria required for their satisfactory performance as geotechnical structures. These could either be for base courses for road, embankment for dam or road, subsoil base for foundation, clay liners for containment of leachates and backfill for retaining walls [5]. In the tropical region, these soils could be lateritic soils, black cotton soils, collapsible soils or any other tropical soils. [6]

Laterite occurs mostly in the tropical and sub-tropical regions with hot, humid climatic conditions. It has been suggested that a mean annual temperature of around 25°C is needed for their formation, and in seasonal situations there should be a coincidence of the warm and wet periods. If there is high rainfall during the cold season, laterites do not develop freely. The minimum annual rainfall required for laterite formation is generally at least 750 mm. The higher the rainfall above this value, the greater is the leaching effect, which removes free silica, reduces the silica/sesquioxide ratio and therefore increases the degree of laterization. [12],[38]

In Ethiopia the construction of road is increasing from time to time. Initially it requires appropriate design. Rural roads network is one of the key factors for rural development. It helps the rural community being accessible to economic and social services. It also increases agricultural product. For low volume and low cost un-surfaced earth and gravel roads in-situ materials should be utilized as much as possible. However, these materials are not always suitable and many problems usually arise, like deterioration of the surface (rutting and potholes). One of the commonly available in-situ materials is laterite soil. Laterite is a widely available material in Ethiopia according to Ethiopian Roads Authority Design Manual [15],[26]. Lateritic materials are found in abundance quantity along Nekempt - Bure road, Asosa –Kumruk road, Nejo – Mendi road and Mendi – Asosa road stretches[25]. lateritic gravels have been used as subgrade material, subbbase, and as gravel wearing course in low volume unpaved roads in many parts of the country (for instance, in Wollega, Arsi and Bale regions). Lateritic gravels are also used as backfill material around drainage and earth-supporting structures.[7]

Lateritic soils also have wide applications in such areas as embankments, low-cost houses, etc. However, weathered under conditions of high temperature and humidity with welldefined alternating wet and dry season results in poor engineering properties such as high plasticity, poor workability, high permeability, tendency to retain moisture and high natural moisture content [1],[8].Besides Lateritic soils, especially those containing excess fines, are possibly weak in strength. If these soils are encountered in the subgrade, thicker pavement structures are needed. If the pavement structures are too thin for a particular class of subgrade (based on its CBR or resilient modulus), large permanent deformations accumulate over time and affect the performance of the pavement. For use in road works, lateritic soils may fall short to satisfy specification requirements, especially subbase or base material specification. Because lateritic material is cheap and abundantly available in tropical areas, its use as in situ subgrade (instead of undercutting, capping layer, etc.) or subbase(instead of select material or crushed rock) or base(instead of crushed rock), will significantly reduce construction costs[7].In such cases, stabilization of the soil to meet or satisfy the desired properties is necessary.

Expansive soil is the term generlly refered to any soil or rock that has potential for shrinking or swelling under changing moisture condition. The primary problem that arises with regard to expansive soil is that the deformations are significantly greater than elastic deformations and they can not be predicted by classical elastic or plastic theories [24]. Movement is usually in uneven pattern and of such a magnitude that it causes extensive damage to the structures and pavements resting on it[3]

Expansive clay soils have a world-wide distribution; their occurrence is not climatic specific though they are particularly widespread in arid to semi-arid climate[10].In Ethiopia these expansive soils (vertisols) occupy 116,785sq.km which accounts to about 10.5% of the total area of the country [4]. The largest extents of Vertisols are found on the volcanic plateaus. Vertisols are also found on colluvial slopes in the central highlands, on the colluvial slopes and alluvial plains along the Sudanese border and on the vast limestone plateaus of central Hararghe. It is also found in sites such as granitic colluvium in basins with seasonal drainage deficiencies in southern Sidamo. Sandstone colluvium is found in valleys in Tigray and the flood plains of the Wabe Shebele and Fafen rivers in the Ogaden [32]. The road sector in Ethiopia is suffering from the high shrink-swell behavior of this expansive soil. Many damages occur each year and road construction over such expansive soil creates serious problems including increasing cost of construction and maintenance [20],[28]. There are several roads in Ethiopia, whose premature failures attributed to the volumetric changes of expansive clay soil; Modjo-Ejerie-Areti Road and Addis-Jimma Road could be examples of such failures.[10]

Stabilization improves the properties of the deficient soils. Soil stabilization is the alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of a soil. Stabilization, in a broad sense, incorporates the various methods employed for modifying the properties of a soil to improve its engineering performance. Soil stabilization also refers to the procedure in which a special soil, cementing material, or other chemical materials are added to a natural soil to improve one or more of its properties. One may achieve stabilization by mechanically mixing the natural soil and stabilizing material together so as to achieve a homogeneous mixture or by adding stabilizing material to an undisturbed soil deposit and obtaining interaction by letting it permeate through soil voids.[19]

2. Literatures Review

Various literatures were referred and the summary was listed below:

Abas K.[26] studied the usefulness of Con-Aid as a stabilizer for laterite soil Sampled from Gidole town ,Southern Ethiopia . The Atterberg limits, compaction and soaked CBR tests carried out without and with Con-Aid chemical, to evaluate the change in the engineering properties of the stabilized soil after curing the treated samples for different periods. From the test results, were not seen a promising reduction of plasticity, increment of maximum dry density and improvement of the CBR value. These indicate that the Con-Aid effect does not exceed the natural effect of the laterite soil because the soil under investigation in Gidole town was naturally cementeous material. Therefore, Abas K.(2011) concluded that Con-Aid is not appropriate stabilizer for laterite soil under investigation.

Bethlehem W.[8] investigated the effect of sugarcane bagasse ash on the geotechnical properties of A-7-6 class lateritic soil collected from Mekenajo, 456km west of Addis Ababa. The lateritic soil was stabilized with 2%, 4%, 6%, 8% and 16% of Sugarcane bagasse ash by weight of dry soil.Test specimens were subjected to atterberg limit, free swell, linear shrinkage, compaction and CBR tests. The analysis of results showed a slight decrease in the maximum dry density and soaked CBR values. The free swell also showed a slight decrement up to 4% of ash then showed an increase. A slight increase in plasticity index, shrinkage limit, optimum moisture content and unsoaked CBR values was also observed. Increase of curing period showed an insignificant effect on the CBR values of the stabilized soils. Generally, from the results it was concluded that sugarcane bagasse ash was not an effective stabilizer for the improvement of some of the geotechnical properties of the soil by its own.

Blen A.[7] studied the strength characteristics of a stabilized lateritic soil with marble dust. The sample of the residual lateritic soil used in the study is taken from Mekanejo area, western Ethiopia in the Oromia National Regional State. A-7-5 lateritic soil was treated at mixing ratio of 0%, 4%, 8%, 12%, 16% and 20% of marble dust by dry weight of the soil and curing the samples at 7 and 14 days for all tests. For 7 and 14 days curing at 20% marble dust content: The plasticity index was reduced from 22% to 16% and 22% to 15%, Unsoaked CBR considerably increased from 5.9% to 20.4 % and 5.9% to 22.1%; and Also the soaked CBR increased from 2.7% to 19.3% and 2.7% to 20.2% respectively. Unconfined compressive strength at 8% marble dust content significantly increased from 132.6kPa to 301.6kPa and from 132.6 kPa to 346.1 kPa at 7 and 14 days curing respectively. The maximum dry density with marble dust content slightly increased from 1.48 g/cm3 to 1.57 g/cm3 and 1.58 g/cm3 with 7 days and with 14 days curing respectively. Adding 20% marble dust is the optimum quantity in terms of improving plasticity index, maximum dry density and soaked and unsoaked CBR properties but for unconfined compressive value, the optimum marble dust content is 8%. Therefore, Blen A.[7] concluded that the addition of marble-dust to the lateritic soil has beneficial effects on its engineering properties.

Haftom H.[21] studied the use of laterite gravels as flexible pavement materials through mechanical and chemical stabilization by Crushed Stone Aggregate(CSA) and lime, respectively on the three samples collected from western part of Ethiopia, Gedo-Nekemt and Gedo-Fincha-Lemlem Berha road project routes in the National Regional State of Oromia. Mechanical stabilization was carried out at 20%, 40% and 60% CSA by volume of blended laterite and the chemical stabilization was investigated with addition of 4%, 8%, 12% and 16% lime by dry weight of blended laterite. The test results indicated that the laterite gravel fulfilled the CBR, Los Angeles Abrasion (LAA) and TFV(Ten Per cent Fines Value) requirement of ERA(Ethiopian Road Authority) when blended it with 40% and 60% Crushed Stone Aggregate for base course and 20% Crushed Stone Aggregate for subbase, regardless of having out values beyond the specification. The plasticity of laterite was reduced with the addition of lime as a result of increase in plastic limit and a slight decrease in liquid limit. The addition of lime has resulted in an increase in optimum moisture content and reduction of maximum dry density for the same compaction effort. The laterite stabilized with 12% lime fulfilled all of the requirements set for sub base materials. It was found out that the natural laterite gravel can be used for base course construction by stabilizing it with a combination of 40% Crushed Stone Aggregate+8% lime and 60% Crushed Stone Aggregate+8% lime for CB2 and CB1(Road note 31 base course strength requirements),respectively. Lowest PI values 4.3 and 5.1% were recorded at a combination of 40% CSA+12% lime and 60% CSA+8% lime, respectively. These mixtures are also satisfying both the strength and durability requirements for flexible pavement materials. The author concluded that CSA and lime as effective stabilizing agents for improvement of laterite gravel for use as flexible pavement materials.

Kedamawit G.[25] investigated the stabilization of laterites by using lime and cement so that it can be used for base course construction. The samples are collected from Assosa–Kurmuk road. The Atterberg limit tests showed that the liquid limit of the treated laterite material decreased, while the plastic limit increased which resulted in the decrease of the plasticity index with the increase of the stabilizers (both lime and cement) content. The treated laterite became slightly non-plastic with 8% (by weight) or more of lime content and 10% (by weight) or more of cement content. As can be observed from the test results, the use of lime to treat the laterite was more effective in reducing the plasticity index than cement. The maximum dry density and optimum moisture content of the treated laterite test results revealed that both the maximum dry density and optimum moisture content of the treated laterite increased with the increase in the lime and cement contents. Compared to the laterite-lime mixtures, the laterite-cement mixtures have slightly higher MDD and slightly lower OMC. The unconfined strength of the treated laterite specimens increased linearly with the increase of both lime and cement contents. As can be observed from the test results, the 7-days strength of the laterite-cement specimens are almost equivalent to the 28-days strength of the laterite-lime mixtures. Therefore, from this study, it was found out that it is possible to use laterite for road base construction by stabilizing it either with lime or cement. In both the lime and cement stabilization cases, the optimum binder content to meet the Joint US Army and Air Force (1994) strength and durability requirements is 10% by weight of the host material. However, the optimum binder contents to satisfy the requirements of Ethiopian Road Authority (ERA) Standard Technical Specification (2013) are 4% and 6% for both lime and cement stabilized laterites, both percent by weight of the host material.

Alemayehu L.[3] investigated the stabilization of expansive soil by using Potassium chloride. The sample was collected from Addis Ababa around Kality area. The proportion of potassium chloride was taken as 0%, 2.5%,5%,10%,15% and 20% . The natural soil was found to be A-7-5 according to AASHTO and CH according to USCS systems. Laboratory tests that were conducted on treated potassium chloride-soil mixtures was Atterberg limits, Free swell test, California Bearing Ratio(CBR), Unconfined compressive strength (UCS) ,Proctor test , Percent swell of CBR and Swell consolidation test. The swelling pressure, CBR-Swell, swell potential and optimum water content, The plasticity index decreased. The UCS value of treated soil for seven days of curing, the CBR value, the maximum dry density for 24hrs cured sample increased. Generally Potassium chloride can be an alternative expansive soil stabilizing chemical where sufficiently abundant and when economically feasible as compared to other methods of soil stabilization.

Bizualem T.[10] has done a research on expansive clay soil sample from Modjo-Ejere Road, with addition of molasses alone, cement alone, and combination of cement and molasses by varying content of stabilizers in steeped concentration of 0, 4, 8 and 12% each by dry weight of the soil, was used to treat the soil. Furthermore, the sample soil was treated with combination of cement and molasses by keeping 4% molasses constant and varying cement content to 4, 8 and 12% by dry weight of the soil .i.e. at 1:1, 2:1 and 3:1 cement to molasses ratio. PH test, compaction test, Atterberg's limit test, linear shrinkage test, California Bearing Ratio (CBR) test, Unconfined Compressive Strength (UCS) test and swelling test on both the native soil and stabilized soil were carried out. Sample soils with molasses application had a relatively higher strength, lower PI (plasticity index) and swelling potentials than those of the native soil. The addition of cement on the sample soil gave significant improvement in strength, eliminated swelling properties and were more effective in improving properties of the natural soil than molasses. However, shrinkage cracks were observed during shrinkage tests and stress-strain curve of the UCS test showed that the soil stabilized with cement had brittle nature. Molasses application on soil-cement mixture gave higher strength, lower PI and negligible swelling potential than those of cement stabilized or molasses stabilized soils; and eliminated shrinkage cracks and reduced brittleness nature of cement stabilized soils. Addition of 4% molasses to 4% cement increased CBR value of 1% of the native soil to 64%, reduced 53% PI value of the native soil to 19%, and reduced 10.4% CBR swell value of the native soil to negligible values. Soil treated with cement and molasses combination showed higher strength values when cement and molasses contents are equal (at 1:1 ratio).Therefore, Bizualem Taye concluded that the addition of sugarcane molasses and cement to expansive soil can adequately stabilize it. Furthermore, 4% sugar cane molasses and 4% cement was found to be optimum stabilizer content for sub-grade stabilization and meet all Ethiopian road Authority ERA (2013) specification requirement for stabilized.

Brook D.[11] determined the optimum amount of water required for lime stabilization of an expansive soil through laboratory experiments. The soil samples used for this research were obtained from eastern Addis Ababa, around Gelan condominium on the Addis Ababa outer ring road project. Lime is then added in proportions of 0%, 2%, 4%, and 6% to the soil sample. As the amount of lime added to the soil increases, the swelling pressure of expansive soil reduces; the UCS of the soil improves; Liquid limit decreases; Plastic limit increases; Plastic index decreases; OMC increases; MDD decreases. After a series of laboratory tests the optimum amount of lime that obtains desirable effect on engineering properties of the soil is determined to be 6%. The results of the research have shown that molding water content does not affect the swelling pressure once optimum amount of lime is added to expansive soil. However, unconfined compressive strength improves significantly on soil specimens prepared on the wet side of optimum moisture content of soil-lime mixture. The improvement in compressive strength on the wet side of optimum moisture content is found to be dependent on the curing time.

Gadise T.[18]determined potential use of molasses as expansive soil stabilizer and identified economical mixing proportion of the molasses with expansive soil. The study area is located in Nefasilk lafto Sub-city of Addis Ababa city commonly named as Jemo condominium. The necessary laboratory tests, index tests, strength testes, swelling tests are incorporated for the natural as well as the stabilized soil. Analyses of the results show that slight improvement on the geotechnical properties of Molasses stabilized soil. The optimum stabilizer content is 8% for UCS and CBR values. The minimum values or the decrease in swelling potentials and swelling pressures is obtained for soils mixtures prepared at 12% molasses by dry weight of the soil. The plasticity index is slightly reduced with increase in Molasses content but increased beyond 14% molasses. The optimum moisture content reduced and the maximum dry densities values increased with increment of molasses content. Curing has an insignificant effect on the geotechnical properties of molasses stabilized soil. He concluded that molasses stabilized soil does not meet the minimum requirement of Ethiopian Road Authority (ERA) pavement manual specification for use as a sub-grade material in road construction.

A research on The chemical treatment of Block Cotton soil to make it usable as a foundation material was done By Aksum T.[2]. For laboratory tests ten samples were taken from Addis Ababa Black –cotton soils and come up with a finding that the geotechnical property of these expansive soils have been improved from a very high expansive soil to a moderate expansive soils by the addition of 6% lime and 12% cement independently by dry weight of the native soil.

Habtamu S.[20] evaluated the performance of a locally manufactured hydrated lime and an imported industry product Anyway Natural Soil Stabilizer (ANSS) based on laboratory test results on expansive sub-grade soils collected from Gerji Area of Addis Ababa city Administration. The sub-grade soil was first characterized based on Atterberg limits, linear shrinkage, CBR and percent swell of CBR. The test results showed that the sub-grade soil is classified as A-7-5 in the AASHTO and MH in USCS systems. Two soil layers on colour variations were observed in the field: the upper dark gray clay soil and the lower light gray clay soil. The soil was mixed with ratios of 2%, 4%, 6% and 8% of hydrated lime and 2%, 4% and 6% of ANSS and the effects of the chemicals were then evaluated on the two soil samples. The improvement of the sub-grade soil samples increased with increasing both dosages as well as curing periods. In general terms, increasing the dosage has more significant effect than that of increasing the curing period and 4% of either chemical has resulted in adequate improvements of the subgrade soil. In almost all the cases the PI and swelling properties has decreased and the CBR has increased with respective increasing of the chemical dosages. In most cases the performance of hydrated lime is better than that of ANSS and the improvement of the dark gray clay soil is better than the light gray clay soil.

Ehitabezau N.[14] investigated the suitability of slightly alkaline liquid sodium silicate for stabilization of montmorillonitic clay and clayey sand with gravel collected from Addis Ababa's Bole Senior Secondary and Preparatory School; and Gergi-Bole Road section. The study was also investigated the effect of applying sodium silicate in combination with hydrated lime or ordinary Portland cement on the engineering properties of treated soils. Atterberg limit test, Proctor test and California Bearing Ratio tests were used to evaluate properties of treated soils. Montmorillonitic clay was treated using 2%, 4% and 6% lime, 1%, 2.5% and 6% liquid sodium silicate and the respective combinations of the additives by dry weight of the soil. Clayey sand with gravel was treated with 3%, 5% and 7% cement, 1%, 2.5% and 6% liquid sodium silicate and the respective combinations of the additives by dry weight of the soil. Sodium silicate reduced plasticity indexes of samples at least by 11.96% compared to untreated soils. Curing enhanced the reduction in plasticity of soils treated with sodium silicate. It was observed that lime reduced the plasticity index of treated soils; however, carbonation reversed improvements. Atterberg limit samples treated with cement resulted in nonplastic soil. Blending clayey sand with sodium silicate or its respective combination with cement proportionally decreased the dry density of the soil. Sodium silicate or its respective combination with lime gave decreased strength values and increased swelling properties compared to the respective lime treatments. Mixing clayey sand with cement gave significant strength values. Applying 1% sodium silicate in concert with cement gave shear strength values larger than the respective cement treatments. When the quantity of sodium silicate was increased to 2.5% and beyond it hindered strength development. Curing enhanced strength development and reduced swelling properties for all treated soils. From the test results it was concluded that Sodium silicate is not a suitable stabilizer for montmorillonitic clay (expansive soils), but it relatively gives encouraging results on course grained materials and Mixing sodium silicate with lime is not a viable option for montmorillonitic clay (expansive soil) stabilization.

Hiwot S.[23] assessed the effect of natural and crushed sand addition to the stabilization of expansive soil. The expansive soil was collected from Nifas Silk- lafto Subcity in a locality known as Jemmo. The test results revealed that there is a significant improvement on soil consistency. The classification of the mixed soil is altered from CH to MH group for both types of sand blended. Additionally, the swelling potential and swelling pressure reduced considerably. For higher proportion of mixture a considerable improvement was attained in the value of unconfined compressive strength. Nevertheless, there is no marked progress achieved in the soaked CBR value. Finally, after making cost comparison for both types sands, 40% sand by weight of soil has showed a cost reduction when compared to total soil replacement.

A laboratory study on the stabilization of expansive soils by using hydrated lime of percent varying from 2 to 12 percent (by dry weight of the soil) was performed by Reshid M.[30]. The study area was located at the south western part of the country named Gambella regional state (Adura-Burbey DS6 Road Segment). The conducted tests are Atterberg limits, Shrinkage limits, Linear shrinkage, Specific gravity, Free swell, Moisture density relationships, California bearing ratio (Soaked CBR) CBR Swell and Unconfined Compressive strength(immediate and 7 days cured). The liquid limit has decreased, with the increase of plastic limit. As a result of this the plasticity index of the stabilized soil has improved to the required level. The shrinkage limit, specific gravity, CBR, optimum moisture content and Unconfined compressive strength of the stabilized sample have increased with the addition of lime. Free swell, maximum dry density and Swelling percentage (CBR Swell) decreased with increasing stabilizer percentage. The lime content of which the CBR values improved for the use of improved subgrade is found out to be 12% by dry weight of the soil.

The performance of marble dust to improve the problematic nature of expansive soils, which is characterized as A-7-5 according to the AASHTO classification, was investigated by Tagel M.[33]. The study area is located in central Ethiopia. The road project starts at Sembo town which is 93 km from Addis Ababa and terminates at Gindeber town of northern Shewa zone. The expansive subgrade soil is blended with increasing percentage by weight (5% to 30) of marble dust. The test results indicates With the higher percentage of marble dust (30%), the swelling potential of the natural soil changed from 'High'to 'Medium', LL reduced from 88% to 63%, PI reduced from 52% to 34%, CBR increased from 0.9% to 2.25% and the CBR swell reduced from 8.6% to 5.3%. Un-soaked CBR test is conducted on the natural subgrade soil and the 30% marble dust blended sample and it has been noted that the subgrade class improves for both indicating significant reduction in project cost as result of reduction in pavement thickness.

Cost-Benefit Analysis of Replacing versus Stabilizing Expansive Soils in Road Construction (Case study for Gambella-Alwero-Rice-Project) were done by Yitagess K.[37]. Replacing material within 2km radius was found satisfying all tests and lime was selected as stabilizing agent. With those selected materials and stabilizing agent, cost-benefit analysis was carried out. Total Cost of Replacing the existing expansive soil with locally available suitable material was found to be 2,862,247.71 (Birr/Km) and total cost of stabilizing the existing expansive soil with Lime from Derba Cement Factory was found to be 1,974,821.28 (Birr/Km) amounting to a saving cost of 32%. From the study, the result of stabilizing the existing expansive soil as compared to replacing with non-expansive soil from the nearby forest has become economical.

Helen H.[22] analyzed the effect of stabilizer ANSS (Anyway Natural Soil Stabilizer) which is categorized as unconventional chemical stabilizers on engineering properties of expansive soils in Addis Ababa City roads. The native soil were combined with different dosages of the stabilizer 2%, 4%, 6% and 8% to find out the optimum dosage of stabilizer. From the laboratory test results it is confirmed that 6% is an optimum dosage of stabilizer for the typical expansive soil in the study area. As it has been observed from the analysis, treated expansive soil with 6% of the chemical stabilizer improves the bearing capacity and Plasticity of the soil to a required level and it saves around 30% of the cost and 42% of the time of road construction in a the city which is constructed in a conventional way, however the performance duration of the stabilizer shall be studied further in the future, as the road which have been done with same technology shall be evaluated after some service years.

Yohannes A.[35] undertaken a study on a light grey (expansive) and a red clay soil from Addis Ababa treated with SA-44/LS-40 chemical alone, lime alone and combinations of both at different application rates. It was observed that the application of lime alone and SA-44/LS-40 chemical with lime shows improvements of varying degree on the engineering properties of both the light grey and the red clay soils. However, no specific mix ratio showed the maximum improvement in all the engineering properties of each soil. The applications of SA-44/LS-40 chemical alone results in promising reduction in the swelling pressure of the light grey clay soil however, it is ineffective in improving the soaked CBR value of this soil. In addition the applications of lime alone results in an increase in the soaked CBR value and reduction in the swelling pressure of the light grey clay soil. Furthermore the applications of the chemical with lime results in even more increase in the soaked CBR value and reduction in the swelling pressure of the light grey clay soil. Thus, the application of the chemical with lime is more suitable for the light grey clay soil. In particular the application of 0.30lit/m3 of SA-44/LS-40 chemical and 2% lime is an optimum proportion in increasing the soaked CBR value and reducing the swelling pressure of the light grey clay soil. Thus, the application of the chemical with lime is more suitable for the red clay soil. In particular the application of 0.08lit/m3 of SA-44/LS-40 chemical and 4% lime is an optimum proportion in increasing the soaked CBR value of the red clay soil. This application changes the sub grade strength class of the red clay soil from S3 to S5 as per the pavement design manual of Ethiopian Roads Authority. This change in subgrade strength class causes reduction in pavement thickness on the red clay subgrade soil.

Danel N.[13] evaluated lime and liquid stabilizer called Con-Aid for stabilization of potentially expansive sub grade soil on samples collected form Addis-Jimma road which had indicated different pavement damages aggravated by the presence of expansive soils. He pointed out that addition of lime reduces the swelling potential but no significant improvement in the engineering properties of the soil was attained by addition of ConAid.

Sertse T.[31]evaluated soil stabilization For Road Works on Highly Expansive soils of Ethiopia. Soil samples collected form Robe –Seru Road project was blended with clay, volcanic cinder and mixed with lime and cement at different proportions. The effects of each mix was investigated in laboratory by performing Consistency, swell and strength tests. Consistency limiting values of the highly expansive soils were decreased by the addition of red clay soil and cinder material. Addition of red clay soil and cinder increased the CBR value but not to satisfactory level. The UCS values decreased with the addition of blending soil.

Nitshit T.[29] has conducted the major laboratory tests on natural expansive soil and treated samples with different percentage (5%, 10% and 15%) of Rice Husk Ash (RHA). Atterberg limits, free swell, compaction, UCS and CBR results shows slight improvement in the geotechnical properties of the expansive soil stabilized with RHA. UCS and unsoaked CBR values increased appreciably with increase in RHA content and curing has significant effect on the RHA stabilized expansive soil.

Bagasse ash as a sub-grade soil stabilizing material was assessed by Meron W.[27]. The stabilizer (5%, 10%, 15%, 20%, 25% and 30%) by dry weight of the soil was used. lime was supplementary added to the (5%,15%,30%) bagasse ash stabilized extra soil samples. All the stabilized soil samples were also cured for 7-days for Atterberg limits, compaction and CBR tests. Analysis of the results shows that Slight improvement on the geotechnical properties of bagasse ash. Baggasse ash reduces plasticity index, swelling and MDD with an increase in OMC and CBR with all higher bagasse ash contents. Curing has an insignificant effect on the geotechnical properties of bagasse ash stabilized soil. From this study it was found out that bagasse ash stabilized soil do not meet the minimum requirement of ERA pavement manual specification for use as a sub-grade material in road construction. In addition the effect of applying 3% lime as an activator in combination with 15% bagasse on the geotechnical properties of the soil for uncured and cured soil samples investigated. The results indicate that lime in combination with bagasse ash is suitable for improving the plasticity index, swelling and CBR. The strength values (CBR) also increased with curing ages, thus indicating that the blend has a potential for time-dependent increase in strength that will reduce the quantity of stabilizer needed for the construction of roads over the expansive soil. Therefore, this study shows that lime in combination with/plus bagasse ash can be effectively used to improve expansive soils with low soaked CBR value and high plasticity.

Tesfahun A.[34] investigated the effect of PURE CRETE and Anyway Natural Soil Stabilizer (ANSS) on the engineering properties of soils that are deemed to be marginal for road subbase and subgrade. The stabilizers were combined with a total of five different soils with classifications according to AASHTO as A-7-5, A-7-6, A-2-7, A-2-4, and A-2-6. Laboratory investigations using the powder product, ANSS, on five soil types has shown substantial effect on the engineering properties. The effect of curing after treatment with ANSS stabilizer on test samples has been clearly observed. Clayey sand treated with 6% ANSS and cured for seven days has shown 56% improvement in plasticity index over uncured sample that received the same proportion of treatment. Similarly, the CBR for red brown clay has shown 100% increment when compared to uncured specimens after applying the same percentage of ANSS. Its effect is more pronounced in the case of light grey clay soil where up to 1201% increment in CBR was observed. In the study conducted using the enzyme product, PURE CRETE, samples from four soil types were mixed with the stabilizer at supplier's recommended application rate and randomly selected very high application rates. Atterberg limits, compacted unit weight, California Bearing Ratio, and free swell potential were measured and compared for untreated and treated soils. Overall, no marked changes in these engineering properties were observed following enzyme treatment in these tests. Although individual cases can be identified in which the stabilizer appeared to improve a property of a particular soil, no consistent trend was observed. Higher application rates, in excess of the supplier recommendations, are not also able to produce more significant, beneficial effects. He concluded that ANSS stabilization induced the most improvement on engineering properties of all soils tested at manufacturer recommended dosages and PURE CRETE failed to show any improvement at manufacturer recommended application rate.

Eskedil A. [17] investigated the stabilization the natural sand, found underneath the black clay soil, with bitumen and cement so that it can be used for road base construction. The study area is found in western Ethiopia, Gambella regional state (Adura – Burbey road). Additives like, sulfur and cement were added to the sand-bitumen mixture to increase the Marshall stability of the mix. The sand-bitumen mixtures were designed according to Marshall method of mix design and the respective properties were assessed based on the Marshall mix design criteria. The sand-cement mixtures were, on the other hand, designed according to the Joint US Army and Air Force methods and the mixture quality was evaluated based on the specifications, developed by the same agencies. It was found out that the natural sand underneath the black clay soil can be used for road base construction by stabilizing it either with bitumen or ordinary portland cement. In bitumen stabilization 15-20 percent sulfur has to be added so that the mix gain sufficient stability. The sand stabilized with 10% ordinary portland cement fulfilled all of the requirements set for base course materials. Economically, cement treated natural sand is the most feasible alternative as compared to the crushed stone base course and bituminous (sand-sulfur-bitumen) base course.

Yitayou E. [36] investigated the performance of mechanically stabilized natural cinder gravels to be used as road sub-base material. To achieve the Ethiopia Road Authority manual specification, the cinder gravel was blended with some trail proportion of 0, 5, 10, 15, 20, and 25% of fine-grained soil by mass and different tests including grain size distribution, Atterberg Limit, compaction, CBR, LAA, absorption and linear Shrinkage are conducted in the laboratory. Based on the laboratory test results it is shown that, from both MDD- percent of fine-grained soil curve and CBR-percent of fine-grained soil curve, the optimum amount of fine-grained soil required in order to improve its properties is 19 % by mass proportion.

3. Conclusion

The paper generally reviewed studies carried out on the stabilization of soil found in Ethiopia. From the review of literatures the following conclusions are drawn:

- Stabilization of lateritic soil with marble-dust, crushed stone aggregate, lime, crushed stone aggregate-lime mix, cement improves some of the geotechnical properties.
- Stabilization of expansive soil with potassium chloride, sugarcane molasses- cement mix, lime, cement, molasses, Anyway Natural Soil Stabilizer (ANSS), natural and crushed sand, bagasse ash-lime mix, marble dust and Rice Husk Ash improves some of the geotechnical properties.
- Majority of the researchers discussed the stabilization of soil for us as base, subbase and subgrade construction material. However the studies regarding other areas are negligible in literatures.
- The effect of stabilization on consolidation properties, permeability and shear strength of soils have not been studied by most of the researchers.
- Investigation on durability and economic aspect of stabilization are limited in literatures
- The above issues should be taken into consideration for the future researches on the stabilization of soils in Ethiopia

References

1. Agapitus A. (2010). Evaluation of changes in index properties of lateritic soil stabilized with fly ash. Leonardo Electronic Journal of Practices and Technologies, Issue 17, 69-78
2. Aksum Tesfaye, 2001, chemical treatment of “Black Cotton” soil to make it usable as a foundation material, M.Sc. Thesis, Addis Ababa University, Technology Faculty, Addis Ababa, Ethiopia
3. Alemayehu L.,2015, STABILIZATION OF EXPANSIVE CLAY SOILS USING POTASSIUM CHLORIDE.’’ Master’s Thesis, Addis Ababa University, Addis Ababa.
4. Alemayehu M., 2003, Country Pasture/ Forage Resource Profiles, Addis Ababa, Ethiopia
5. Alhassan, M. and Mustapha, A. M.,2015, “Improvement of Deficient Soils in Nigeria Using Bagasse Ash - A Review”, Proceeding of 17th International Conference on Civil and Building Engineering, Dubai, pp. 1040-1049.,
6. Alhassan, M. and Mustapha, A. M.(2017). Utilisation of rice husk ash for improvement of deficient soils in nigeria: a review. Nigerian Journal of Technology (NIJOTECH), Vol. 36, No. 2, pp. 386 – 394
7. Blen A. 2016, Investigating the strength characteristics of laterittic soil blended with marble dust Master’s Thesis, Addis Ababa University, Addis Ababa, Ethiopia
8. Bethlehem W. ,2015, Stabilization of Lateritic Soil with Sugarcane Bagasse Ash’’ Master’s Thesis, Addis Ababa University, Addis Ababa, Ethiopia.
9. Beniam Alemu, 2010, Engineering Geoloical Characterization of Granular Sub base Using Lime-aCase Study of Ambo-Gedo Road Project, M.Sc. Thesis, Addis Ababa University, Science Faculty, Addis Ababa, Ethiopia
10. Bizualem T., 2015, Stabilization of expansive clay soil with sugar cane molasses and cement, MSc thesis,

Addis Ababa University, Ethiopia.
11. Brook D.,2015, Influence of molding water content on the engineering properties of lime stabilized expansive soil. Master's Thesis, Addis Ababa University, Addis Ababa, Ethiopia.
12. CIRIA, 1995. Laterite in road pavements. Westminster, London. Special publication 47 for TRANSPORT RESEARCH LABORATORY (TRL)
13. Daniel Nebro, 2002, Stabilization of Potentially Expansive Sub-grade Soil using Lime and Con-aid,,M.Sc. Thesis, Addis Ababa University, Technology Faculty, Addis Ababa, Ethiopia.
14. Ehitabezahu, N. ,2011, Evaluation of Sodium silicate and its combinatiion with cement/lime. Msc. thesis , Addis Ababa University, Ethiopia.
15. ERA, Design Manual, 2001 & 2002. Addis Ababa, Ethiopia.
16. Eshete, Y., 2011, Blending of Cinder with Fine-Grained Soil to be Used as Sub-Bas Materials: the case of Butajira-Gubre Road , MSc thesis, Addis Ababa University, Ethiopia.
17. Eskedil A. ,2014, stabilization of natural sand with cement, and bitumen and sulfur for base course. Master's Thesis, Addis Ababa University, Addis Ababa
18. Gadise T. ,2016, Expansive soil stabilization by sugarecane molasses. Master's Thesis, Addis Ababa University, Addis Ababa, Ethiopia
19. Habiba Afrin. (2017).A Review on Different Types Soil Stabilization Techniques. International Journal of Transportation Engineering and Technology. Vol. 3, No. 2, , pp. 19-24. doi: 10.11648/j.ijtet.20170302.12
20. Habtamu S.,2011, Chemical Stabilization of Expansive Sub-grade Soil Performance Evaluation on Selected Road Section in Northeastern Addis Ababa, Master's Thesis, Addis Ababa University, Addis Ababa, Ethiopia.
21. Haftom H. ,2015, Mechanical and chemical stabilization of laterite gravel with crushed stone aggregate and lime for use as flexible pavement material. Master's Thesis, Addis Ababa University, Addis Ababa., Ethiopia
22. Helen H. ,2016, Cost and Time Effect of Using Sub Grade ANSS Chemical Stabilizer in Road Construction (A Case Study of Addis Ababa City, Road Construction on Expansive Soil). Master's Thesis, Addis Ababa University, Addis Ababa, Ethiopia.
23. Hiwot S.,2016, An alternative for stabilization of addis ababa expansive soil by crushed and natural sand. Master's Thesis, Addis Ababa University, Addis Ababa, Ethiopia
24. John D.Nelson and Debora J.Miller, Wiley. (1992). Expansive soil problems and Practice in Foundation and Pavement Engineering., New York,
25. Kedamawit G. ,2017, stabilization of laterite for base course construction, Master's Thesis, Addis Ababa University, Addis Ababa, Ethiopia.
26. Kedir, A. ,2011, Investigation on improving the geotechnical properties of lateritic soil by blending with chemical stabilizer: the case of Gidole, South Ethiopia. Master's thesis, Addis Ababa University, Addis Ababa, Ethiopia.
27. Meron, W. ,2013, Bagasse ash as a Sub-grade Soil Stabilizing Material. Msc Thesis,Addis Ababa University, Addis Ababa, Ethiopia.
28. Ministry of Works and Urban Development, 1995, Code of Standards for Seismic Loads, EBCS-8, Addis Ababa, Ethiopia.
29. Nitshit Tedla ,2016, Stabilization of expansive soils using Rice Husk Ash (RHA), MSc. Thesis, Addis Ababa University, Ethiopia
30. Reshid, M. ,2014,. Stabilization of expansive soils with lime (A Case Study on the Adura-Burbey DS6 Road Segment). Msc Thesis. Addis Ababa University, Addis Ababa, Ethiopia.
31. Sertse Tadesse, 2003, Corporation Waste Treatment Manual Soil Stabilization for Road Works on Highly Expansive Soil of Ethiopia. MSc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia.
32. Srivastava KL, Mesfin Abebe, Abiye Astatke, Mitiku Haile and Hailu Regassa,Improved management of vertisols for sustainable crop-livestock production, FAO Corporate Document Repository, http://www.fao.org/Wairdocs/ILRI/x5456E/x5456e04.htm,accessed on December 14, 2010.
33. Tagel M. ,2016, Application of Marble Dust to Improve the Engineering Properties of Expansive Soils to be used as Subgrade Material. Master's Thesis, Addis Ababa University, Addis Ababa, Ethiopia.
34. Tesfahun, A. (2010). Performance of unconvensional Soil stabilizer. Msc thesis, Addis Ababa University, Addis Ababa, Ethiopia.
35. Yohannes, A. ,2008, Stabilization of Light Gray and Red Clay Subgrade Using SA-44/LS-40 Chemical and Lime. Msc Thesis, Addis Ababa University, Addis Ababa, Ethiopia
36. Yitayou E.,2011, Blending of cinder with fine-grained soil to be used as sub-base materials (The Case of Butajira-Gubre Road). Msc Thesis. Addis Ababa University, Addis Ababa, Ethiopia
37. Yitagess K.,2013, Cost-Benefit Analysis of Replacing versus Stabilizing Expansive Soils in Road Construction (Case study for Gambella-Alwero-Rice-Project). Master's Thesis, Addis Ababa University,

Addis Ababa.

38. Zelalem, A.,2005, Basic Engineering Properties of Lateritic Soils found in Nejo-Mendi Road Construction Area, Wolega. Master’s Thesis, Addis Ababa University, Addis Ababa, Ethiopia.