Effect of marble dust and steel slag on consistency limits and compaction characteristics of lateritic soil

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Abstract. Engineers are faced with the problems of providing very suitable materials for highway and other foundations construction. Lateritic soils are highly weathered indigenous soil available in large quantities but generally need improvements to adequately satisfy the required construction purposes. This research investigates the influence of steel slag and marble dust addition on some geotechnical properties of lateritic soil. The results revealed that the soil is well graded based on particle size distribution and is classified as A-2-5 under AASHTO system. With progressive increase in each stabiliser, both the liquid limit, plastic limit and plasticity index exhibit fluctuating patterns. In addition, both marble dust and steel slag increased the maximum dry density with increasing proportions in the soil sample but exhibit irregular patterns for optimum moisture content. This research provides an insight to the quality of lateritic soils obtainable in the study area, and the level of improvements required before they are suitable for road construction.

1. Introduction
Lateritic soil is abundantly available in many parts of Africa, especially, in Nigeria. It is routinely used in civil engineering works in the tropics as a result of its availability and cost effectiveness[1]. Most lateritic soils require improvement on their engineering properties before they are used in construction work, and the improvement normally brings them within acceptable limits for engineering works such as road pavement construction, landfills and building foundation construction[2-4]. Stabilisation is a means by which soil properties are improved and made more suitable for construction purposes. Conventional chemical stabilisation of soil is done by the addition of cement or lime. However, the vogue in soil stabilisation is to examine constructive reuse of waste products from industries as stabilising agents[5].

Steel slag (SS) is produced as a by-product of manufacturing of steel. It is produced during the separation of steel from impurities, and it results from the fusion of limestone flux with ash from coke and the siliceous and aluminous residue. Steel slag has pozzolanic properties and a high potency for synthesis of alkaline activated products [6]. Marble dust (MD) results from the quarrying and crushing of marble. Substantial quantities of marble dust are produced annually from marble deposits in Igbeti, Nigeria[7]. Marble dust has been extensively used as filler material in concrete and its potential as cement replacement have been previously investigated[8].
In this research, the influence of marble dust and steel slag on the Geotechnical properties of lateritic soils taken from Ogbomoso, Nigeria are examined. The lateritic soil sample was characterised, the effect of marble dust and steel slag on the grading and consistency limits of the soil were studied, along with their influence on compaction characteristics of the lateritic sample.

2. Methodology

2.1. Materials

2.1.1. Lateritic soil
The soil used was obtained from a borrow pit in Mayin, Surulere local government of Oyo State Nigeria, which lies within the geographical coordinates of N8° 7' 60” & E4° 15’ 0” geologically. The samples were taken at below 1m depth (after the top soil had been removed), sealed in polythene sacks and transferred to the laboratory.

2.1.2. Marble Dust
Marble dust was collected from Igbeti, Olorunsogo local government area of Oyo State, Nigeria [7, 9]. The location lies within the coordinates of 8° 45’ 09”N and 4° 08’ 06” E. The marble dust was generated from cutting and polishing of marble stones, a flourishing natural resource of the area.

2.1.3. Steel Slag
The steel slag was collected from Phoenix steel company in Ogun state, Nigeria, which lies within the coordinate of 6° 84’ 56” N and 3° 62’ 43” E. The steel slag was produced via blast oxygen furnace (BOF)[10]. The steel slag samples were crushed and grinded to reduce the particle size to be less than 0.425mm, while debris and all other foreign materials were removed by hand before usage.

2.2. Experimental Tests
Natural soil sample was tested for Atterberg limits, Sieve Analysis, Specific Gravity and Compaction tests in accordance with BS 1377-2;1990 and BS 1377-4;1990[11]. The tests were conducted for natural soil, soil with marble dust, soil with steel slag and later repeated for the soil - marble dust - steel slag mixture. Laboratory test was done to ascertain the engineering properties of lateritic soil under investigation and laboratory tests on stabilized lateritic soil with marble dust and steel slag. Dynamic compaction was carried out for both British Standard Light (BSL) and West African Standard (WAS) compaction methods [1, 2, 12-14].

3. Results and Discussions

3.1. Natural Soil
Table 1 shows the summary of the grain size distribution analysis for the natural lateritic soil sample. The percentage passing Sieve No 200 is less than 35% with LL and PI of 42% and 10% respectively which was classified under the AASHTO classification as A-2-5. This indicates that the sample is Silty or Clayey Gravel and Sand, and it further justifies that lateritic soil sample is a good material for subgrade in road construction.

| Property                | Value  |
|-------------------------|--------|
| Natural Moisture Content| 10.98% |
| Specific Gravity (Gs)   | 2.66   |
| Liquid Limit (LL)       | 52.00% |
| Plastic Limit (PL)      | 42.00% |
Plasticity Index (PI) 10.00%
AASHTO soil classification A – 2 – 5
Group Index (GI) Zero
Maximum Dry Density (MDD) 2.06
Optimum Moisture Content (OMC) 12.11
Color Reddish Brown

3.2. Sieve Analysis
Figure 1 shows the effect of steel slag on the sieve analysis of the lateritic soil. From the figure, the percentage passing sieve No 200 increased as the proportion of the steel slag increases, with the values ranging between 0.72% and 1.39%. In addition, for well graded sand, the coefficients of uniformity, $C_u$ ranged between 8.75 and 15; while the coefficient of curvature, $C_c$ ranged from 0.6 to 3, respectively. Therefore, the sample can be described as well graded sand.

![Figure 1. Particle size distribution curve of lateritic soil containing different amounts of SS.](image)

The influence of marble dust on the grading curve of lateritic soil is depicted in Figure 2. The percentage passing Sieve No 200 ranged between 0.48% and 2.37%. The results show that, as the proportion of the marble dust increases, the percentage passing Sieve No 200 increases significantly. This sample can also be classified as well graded sand, since the $C_u$ and $C_c$ ranged between 10 to 20 and 0.8 to 2.5, respectively.
Figure 2. Particle size distribution curve of lateritic soil containing different amounts of MD.

The combined effects of the steel slag and marble dust on the particle size distribution are presented in Figure 3, it shows the samples passing Sieve No 200 which ranged between 1.17% and 4.64%. The samples can also be described as well graded sand since all the samples ranged between 8.75 to 12 and 0.5 to 2.5 of $C_u$ & $C_c$, respectively. Based on the results obtained from sieve analysis in Figures 1-3, the $C_u$ and the $C_c$ ranged within the specification of well graded sand which says $C_u > 6$ and $C_c$ is 1-3. Therefore, all the samples are classified as well graded sand.

Figure 3. Particle size distribution curve of lateritic soil containing different amounts of SS and MD.
3.3. Specific Gravity
The specific gravity of the natural soil sample, MD and SS were determined to be 2.66, 2.81 and 2.31 respectively. The result from Figure 4 shows that the MD decreases the specific gravity of the soil while the specific gravity of the soil sample increases with addition of SS. The specific gravity increased with combine mixture of MD & SS at 8,8%, 8,12%, 12,4%, 12,8% and 12,12% compared to the natural soil.

![Figure 4. Specific Gravity of lateritic soil containing varying amounts of MD and SS.](image)

3.4. Atterberg Limits
The results of the liquid limit, plastic limit and plasticity index of the lateritic soil sample added with different amounts of marble dust and steel slag are presented in this section. Figure 5 shows that, with progressive increase in each stabilizers, the liquid limit exhibited a fluctuating pattern, while that of combined mixture of MD & SS made the liquid limit to reduce at every proportion added. The liquid limit of SS and combined mixture (SS,MD) ranged between 17 - 31% and 17 - 49% respectively, while that of MD remained constant at 53%. The results from Figure 6 show that progressive increase in SS, MD and the combined mixture of MD & SS made the plastic limit of the sample to be reducing and fluctuating at every proportion. Also the results of the plastic limits apart from 0% which is 42% ranged between 14 and 28%. Figure 7 shows that, the plasticity index exhibited a fluctuating pattern with the addition of stabilizer to the soil sample. Plasticity index ranges between 1 and 25%.
Figure 5. Effect of MD and SS on liquid limit of lateritic soil.

Figure 6. Effect of MD and SS on plastic limit of lateritic soil.
From the results, the LL, PL & PI ranged between 17 - 53%, 14 - 42% and 1 - 25% respectively. Based on Nigerian general specification for roads and bridges[15] which says LL & PL must not exceed 50% and 30% respectively, all the LL of the samples are less than 50% except 0% (natural soil), 8% Steel Slag and 4%, 8% & 12% Marble Dust which are 52, 53, 53, 53 & 53% respectively. For the PL, all the stabilized samples are less than 30%, except that of natural soil which is 42%. This implies that the stabilized samples are suitable for construction of highways except 8% SS and 4, 8 & 12% MD.

3.5. Compaction

3.5.1. British Standard Light (BSL)
The results of BSL showing the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for the variation of sample of soil, marble dust and steel slag are presented in Figures 8-10. According to the results of the compactions of the soil sample together with SS shown in Figure 8, it could be seen that with increase in stabilizer, the MDD increases while that of OMC exhibited a fluctuating pattern. Similarly, Figure 9 indicates that MD increased the MDD at each proportion of the soil sample while it exhibits a fluctuating pattern for OMC.

Figure 10 shows the BSL compaction of the lateritic soil under the combined behavior of MD & SS. According to the figure, it could be seen that with increase in MD & SS, the MDD increases while that of OMC exhibited a fluctuating pattern. The MDD and OMC for all samples ranged from (2.02 and 2.31g/cm³) & (4.45 and 15.31%) respectively. However, the highest MDD & OMC is 8,4% (MD,SS) and 4,8% (MD,SS), respectively.
Figure 8. BSL compaction curve showing the effect of SS on lateritic soil.

Figure 9. BSL compaction curve showing the effect of MD on lateritic soil.
3.5.2. West African Standard (WAS)

The graphs showing the results of the compaction test at West African Standard (WAS) energy are presented Figures 11-13. For samples containing SS additions, the MDD and OMC ranged from 2.37 - 2.43 g/cm$^3$ and 12.57 - 13.36%, respectively. The MDD and OMC decrease as the SS increases. Figure 12 shows the behaviour of MDD and OMC under different percentages of MD. The MDD ranged between 2.39 to 2.51 g/cm$^3$ and OMC ranged between 9.75 to 15.38%. The results show that 12% MD has the highest MDD with lowest OMC. Furthermore, Figure 13 shows the WAS compaction under the combined behaviour of MD & SS which shows the ranges of MDD and OMC as 2.36 – 3.23 g/cm$^3$ and 8.35 - 16.86%, respectively. It could be inferred that 8.8% MD-SS from WAS energy level has the highest MDD which is 3.23 g/cm$^3$ compared to BSL, due to the increase in weight of the rammer and its falling height which caused the soil particle to be closely packed and reduction in voids within the particle.
Figure 11. WAS compaction curve showing the effect of SS on lateritic soil.

Figure 12. WAS compaction curve showing the effect of MD on lateritic soil.
4. Conclusion
Geotechnical laboratory tests were carried out on Lateritic soil samples taken from Mayin, Ogbomoso, Oyo State, Nigeria. The grading analysis revealed that the percentage passing Sieve No 200 is less than 35%, which makes the samples to be regarded as well graded. Further tests on consistency limits on the lateritic soil sample revealed that the addition of SS and MD as stabilisers improved the AASHTO classification of the soil sample from A-2-5 to A-2-4, indicating the soil sample as Silty or Clayey Gravel and Sand. Also, the compaction results revealed that 8.8% MD-SS from WAS energy level has the highest MDD which is 3.23g/cm$^3$. Thus the soil sample is ‘excellent to good’ for sub-grade level in the construction of roads.

Since the geotechnical properties of various proportions of steel slag and marble dust stabilised soil samples are known, together with the optimum proportions which yield the best values, and meet the requirements of the standards, the construction of roads on lateritic soils can be achieved by sourcing the entire base course materials locally and at a reasonable cost and reduced time.

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