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Significance of Sampling Location and Percentage Replacement of Additives on Index Properties of Stabilised Subgrade Soils: A Statistical Approach

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Abstract: *Laboratory tests were conducted on soil samples collected from three locations namely, Osu, Ajebandele and Aba-gbooro, in Osun state. Some geotechnical properties of soils were examined, thereafter steel slag (SS) collected from Ife Iron and Steel Company and saw dust ash (SDA) obtained from open air burning of saw dust collected from a saw mill in Ile-Ife were added to the soils at 20, 15, 10 and 5 % replacement of soil with SS and 10, 7, 5 and 3 % replacement of SS with SDA in order to determine their effects on consistency and compaction characteristics of the selected subgrade soils. Liquid limits (LL) of the soil samples were >50 % for subgrade (INDOT, 2008). At 20 % replacement, average LL was 43.52 % and 43.67 % for soil+SS and soil+SS+SDA mix respectively. Plasticity of sample A remained intermediate (i.e. 35 – 50 %); while samples B and C reduced from intermediate to low plasticity (i.e. < 35 %) with the addition of SS and SDA (Withlow, 1995). The MDD of the soil samples reduced for all mixes with SS only. MDD was highest for samples A and B at 5 and 7 % SDA, while sample C improved at all mix ratios. The study concluded that consistency of the soil samples reduced at high percentages of additives (i.e. 10 – 20 %). SS had no significant effects on the MDD and OMC of samples A, B and C for all mix ratios, except at 15 and 20 % SS respectively for sample C. The addition of 10 – 15 % saw dust ash into the mix ratio increased the MDD significantly for all samples; while OMC decreased at all mix ratios.*

Keywords: *Consistency, Maximum Dry Density, Optimum Moisture Content, Steel Slag, Saw Dust Ash.*

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I. Introduction

Soil is formed by weathering (mechanical and chemical) and other geologic processes that occur on the surface of the solid rock or near the surface of the earth[1,2]. The mineral particles may be uncemented or weakly cemented and the void space between the particles containing water and/or air[3]. Soil at formation also contained organic particles formed from biochemical process that transforms dead vegetation and organisms into soil organic matter[4].

Soil formation is a component of the larger geologic cycle. The rocks making up the local geology is the parent material that eventually breaks down into finer and finer pieces which, combines with decomposing plant and animal matter brought by organisms living to form what is called soil[5]. The fundamental differences between soil and other engineering materials is that; it is a particulate material, i.e. it is an assemblage of particles rather than being a continuum (a continuous solid mass)[6]. Hence, the engineering properties of soil such as strength and compressibility are dictated by the arrangement of its particles and the interaction between them, rather than by their internal properties. Soil, is an aggregate of mineral particles, together with air and/or water in the void spaces; they form three-phase systems[7]; it also has a peculiar characteristic that set it apart from all other engineering materials in that it can simultaneously comprise of all the three phases of matter, i.e. solid, liquid and gas. The geotechnical properties of soil, such as its grain size distribution, plasticity, compressibility, and shear strength, can be assessed by proper laboratory testing[1].

The parent material from which the soil has been derived have a profound influence on the characteristics of the soil because the mineralogy and morphology of the parent material is mirrored in the soil formed[4,8]. This study attempts to statistically examine the relationship between index properties of selected soil samples and the location (i.e. formation) from which they were collected.

II. Material and Methods

Selection of Sampling Locations: Three soil samples (one from each location) were collected from geologically distinct formations randomly selected on Iwo Sheet 60 geological map which shows the geological map of Ile-Ife and environs (Figure no 1). The three geological formations are located in Atakumosa-West and Ife-Central Local Government Areas in Osun State, Nigeria (Figures no 2). Sample A was collected at Osu (N–07^{o}34’28.0”, E–004^{o}36’44.0”); it is red in colour with some mica content, sample B was collected at Ajebandele (N–07^{o}29’35.7”, E–004^{o}28’57.7”), the soil is whitish with some ting of red and yellow, and some mica, while soil sample C which has chocolate brown colour and substantial mica content was collected at Aba-gbooro village in Obafemi Awolowo University campus Ile-Ife (N–07^{o}32’25.2”, E–004^{o}30’59.5”).

Collection and Handling of Soil Samples: Disturbed soil samples from the three locations were collected with digger and shovel into sacks labelled A, B and C representing Osu, Ajebandele and Aba-gbooro village respectively. The soil samples were spread on plinths in the laboratory to air-dry for about 10 days. The soil samples were pulverized with mortar and pestle and sieved with 425µm sieve to extract samples to be used for Atterberg limits tests. Granulated steel slag (SS) was collected from Ife Iron and Steel Company located at Akinola Village along Ife-Ibadan expressway, Ile-Ife was sieved through 425 µm sieve (BS No. 36) to obtain fine particles of steel slag for the index properties tests. Raw sawdust (with particles of different colours; yellow, brown, cream etc.) was collected from a saw mill within the premises of the plank market opposite Olopomeji bus stop along Ilesa road Ile-Ife. The sawdust was sun-dried for 5 days and packed afterwards into a steel drum where it was burnt in open air until it completely turned into ash. The ash was left to cool down before it was packed and sieved through 425µm sieve (BS No. 36).

Methodology: Geotechnical properties were determined at the geotechnical laboratory of Civil Engineering Department, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria in accordance with standard procedures outlined in BS 1377-1 (2016). Index properties of the soils samples were determined from Atterberg limit (AL) tests namely liquid limit (LL), plastic limit (PL), plasticity index (PI) and linear shrinkage (LS). The properties of the natural soil samples were first determined; thereafter the properties for soil+SS mixtures, and soil+SS+SDA mixtures were determined. The quantities of soil samples, steel slag and saw dust ash that were mixed together was based on percentage replacement by weight of dry soil with SS in the ratio 95:5, 90: 10, 85:15, 80:20; while 3, 5, 7, and 10 percentages by weight of SS in the former mix ratio was replaced with SDA in the latter. The results of the laboratory test were subjected to two-way ANOVA analysis (i.e. within each sample and among the three samples) without replacement at 5% level of significance ($p \leq 0.05$). The level of statistically significant effect of two independent variables; percentage replacement (of dry soil with SS and SDA) and location (of samples collection) on the dependent variables (i.e. results of each of the laboratory tests conducted) were determined. The results of the two-way ANOVA also indicated the level of statistical association between the independent variables and the dependent variable. The outcomes considered to be significant are those with $p \leq 0.05$. The level of statistical association between the independent and dependent variables was also used to validate to result of laboratory analysis.

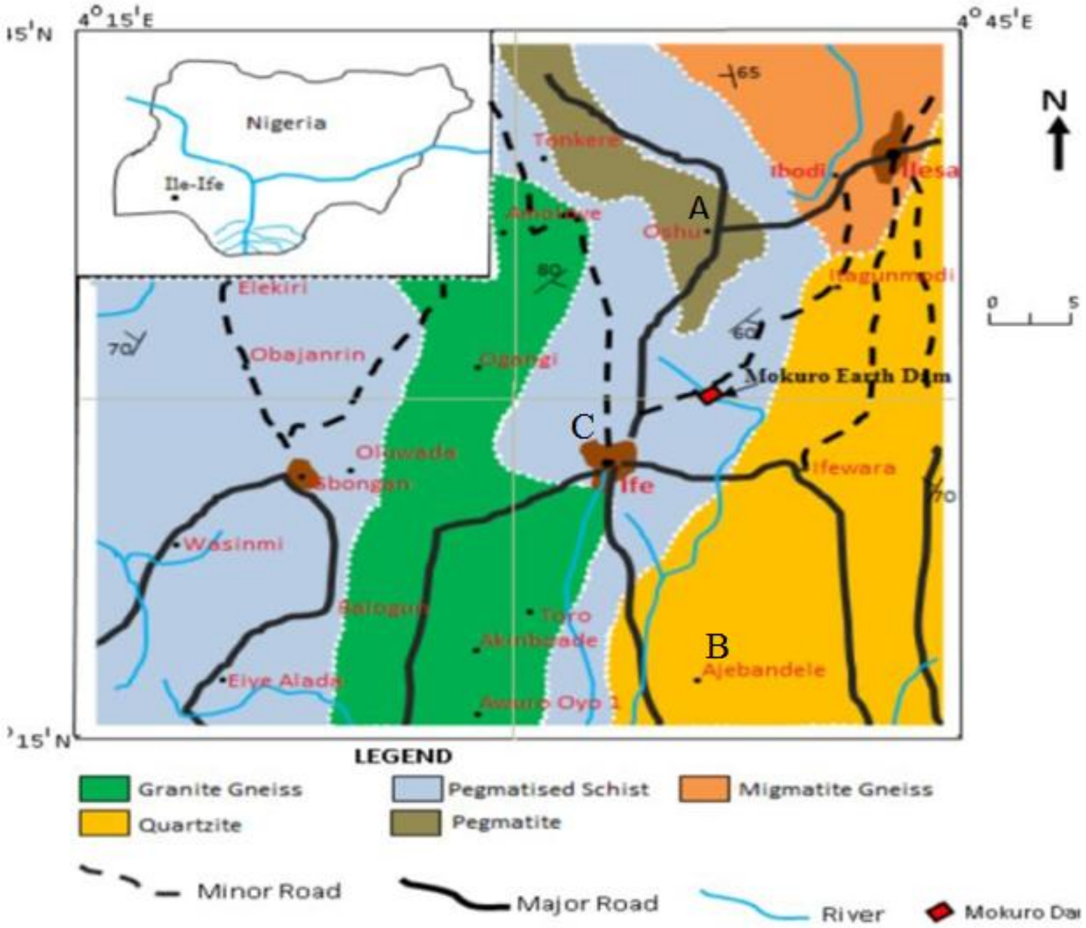


Figure no 1: Geological Map of the Area around Ile-Ife (Adapted from Microsoft Encarta 2009 and Iwo Sheet 60 Geological Map)

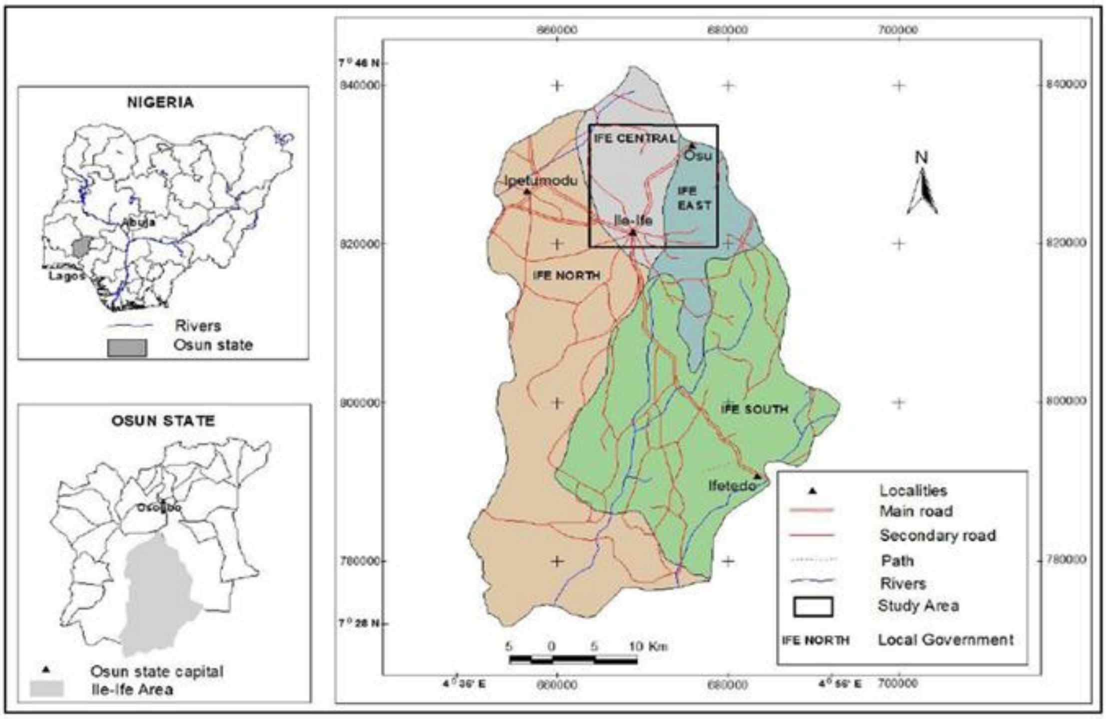


Figure no 2: Map of Ile-Ife and Environs Showing Study Area (Source:https://www.researchgate.net/profile/Joseph_Oloukoi/publication)

III. Results and Discussions

General descriptions of the soil samples and a summary of the results of laboratory tests conducted on the soil samples are shown in Table no 1. Considering the geotechnical properties of the collected soil samples and criteria for suitability of soil for subgrade application; the soil samples can be said to be in the silty sand category with poor load support properties, fair to poor drainage characteristics and are highly susceptible to frost action (in temperate regions)[9]. The natural moisture content of the selected soil samples A, B and C were 12.72 %, 22.37 % and 15.56 %, respectively. These values indicated that the samples contained some reasonable quantity of moisture in their natural state. Specific gravity of samples A, B and C are 2.84, 2.01 and 2.79, respectively, while that of steel slag is 2.92. However, the specific gravity of sand, silt and clay materials, generally ranged between 2.60 and 2.80, while that of iron-rich tropical laterite ranged between 2.75 and 3.0[10,11,12]. Atterberg limit results for the natural soils showed that LL and PL values were 51.80, 51.60 and 57.90 % and 42.32, 39.24 and 43.15 for samples A, B and C respectively in Figure no 3. Samples A, B and C may contain kaolinite with LL ≥ 52.0%[13], while PL is intermediate; since the values obtained for the samples ranged between 35 and 50 %[2]. The soil samples may not qualify to be regarded as subgrade soils because LL of subgrade soils should be < 50 %[14].

Table no 1: Summary of Geotechnical Properties of Soil Samples

Geotechnical Property	Sample A	Sample B	Sample C	Steel Slag
Natural Moisture Content (%)	12.72	22.37	15.56	-
Specific Gravity	2.76	2.01	2.79	2.92
Liquid Limit (%)	52.00	52.40	56.31	-
Plastic Limit (%)	42.32	39.24	43.15	-
Plasticity Index	9.68	13.16	13.16	-
Shrinkage Limit (%)	0.056	0.062	0.105	-
AASHTO Soil Classification	A – 2 – 5	A – 2 – 7	A – 2 – 7	A – 1 – b
Group Index	0	0	0	-
Universal System of Soil Classification	SM	SM	SM	SW
Description of Significant Constituent Materials	Silty Gravel and Sand	Clayey Gravel and Sand	Clayey Gravel and Sand	Stone Fragments, Gravel and Sand
General Rating as Subgrade (AASHTO rating)	Excellent to Good	Excellent to Good	Excellent to Good	Excellent to Good

AASHTO classified sample A as A-2-5 soil (% passing 75 µm < 35 %, LL > 40 %, PI < 10 %), whereas samples B and C were classified as A-2-7 (% passing 75 µm < 35 %, LL > 40 %, PI > 11 %). Steel slag (SS) was classified as A-1-b (% passing 75 µm < 25 %). By USCS classification, the sample A was classified as SM i.e. Sandy-Silt (% passing 75 µm = 0.5 %, PI < 10 %), samples B and C were classified as SC i.e. Sandy-Clay (% passing 75 µm = 0.5 %, PI > 11 %). SS was classified as well graded sand (SW) as a greater percentage of the material falls within the sand bracket (coarse and medium dense sand) also the percentage of materials of different particle sizes that constitute the slag are within the same range as shown on Table no 2.

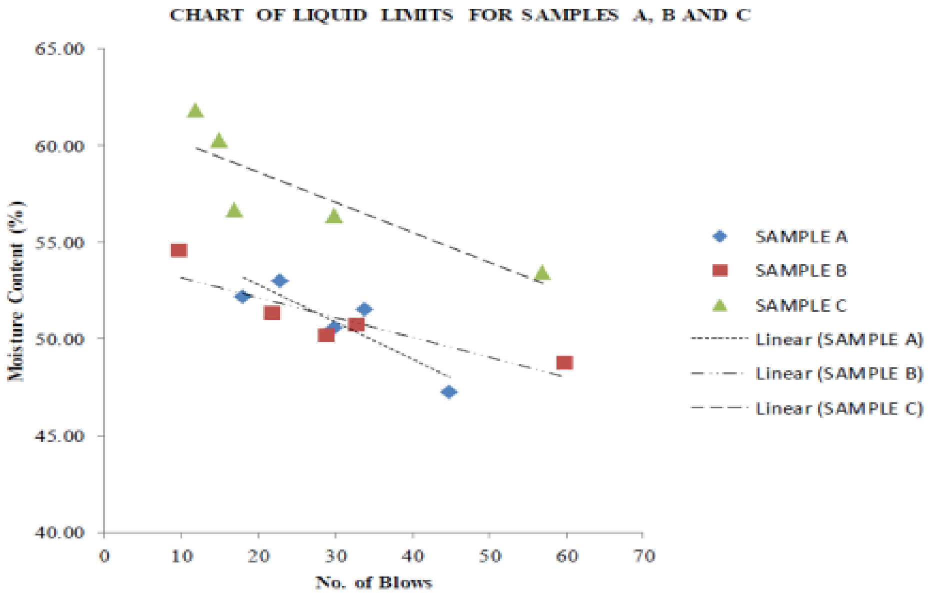


Figure no 3: Liquid Limit Chart for Samples A, B and C

Table no 2: Summary of Sieve Analysis Chart showing Percentage Composition of Grain Sizes

Parameters	Sample A	Sample B	Sample C	Steel Slag
$C_u = \left(\frac{D_{60}}{D_{10}}\right)$	39.13	45.00	34.78	100.09
$C_c = \frac{(D_{30})^2}{D_{60} x D_{10}}$	1.57	0.20	1.55	11.12
Percentage of Gravel (>4.75mm)	15.95	1.75	7.17	29.54
Percentage of Coarse Sand (4.75mm – 2.00mm)	7.80	9.55	9.97	24.21
Percentage of Medium Sand (2.00mm – 0.425mm)	34.38	49.57	35.72	29.19
Percentage of Fine Sand (0.425mm – 0.075mm)	16.40	8.72	21.70	0.23
Percentage of Fines (<0.075mm)	0.5	0.3	0.5	0.0

The PIXE analysis result in Table no 3 showed that percentage concentration of major elements in the soil samples and additives. The steel slag and soil sample contained higher percentages of Silicon, Aluminum and Iron (ranging from 2 – 21 %), followed by Potassium (0.5 – 3 %) and Magnesium (0.2 – 0.5 %), other elements are in trace concentration. The percentage of calcium and magnesium carbonate in subgrade soil should be ≤ 3 %[14]. Samples A, B and C therefore qualify as subgrade soils since the percentage concentration of calcium and magnesium in the soils are all < 3 %. Calcium and Silicon are in higher concentration in SDA (≈ 6 %) followed by Magnesium and Potassium 2 and 5 % respectively. This is followed by Potassium (K) with 4.73 % and Magnesium (Mg) with 2.38 % concentration. The percentage of Iron (Fe) and Aluminum (Al) in sawdust ash are 0.21 and 0.04 % respectively. Steel slag sample is suitable as subgrade material considering the percentage concentration of calcium and magnesium it contained[14]. The major elements found in the sawdust ash also agrees with submission of other researchers[15,16,17,18], although the percentage compositions differs probably due to the fact that the species of tree from which the sawdust was obtained.

The effects of varying percentages of SS and SDA on Atterberg limits of samples A, B and C are shown in Figures 5, 6 and 7. The LL and PL of the soils dropped to 44.32, 41.00 and 45.23 %, and 35.65, 32.12 and 31.64 % when 20 % by weight of the soil was replaced with SS for samples A, B and C. However, the values rose gradually back to over 50 % and 40 % respectively as the percentage replacement of soil with SS reduce to 5 %. The addition of SDA into the mix showed similar trend; LL and PL values of the soils dropped to 44.95, 41.67, and 44.29 %, and 35.89, 32.60, and 31.75 % respectively at 20% replacement of soil with SS+SDA, and gradually rose back to over 50 % and 41 % respectively as the percentage replacement of soil with SS+SDA reduce to 5 %. Plasticity index (PI) for each of the soil samples reduced from 9.68 % for sample A and 13.16 % for samples B and C for soil only to 8.67, 8.88 and 13.59 % for samples A, B and C respectively when 20 % SS was added. The PI rose gradually as the quantity of steel slag reduced. Figure 6 showed that the soils reacted almost in similar manner to moisture at 5 % SS; as their PI were approximately the same value.

Table no 3: Result of particle induced X-ray emission (PIXE) analysis

Element Symbol	Concentration (%)				
	Sample A	Sample B	Sample C	Saw-dust ahs	Steel slag
Na	0.00000	0.00000	0.00000	0.00000	0.04011
Mg	0.50395	0.18386	0.21275	2.38293	0.18559
Al	12.54850	13.04462	12.62759	0.03616	5.05667
Si	19.68593	18.88880	20.73521	5.49949	18.56999
P	0.00000	0.00000	0.02199	0.89330	0.03127
S	0.03401	0.00000	0.00000	1.82350	0.01881
Cl	0.03651	0.00000	0.00000	0.31316	0.06806
K	2.78583	0.46066	1.94459	4.72545	0.16545
Ca	0.05772	0.02403	0.02750	5.98847	0.91424
Ti	0.41557	0.04030	0.13110	0.03548	0.36381
V	0.00000	0.00000	0.00000	0.00000	0.01084
Cr	0.00000	0.00033	0.00095	0.00573	0.25906
Mn	0.01692	0.00393	0.01301	0.03154	1.64985
Fe	5.47314	1.64752	3.23649	0.21023	7.27306
Cu	0.00642	0.00658	0.00644	0.00095	0.05770
Ga	0.00000	0.00361	0.00270	0.00000	0.00000
Zn	0.00995	0.00000	0.00607	0.10102	0.55123
Rb	0.01331	0.00000	0.00782	0.00303	0.01572
Zr	0.00241	0.00000	0.00000	0.00409	0.00000
Sr	0.00000	0.00000	0.00000	0.01628	0.02166
Ba	0.00000	0.00000	0.00000	0.00000	0.11210
Pb	0.00000	0.00000	0.00000	0.00000	0.09260

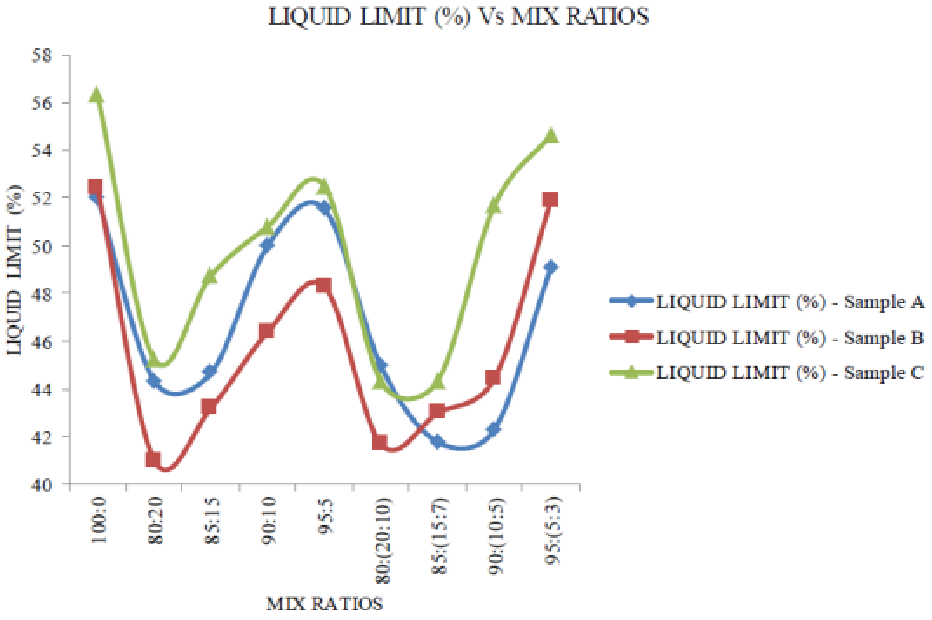


Figure no 5: Liquid Limit Chart for Samples A, B and C + Various Mix Ratios of SS and SDA

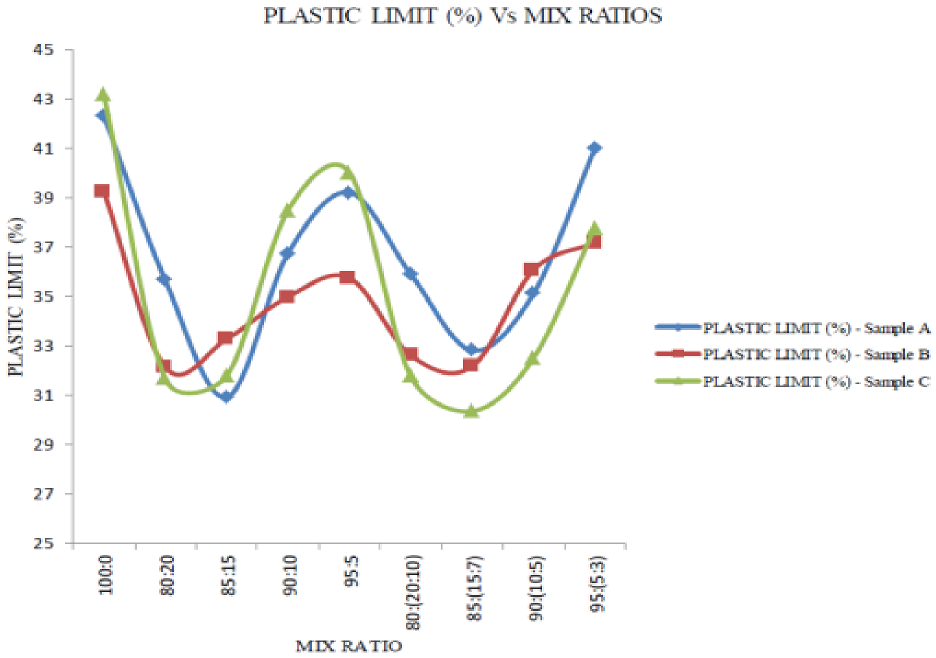


Figure 6: Plastic Limit Chart for Samples A, B and C + Various Mix Ratios of SS and SDA

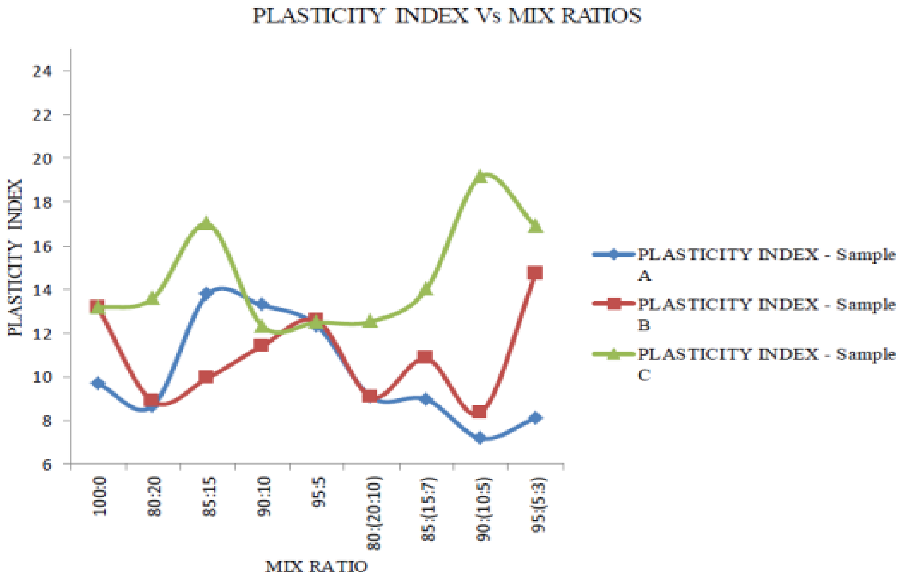


Figure no 7: Plasticity Index Chart for Samples A, B and C + Various Mix Ratios of SS and SDA

The data presented in Table no 4 shows the significance of location and percentage replacement (independent factors) on the Atterberg limits of the soil samples+SS (dependent factor). R squared of 0.943 implies a very strong statistical association between the independent and dependent variables; i.e. 94 % of the variance in the mean of liquid limit can be explained by location and percentage replacement. Also, the 0.932 Partial Eta^2 for percentage replacements and 0.743 for location were indications of the strong relationship between these variables. The two independent variables; location and percentage replacement had statistically significant effect on the liquid limit (i.e. $p < 0.05$). The statistically significant effect of the independent variables on the plastic limit indicated a very strong statistical association between the independent variables and the dependent variable since the coefficient of determination (R squared) is 0.895. This implied that approximately 90% of the variance in the mean of the plastic limit can be explained by the independent variables. The independent factors also had statistically significant effect on the plastic limit at $p < 0.05$. The level of significant difference in the plasticity index (PI) based on location and replacement percentage showed that 87 % of the variance in the mean of the plasticity index can be explained these independent variables (R squared = 0.871). A very strong statistical association therefore exists between the independent variables and the dependent variable. There is a strong statistical relationship between replacement percentages and plasticity index with the large Partial Eta^2 values of 0.871, while the small Partial Eta^2 values of 0.038 for sampling location indicated a weak relationship between location and plasticity index i.e. location of sampling did not statistically influence the PI of the samples, however percentage replacement was a significant factor. The percentage replacement of steel slag had a statistically significant effect on the plasticity index of samples ($p < 0.05$), however, locations of soil sampling, had no statistically significant effect on the plasticity index because $p > 0.05$. These results implied that percentage of SS used as replacement for soil sample in each mix ratio influenced the value of PI for each test. The level of significant difference in the shrinkage limit based on location and replacement percentage showed R squared to be 0.730, which implied that a strong statistical association existed between the independent variables and the dependent variable, i.e. 73% of the variance in the mean of the shrinkage limit can be explained by location and replacement percentage. The percentage replacement of SS with soil samples had no statistically significant effect on the shrinkage limit ($p > 0.05$), whereas the sampling location has a statistically significant effect at a p-value of 0.013 (i.e. $p < 0.05$).

Table no 4: Summary of ANOVA Analysis of Effects of Steel Slag (EAF) on Soil Samples

Dependent Variable	Significance		R Squared[c]	Partial Eta Squared	
	Independent Variable				
	Percentage Replacement[a]	Location[b]		Percentage Replacement	Location
Liquid Limit	0.000	0.004	0.943	0.932	0.743
Plastic Limit	0.001	0.034	0.895	0.877	0.571
Plasticity Index	0.001	0.857	0.871	0.871	0.038
Shrinkage Limit	0.297	0.013	0.730	0.424	0.663
Maximum Dry Density	0.034	0.082	0.756	0.691	0.464
Optimum Moisture Content	0.046	0.182	0.716	0.665	0.347
California Bearing Ratio (Soaked)	0.928	0.641	0.181	0.093	0.105

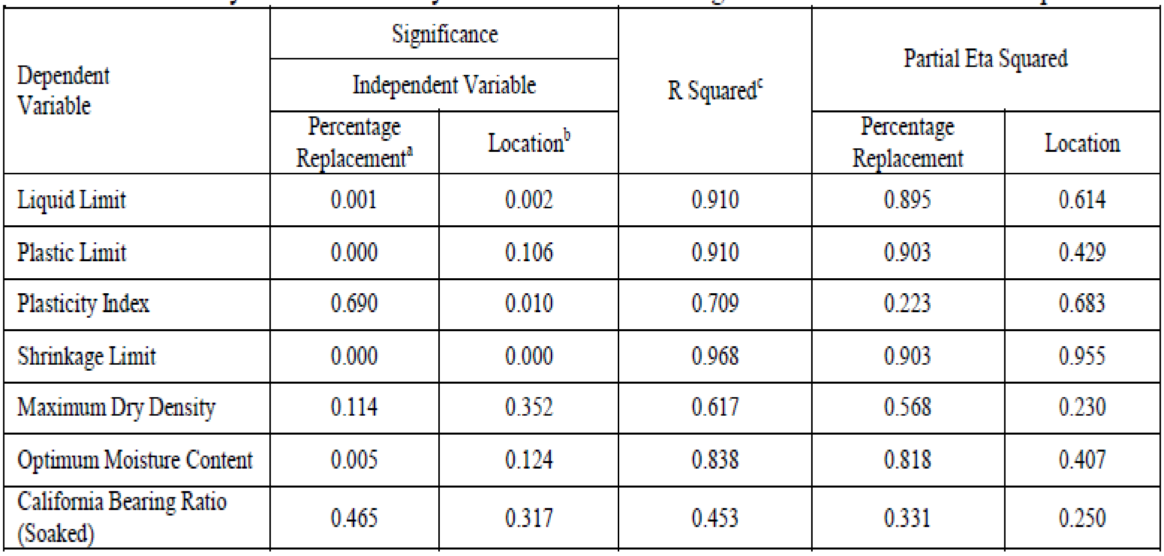
[a] - there is a statistically significant effect on the dependent variable if $p < 0.05$, otherwise there is no statistically significant effect

[b] - there is a statistically significant effect on the dependent variable if $p < 0.05$, otherwise there is no statistically significant effect

[c] - R squared (coefficient of determination) indicates the level of statistical association between the dependent and independent variables

The significance of sampling location and percentage replacement (independent factors) on the liquid limits of soil samples mixed with SS and SDA are presented in Table no 5. R squared value of 0.91 implies a very strong statistical association between the independent and dependent variables; i.e. 91 % of the variance in the mean of liquid limit of soil sample+SS+SDA can be explained by location and percentage replacement. Also, the 0.895 Partial Eta^2 for percentage replacements indicated a strong relationship between the variables while 0.614 Partial Eta^2 for location indicated a weak relationship between these variables. The two independent variables; location and percentage replacement had statistically significant effect on the liquid limit (i.e. $p < 0.05$). The statistically significant effect of the independent variables on the plastic limit indicated a very strong statistical association between the independent variables and the dependent variable since the coefficient of determination (R squared) is 0.910. This implied that approximately 91 % of the variance in the mean of the plastic limit can be explained by the independent variables. The percentage replacement had statistically significant effect on the plastic limit at $p < 0.05$, while there is no statistically significant effect of sampling location on plastic limit. The level of significant difference in the plasticity index (PI) based on location and replacement percentage showed that 71 % of the variance in the mean of the plasticity index can be explained these independent variables (i.e. R squared = 0.871); this connotes that a very strong statistical association therefore exists between the independent variables and the dependent variable. There is a very weak statistical relationship between replacement percentages and plasticity index with the large Partial Eta^2 values of 0.223, while the Partial Eta^2 value of 0.688 for sampling location indicated a good relationship between location and plasticity index i.e. location of sampling can (reasonably) statistically influence the plasticity index of the soil samples, whereas percentage replacement is not a significant factor. The percentage replacement of SS+SDA has no statistically significant effect on the plasticity index of samples ($p > 0.05$), however, locations of soil sampling, has a statistically significant effect on the plasticity index ($p < 0.05$). These results implied that percentage of SS used as replacement for soil sample in each mix ratio would not influenced the value of plasticity index for each test; whereas the sampling location would to a reasonable extent. The level of significant difference in the shrinkage limit based on location and replacement percentage showed R squared to be 0.968, which implies that a strong statistical association exists between the independent variables and the dependent variable, i.e. 97 % of the variance in the mean of the shrinkage limit can be explained by location and replacement percentage. The effects of percentage replacement of SS+SDA on shrinkage limit of soil samples are statistically significant since the p-values for percentage replacement and sampling location are both less than 0.05.

Table no 5: Summary of ANOVA Analysis of Effects of Steel Slag + Saw Dust Ash on Soil Samples



Dependent Variable	Significance		R Squared[c]	Partial Eta Squared	
	Independent Variable				
	Percentage Replacement[a]	Location[b]		Percentage Replacement	Location
Liquid Limit	0.001	0.002	0.910	0.895	0.614
Plastic Limit	0.000	0.106	0.910	0.903	0.429
Plasticity Index	0.690	0.010	0.709	0.223	0.683
Shrinkage Limit	0.000	0.000	0.968	0.903	0.955
Maximum Dry Density	0.114	0.352	0.617	0.568	0.230
Optimum Moisture Content	0.005	0.124	0.838	0.818	0.407
California Bearing Ratio (Soaked)	0.465	0.317	0.453	0.331	0.250

[a] - there is a statistically significant effect on the dependent variable if $p < 0.05$, otherwise there is no statistically significant effect

[b] - there is a statistically significant effect on the dependent variable if $p < 0.05$, otherwise there is no statistically significant effect

[c] - R squared (coefficient of determination) indicates the level of statistical association between the dependent and independent variables

IV. Conclusion

It was established from the two-way ANOVA analysis conducted on the results of laboratory tests on index properties of the soils samples mixed with additives that both independent variables; sampling location and percentage replacement of soil samples with additives had statistically significant effects on the geotechnical properties of the soil samples. The result further established that the effect of percentage replacement of SS only, and SS+SDA on index properties of soil samples is much more statistically significant (p-values of 0.000 – 0.001) than that of location of sampling point (p-values of 0.000 – 0.034). It therefore can be inferred that for index properties; the soil physical characteristics (grains size, water content etc.) are more important in determining the index properties than the location from which soils are sampled.

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