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Laboratory Investigation on Improving Strength of Weak Subgrade Soil using Saw Dust Ash with Stone Dust

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Abstract— **Performance of Flexible Pavement depends on the functions of the component layers especially subgrade. Subgrade is natural layer of soil which takes all load of pavement as well as load coming to pavement. Stability of pavement depends upon stability of subgrade. The conventional approach of stabilization of soft subgrade is to remove the soft soil, and replace it with soil of high strength. The high cost of replacement of weak soil has caused highway agencies to assess alternative methods to construct the highway over weak subgrade. Soil stabilization is one of the most suitable alternatives which are widely used in pavement construction. Soil stabilization can be achieved by treating it with various admixtures. Different solid wastes such as rice husk ash, saw dust ash and fly ash can be used to stabilize soils in place of (or in addition to) cement or lime. In this research Saw Dust Ash (SDA) and Stone Dust (SD) has been selected as a stabilizer. The California bearing ratio (CBR) and unconfined compression strength (UCS) test is conducted by making the specimens of weak sub-grade by adding the variable percentages of mixture of SDA and stone dust. First the soil is mixed up with SDA up to 8% by weight with an increment of 2%. Then an optimum value at 4% of SDA was determined on the basis of some geotechnical properties of mixture and weak sub-grade soil. Again, the test soil samples were prepared by mixing with varying proportion of stone dust from 10% to 30% at 4% optimum value of SDA constantly. The CBR, UCS and maximum dry density values were determined of modified soil. The soaked CBR and UCS value of weak subgrade soil increased 2.1 and 2.16 times respectively after modified by 20% stone dust with constant 4% SDA and total pavement thickness decreased to 775 mm. The minimum pavement construction cost per square meter with combination of 4% SDA and 20% SD which is economical by 1.73% than conventional method. Hence, strengthening by SDA and SD is found economical.**

I. INTRODUCTION

Construction of pavements on weak subgrade is unavoidable due to several constraints. The existing subgrade materials do not always comply these requirements set forth and may require improvements to their engineering properties in order to transform these inexpensive earth materials into effective construction material which may accomplished either by stabilization or modification of these weak soils. The stabilization of subgrade soils can be accomplished into two main categories- mechanical stabilization and chemical stabilization [1]. Among the different variant within the domain of stabilization, SDA and SD can be considered as best stabilizers as are economical, obtainable and thus sustainable viable option. The chemical composition of SDA proves that it has sufficient amount of silica and alumina due to which SDA becomes pozzolanic and can be used as a supplemental cementitious material in weak soil applications [2]. The amount of sawdust generated every year constitutes up to 10-13% of the total volume of wood log [2]. The amount of sawdust generated is 7974.5 kg and bark and edge is 25424 kg from 99756.8 kg of log in six weeks from one saw mill in Nepal [3]. SD is formed as by-product in process of crushing, screening and stock piling during crushing operation. It is a waste product and leads to pollution and problem of stock piling in crushing plant [4]. Quarry dust exhibits higher shear strength, which is highly beneficial for its use as a geotechnical material [5].

[6] presented the results of an experimental study on soft soil with sawdust ash (SDA) additive using different percentages (0, 2, 4, 6, 8 and 10% by dry weight of soil). The mixture of sawdust ashes with soft clay soils improves most other physical and mechanical properties of the soil, as expressed by a general reduction in specific gravity and maximum dry density (MDD), as well as a reduction in the compression coefficients (Cc and Cr) with an increase in SDA content. While increasing the optimum moisture content (OMC) and the undrained shear strength (cu) with the increase in SDA content. [7] presented the results of an experimental study on the characteristic of clayey soil and to control swelling of expansive soil below the pavement layers. In this study, a series of California bearing ratio (CBR) tests in soaked and unsoaked condition and UCS tests were carried with specimen prepared with virgin clayey soil as well as clayey soil mixed with SDA in different proportions (i.e. 0%, 4%, 8% & 12% of dry weight soil). The result shows that the addition of SDA results a significant increase in CBR and unconfined compressive strength. Specimens prepared from lateritic samples were tested for its gradation (sieve analysis), unconfined compressive strength (UCS) and compaction parameters (MDD and OMC). The samples were admixed with varying percentages of SDA (i.e. 0%, 4%, 8% & 12% of dry weight soil) and the tests were repeated on the admixed samples. UCS values also peaked to 237.12 kN/m^2 at 4% SDA content while the compaction parameters were still best [8]. This study investigates the geotechnical performance of soil stabilized with the blend of cement and SDA. The blend consists of 9% cement by weight and up to 10% of SDA at interval of 2%. The results of this investigation showed that improvement of soil for construction purpose can be achieved when SDA is applied as a stabilizer in a cement stabilized soil, up to 6% by weight of cement [9]. [10] performed research on subgrade soil stabilization using stone quarry dust. They concluded the MDD decreases, OMC and CBR value increases as stone dust increased from 0% to 30%. On further addition of SD the CBR value decreased. A comprehensive research about the potential usage of CKD on four type indigenous eastern Saudi soils with low plasticity, cohesion less marl and plastic marl was conducted. The test on 256 specimens suggests that for sandy soils chemical stabilization was manifested due to binding characteristics of CKD whereas for clayey soils direct cementation and promotion of cation exchange was the main reason for stabilization [11]. With the addition of 20% of CKD with curing for 14 days, increase in CBR value from 3.4% for untreated soil to 48% for treated soil; also, reduces the swelling ratio and subsequently reduces the cost of pavements by $25.875 per square meter [12]. The black cotton soil was treated with up to 10% CKD was evaluated for use as a construction material for flexible material. The index properties of the soil get improved with CKD treatment. The cation exchange reaction that caused the flocculation of clay particles and thus ultimately decreases OMC with increase in CKD [13]. A research conducted on soil stabilization with the addition of CKD in varying portion from 0% to 30% by dry weight of soil reflects that CBR values increases with increasing proportion of CKD [14]. CBR values gradually increased with increase in percentage of quarry dust. The improvement in CBR values can be manifested as significant improvement in angle of shearing resistance. Higher CBR values of soil-quarry dust mixes enhance their use as stabilizers for subgrade. A study have been performed on the effect on geo-technical parameter of fine-grained soil with the addition of stone dust. Weak subgrade sample was collected and modification of soil was carried out by addition of QSD in the range of 0 to 50% with the increment of 10%. When stone dust is added, cation exchange takes place on clay surface. This results in shrinkage of diffuse double layer reducing the Plasticity Index. The rearrangement of soil particles and addition of non-plastic material increase the MDD of soil which ultimately improves the bearing capacity of the soil. The cohesiveness of soil decreases and angle of internal friction increases with addition of QSD. The stress-strain plot for different percentage of QSD shows that with increase in percentage of QSD the mode of failure shifts from ductile to brittle. The increase in value of UCS could be due to cation exchange, flocculation and pozzolanic reaction [4].

The CBR check is conducted by making the specimens of weak sub-grade by adding the variable percentages of mixture of lime and stone dust. First the soil mixed up with lime to 12% by weight with an increment of 3% again the soil was mixed with stone dust with increment of 10% up to 50% by weight of soil. Then an optimum value 3% of lime was determined on the basis of some geotechnical properties of mixture and cost of lime and weak sub-grade. Then Stone Dust was mixed up to 40 % by weight with an increment of 10% in the optimized mixture of lime-Weak sub-grade. CBR and maximum dry density values were determined of these modified mixes. The CBR is increased to 15% and total pavement thickness decrease to 725 mm for 50% stone dust addition with 4.89 % in cost reduction [15].

Different scholars conducted the comprehensive research regarding the uses of different stabilizers either in combination or alone in different kind of soil type following different experimental methods for soil stabilization [4], [16], [14], [17], [18], [19], [20], [5], [21]. However the use of SDA and SD in combination remains unexplored.

The general objective of this study is to perform a laboratory investigation on improving strength of weak subgrade soil using SDA and SD.

II. MATERIALS AND METHODS

To achieve the objective of the study, the soil samples were extracted from Mulpani-Besi Gaun road section of Bhaktapur District as this section possess low CBR value [22]. Soil sample was collected in conformance to Standard Specification for Road and Bridge Works published by DOR. The saw dust was collected from local saw mill in Bhaktapur area and was dried for proper burning. The dried saw dust was burnt under uncontrolled condition and cooled after completion of burning then sieved through a sieve of 19mm IS sieve. Then, it was stored in an air tight container to prevent moisture loss and any form of contaminations. The physical properties of SDA was analyzed for the study. Stone Dust was procured from stone crusher plant of Bhaktapur area. The physical properties of stone dust was analyzed on laboratory for the study. Tab 1 shows the tests that are carried out on the soil sample.

TABLE I. TEST ON SOIL SAMPLES

SN	Name of Test	Test Procedure
1	Sieve Analysis	IS 2720 (Part 4)
2	Specific Gravity	IS 2720 (Part 3)
3	Liquid Limit	IS 2720 (Part 5)
4	Plastic Limit	IS 2720 (Part 5)
5	Standard Proctor Compaction	IS 2720 (Part 8)
6	California Bearing Ratio	IS 2720 (Part 16)

7	Unconfined Compressive Strength Test	IS 2720 (Part 10)

Laboratory tests were conducted on selected virgin soil, soil mixed with SDA until optimum percentage was obtained then varying percentages of SD were mixed with optimum SDA and subgrade soil. The modified Proctor tests was also performed on soil samples alone as well as their mixes with an increasing percentage of SDA by weight (2, 4, 6 and 8 percentage) of soil, SD with (10, 20 and 30 percentage). All together fifty-four samples are prepared to study about the variation in CBR and UCS values.

III. RESULTS AND DISCUSSIONS

Soil was classified as per the Unified Soil Classification System Plasticity Chart of SSRBW. Soil had the liquid limit greater than 50% and lying below A - line with plasticity index 31.45%. Hence, soil sample was classified as (MH) High plasticity clay. The sub grading for MH type soil is permissible only if CBR is greater than 5% otherwise stabilization has to be carried out [23]. Sieve analysis was carried out to identify whether the soil is fine-grained or coarse-grained soil. The result of sieve analysis of soil represented in Tab 2 shows that as more than 50% of soil is passing through a 75 micron sieve, soil is classified as fine-grained soil.

Stone Dust was procured from stone crusher plant of Bhaktapur area. The physical properties of stone dust was analyzed on laboratory for the study. Tab 2 illustrates the physical properties of stone dust used for the study.

TABLE II. PHYSICAL PROPERTIES OF STONE DUST

S.N.	Description of Property	Value
1	Specific Gravity	2.58
2	Colour	Grey

The test on the physical properties of SDA is shown in Tab 3.

TABLE III. PHYSICAL PROPERTIES OF SDA

S.N	Properties	Value
1	Specific gravity	2.07
2	MDD (gm/cm^3)	1.65
3	OMC (%)	9.3
4	Colour	Grey

In order to determine the optimal percentage of SDA for weak subgrade soil various laboratory test were performed with varying percentages (2%, 4%, 6%, and 8%) of SDA. The liquid limit of soil decreases gradually with increase in SDA content at 2% to 6 % from 65.32 to 40.05 then increases to 53.43 at 8% SDA. The PL of soil decreases gradually with increase in SDA content at 2% to 6 % from 33.87 to 19.94 then increases to 24.88 at 8% SDA. PI of soil decreases gradually with increase in SDA content at 2% to 6 % from 31.45 to 20.11 then increases to 28.55 at 8% SDA. The plasticity indices of samples decreased from 31.45 to 20.11 at 6 % SDA addition may be considered as indication of soil improvement. This can happen as a result of the addition of SDA, which has less affinity for water and yields a decrease limit of liquid [24]. In order to determine the optimum percentage of SDA, subgrade soil was mixed with 2%, 4%, 6% and 8% SDA and the test results are shown in Tab 4.

TABLE IV. TEST RESULTS OF SUBGRADE SOIL MODIFIED WITH SDA

S.N	Soil Sample	MDD (gm/cc)	OMC (%)	CBR (%)	UCS (Kg/cm^2)
1	Subgrade Soil	1.837	11.5	3.94	0.91
2	Subgrade Soil + 2% SDA	1.881	11.5	4.18	0.99
3	Subgrade Soil + 4% SDA	1.93	10	5.69	1.54
4	Subgrade Soil + 6% SDA	1.9	10	5.25	1.36
5	Subgrade Soil + 8% SDA	1.822	10.5	4.81	1.18

The MDD and OMC for weak subgrade soil were found to be 1.837gm/cc and 11.5% respectively. After addition of SDA in weak subgrade soil, the MDD value increased from 1.837 gm/cc to 1.93 gm/cc up to 4% addition of SDA and decreased on addition of 6% & 8% SDA. The increase in its compaction behaviour is due to the addition of ash which compacts the soil grains by filling in the space between the soils particles. The empty voids that exist between the soil particles contact area are now occupied by fine ash particles. They tend to block the easy flow of water as well as permit the denseness of soil [25]. The decreases in MDD with increase in SDA content may be due to the lower specific gravity of the SDA [6]. Whereas OMC values decreased up to addition of 4% SDA and further increased on addition of 6% & 8% SDA found to be 11.5%, 10%, 10%, and 10.5% respectively. An increase in the optimum moisture content may be as a result of water needed to be hydrated and compaction of soil–ash mixtures [6]. The weak soil without modification was tested for soaked CBR test and the CBR value was found to be 3.94 %. The weak soil was modified with SDA by addition of 2%, 4%, CBR value increases from 4.81% to 5.69% and further increased on SDA, the CBR Value decreased to 4.81% is shown in figure 4.6. The

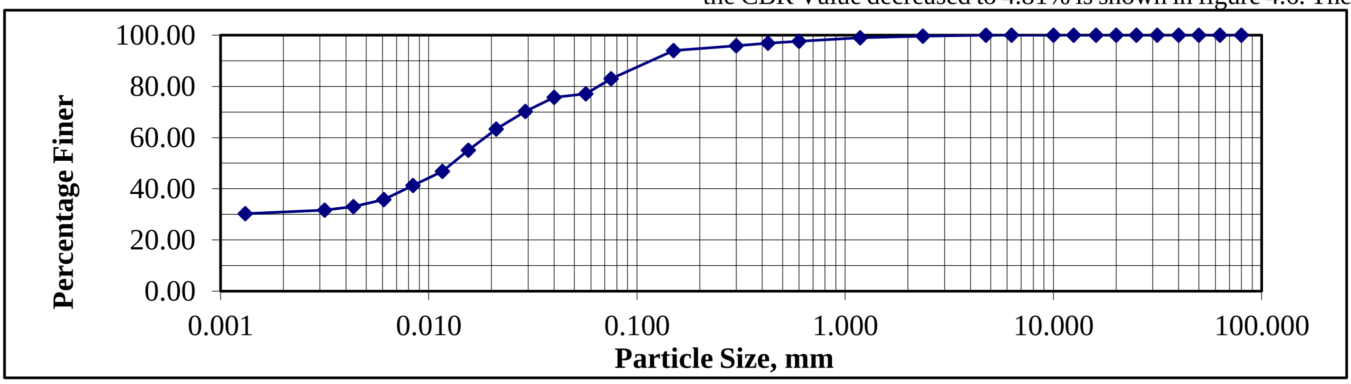

Fig. 1. Sieve Analysis of Subgrade Soil

increase in the CBR may be due to the pozzolanic effect of SDA. The observed decrease after 6% replacement could be due to consumption of pore water that is needed to sustain the hydration process [24]. The UCS test of weak subgrade soil with addition of varying percentage of SDA (2%, 4%, 6%, & 8%) which shows that there is increment in UCS value from 0.91 Kg/cm^2 to 1.36 Kg/cm^2 on addition of SDA up to 4% on further increase in percentage of SDA, UCS value reduced from 1.18 Kg/cm^2 on addition of 8 % SDA. The increase in strength may be due to the pozzolanic reactions of SDA to form the cementous products between the CaOH pre-sent in the soil and the pozzolana present in SDA. The decrease in strength is due to the low strength of the SDA which consequently occupies within the sample [6]. On the basis of laboratory investigation 4% SDA was considered as an optimum dose and further tests were conducted by adding SD.

The compaction test, CBR and UCS test was carried out as per IS 2720 part 8 for subgrade soil by adding 10%, 20% & 30% SD with 4% of SDA and the test results are shown in Tab 5.

TABLE V. TEST RESULT OF SUBGRADE SOIL MODIFIED WITH 4% SDA AND SD

S.N	Soil Sample	MDD (gm/cc)	OMC (%)	CBR (%)	UCS (Kg/cm^2)
1	Subgrade soil + 4% SDA + 10 % SD	1.883	10.75	7.00	1.81
2	Subgrade soil + 4% SDA + 20 % SD	1.920	10.50	8.31	1.97
3	Subgrade soil + 4% SDA + 30% SD	1.950	10.00	7.44	1.71

Addition varying percentages of SD from 10% to 30% with constant 4% SDA to weak subgrade soil, the MDD value increased up to 30% of SD whereas OMC values decreased as percentages of SD increases. This increase in MDD and decrease in OMC is due to change in particle size distribution and SD has a greater specific gravity than subgrade soil, SDA and SD fills the spaces between soil grains which reduces soil voids and improve MDD.

As addition of SD in the soil mixed with 4 % SDA increases the CBR value increases since both silica in all the finer particles of soil and SDA are used up to this value respectively. The CBR values 7%, 8.31% and 7.44% are acceptable for SDA and SD stabilized sub grade. The reason of this effect is the pozzolanic reactions of SDA with the amorphous silica and alumina present in soil and SD. The probable reason for increase in CBR value of soil is by addition of stone dust in comparison with original soil may be due to increase in density of modified soil mass having more strength [26].

The UCS test is performed with 4% of SDA and varying percentages of SD (10%, 20%, and 30%) also there is increment in UCS value up to addition of 20% SD i.e. 1.81Kg/cm^2 to 1.97 Kg/cm^2. Further increase in percentage of SD the UCS value decreased to 1.71 Kg/cm^2. With addition of SD, the Cohesion of soil decreases and angle of internal friction increases. The stress-strain plot for different percentage of SD shows that with increase in percentage of SD the mode of failure shifts from ductile to brittle. The percentage strain for ultimate shear strength for lower percentage of SD is more as compared to that for higher percentage of SD. It is due to the addition of SD beyond 30% gives the negative effect to the UCS [27].

IV. CONCLUSIONS

This study was aimed to modify weak subgrade soil with SDA and SD to find strength properties of sub grade soil after modification. From the results and discussion, it can be concluded that – (1) The weak subgrade soil has been classified as MH soil (High plasticity clay) with LL, PL, PI, OMC and MDD as 65.32, 33.87, 31.45, 11.5% and 1.837 g/cc respectively; (2) Optimum content for modification of subgrade soil with saw dust ash has been determined as 4% by weight considering CBR value and UCS value; (3) The dry density changes from 1.883g/cc to 1.95g/cc and shows increasing trend with a maximum value at 30% SD addition with optimum 4% SDA; and (4) The soaked CBR value of weak subgrade soil increased up to 2.1 times and UCS increased 2.16 times after modification with SDA and optimum SD.

It is recommended to modify subgrade soil with 4% SDA and 20% SD based on strength and physical attributes.

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