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Research Paper

Optimisation of the Geotechnical Properties of Spent Ore for Road Construction in Ghana

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ABSTRACT

Mining operations generate large volume of wastes and due to its potential toxic nature, it is managed in accordance to very strict environmental regulations in Ghana. The spent ore can be reutilized as a construction material especially for road, however, due to its granular nature, it is not possible to compact the materials to achieve the required strength for engineering purposes. Laterite which is abundantly found in Ghana was used to improve the engineering properties of spent ore for road base and subbase construction. The laterite was added to the spent ore in range of 10% to 50% to form composites. Physical and engineering laboratory tests including moisture content, Atterberg Limits, compaction and Californian Bearing Ratio were conducted on the composites in accordance with British Standards. The results show that the Liquid Limit of the composites are between 18.7% and 30%, the Plasticity Index are between 1.3% and 11.3%. The soaked CBR values are between 32% and 62%, the unsoaked values are between 31% and 64%. The results show that, 30% addition of the laterite will improve the spent ore for only subbase construction based on Ghana Highway Authority standards for base and subbase materials in Ghana.

1. Introduction

Mining operations generate large volume of waste material and due to its potential toxic nature, it is contained and not exposed to the environment. Mining companies are required to provide disposal plan for the waste after decommissioning as part of the environmental impact assessment. Huge funds are required to ensure that, the waste are contained and not allowed into the environment during mining and after closure. Arhinful and Agyei (2017) estimated the cost of closing a waste dump at Iduapirem Mine at Tarkwa in Ghana and reported that, the total closure and reclamation cost was estimated to be US$ 581 488.18. Some mining companies in Ghana have therefore considered the reutilisation of the waste material due challenges in disposal after decommissioning.

Several research have been conducted into the reuse of mine waste for construction and other purposes all over the world (Gaonkar, et al, 2010), (Lottermorser, 2011), (Aravind and Das, 2012), (Nunes *et al*., 1996) and (Sherwood, 1995). Mahmood (2010) investigated the use of mine tailings for unpaved road base and concluded that, the tailings if stabilized with cement can be used for road construction. Cesare et al (2016) also used alkali activated based methods to improve mine wastes for road pavements, the research shows that large volumes of mine waste could be recycled in the

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industrial production of pre-cast segments for civil engineering construction purposes, in particular for transportation infrastructures. The forgoing literature review shows that extensive research into reutilization of mine waste has been ongoing and it can be established that it is a potential road construction material if the appropriate additives are used to improve the geotechnical properties.

Road construction in the country is gradually depleting natural road construction materials and other resources. It is therefore necessary to find other alternative road construction materials to minimise the depleting of the natural materials. Spent ore which is a byproduct of heap leaching is produced in large quantities in some mining companies in Ghana. These materials are potential road construction materials that can be used to reduce the depletion of natural materials for road construction. However, spent ore is granular in nature and therefore it is difficult to compact the materials to achieve the required strength for engineering design. Soils with low to intermediate plasticity can be used to improve the geotechnical properties of the spent ore for road pavement construction. Laterite is found abundantly in Ghana and mostly used for construction purposes. Research on most lateritic soils in Ghana by Gidigasu (1972) shows that, laterite consist of soils with clay and silt fraction that are plastic. The addition of laterite to the spent ore will provide the needed plasticity that will make it compactable for engineering purposes. This will enable laboratory tests such as Atterberg Limits, compaction, and California Bearing Ratio (CBR) to be conducted on the spent ore to determine its suitability for road subbase or base construction. It is against this background that this research intends to determine the composite properties of spent ore and the laterite for road pavement construction.

1.2 Study Area

Tarkwa is located in the Western Region of Ghana and is between Latitude 4º5′ and Longitude 5º5′ (Figure 1). It is about 300 km from the Accra and 85 km from Takoradi. Tarkwa host some of the major mining companies in Ghana which includes AngloGold Ashanti and Goldfields Ghana Limited, Tarkwa Mine. Tarkwa is the administrative capital of the study area and subsistence farming is the main occupation of the people and mining being the main industrial activity (Avotri et al., 2002). The Tarkwa area lies within the main gold belt of Ghana that stretches from Axim in the southwest, to Konongo in the northeast (Kortatsi, 2004).

Fig. 1 Study Area

1.3 Geology of the Study Area

The study area falls within the Banket Series within the Tarkwaian geological unit. According to Kesse (1985) rocks of the Tarkwaian Group are concentrated mainly at the South-western part of Ghana in the Tarkwa area where they outcrop in a NE-SW trending belt. The belt stretches from near Axim to the edge of the Voltaian basin near Agogo, a distance of about 250km. The Tarkwaian rocks consist of thick series of argillaceous and arenaceous sediments (mainly arenaceous) in the lower members of the system. The Tarkwaian Group is considered to be of shallow water continental origin derived from the Birimian and associated granites. The Tarkwaian is thought to rest unconformably on the Birimian, though in some places, the metasedimentary Birimian and the Tarkwaian are inter-folded due to post Tarkwaian orogenic activity. The common minerals are chlorite, sericite, zoisite, calcite, quartz, limonite and chloritoid. The sediments must be regarded as integral part of the Eburnean orogenic cycle of which they represent the final molasse stage. The Tarkwain is divided into five main series, Kawere Group, Banket Series, Tarkwa Phyllites, Huni Sandstone and Dompim Phyllites. Banket Series represents a fluviatile series with a thickness varying between 120-600m being greater south and west of Tarkwa. It is essentially an accumulation of high energy, coarse clastics, represented by conglomerates, grits, quartzites, which have suffered low-grade metamorphism (Kesse, 1985). Four reefs or conglomerate bands have been identified typical in the western and southern parts of the Tarkwa Goldfields namely:

- Breccia Reef
- Quartzite and grit
- Middle Reef
- Quartzite and grit
- Basal or Main Reef
- Quartzite and grit
- Sub-basal Reef

Three of the units are persistent i.e. breccia reef, middle reef and a unit of basal conglomerates. The Basal or Main reef is the most persistent conglomerate bed in the area and is by far the richest in gold. Furthermore it is generally better sorted than the other reefs and more uniform in thickness, composition, size and in distribution of pebbles. The matrix of the conglomerates consists principally of quartz and sand (mainly hematite with ilmenite, magnetite and rutile), minor constituents are sericite, chlorite, tourmaline, garnet, zircon and gold. Epidote and pyrite are rare except near dykes, faults and quartz veins.

2. Materials and Methods

2.1 Sampling

The spent ore was obtained from a mine the in Tarkwa area. 200kg samples of the spent ore were sampled randomly from the bulk spent ore. The samples were bagged and labeled and transported to the CSIR Building Road Research Institute (BRRI) Geotechnical Laboratory. The laterite samples were obtained from the Tarkwa area by excavation with pick and shovel at a base of a road cut about 2.5 below the ground surface. Bulk samples were taken from the excavation. The samples were bagged and labeled and transported to the CSIR BRRI Geotechnical Laboratory.

2.2 Laboratory Tests

The following laboratory tests were conducted in accordance with British and ASTM Standards at the CSIR BRRI Geotechnical Laboratory

Moisture Content

- Particle Size Distribution
- Atterberg Limits
- Compaction
- California Bearing Ratio
- Chemical tests

Air drying of the samples is presented in Figure 2

Fig. 2 Air Drying of Samples

2.3 Laboratory Tests on the Spent Ore and Laterite Composites

Table 1 shows the various percentages of laterite that was added to the spent ore for the laboratory test. The percentages ranges from 10% to 50%, these percentages were selected because the laterite is inert and requires higher amount to affect the geotechnical properties of the spent ore.

Table 1 Composite of Spent Ore and Laterite

Item	Spent Ore (S) %	Laterite (L)%
1	90	10
2	80	20
3	70	30
4	60	40
5	50	50

3. Results and Discussions

3.1 Properties of Spent Ore

The summary of the results of the laboratory tests conducted on the raw spent ore is presented in Table 2 with Ghana Highway Authority (GHA) requirements for materials for base and subbase constructions.

Table 2. Summary of Properties of Spent Ore

Property	Value	GHA Requirements	
		Base	Subbase
LL (%)	-	25 max	30 max
PI (%)	-	10 max	12 max
PM	-	200 max	250 max
OMC (%)	10.0	-	-
MDD (g/cm^3)	1.30	-	-
CBR (%)	5.2	80 min	60 min
Soaked CBR (%)	4.1	80 min	60 min
Swell (%)	0	0.25 max	0.5 max
Specific Gravity	2.79	-	-
Gravel%	42	-	-
Sand%	47.7	-	-
Silt%	10.3	-	-
Clay%	0	-	-

3.2 Grading Properties

The laboratory test results indicate that, the spent ore consists predominantly of sand and gravel with minor silt content. The spent ore is poorly graded soil with less fines and does not meet the requirement for base and subbase. The material is non plastic with a specific gravity of 2.79. A plot of the envelope of grading limits permitted for base and subbase materials and superimposed on the grading curves of the spent ore is presented in Figures 3 and 4 respectively. It can be observed from both graphs that the grading curve of the spent ore falls outside the grading limits.

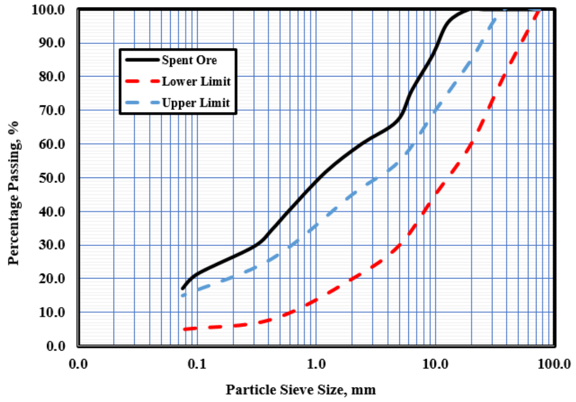

Fig. 3 Grading curves of spent ore superimposed on the grading envelope for base material.

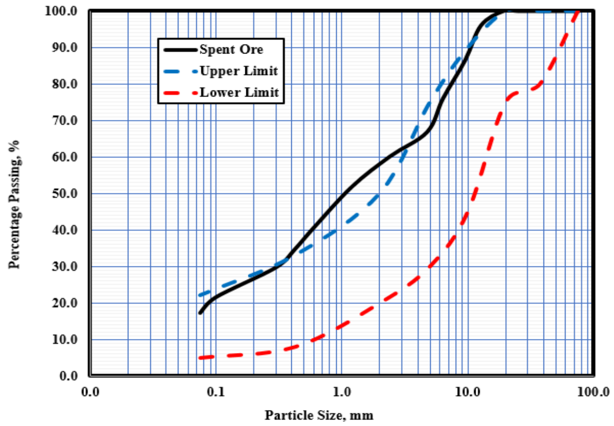

Fig. 4 Grading curves of spent ore superimposed on the grading envelope for subbase material.

3.3 Chemical Properties of Spent Ore

The level of cyanide measured ranges from 0.14 – 0.30mg/L. The residual cyanide content is below the maximum allowable content of 40 mg/kg per international best practices (Anon, 2012). The sodium sulphate soundness and alkali-silica reactivity tests indicate that the materials are generally free from deleterious materials which would not cause expansive reactions in concrete. The sulphate and chloride test results also indicate that the materials are free from constituents harmful to concrete.

3.4 Properties of Laterite

Summary of the properties of the laterite are presented in Table 3. The laboratory test results indicate that, the laterite consists predominantly of silt and clay with some sand. The liquid limit is 42% with a plasticity index of 25%, this is classify as clayey soils with low plasticity on the plasticity chart. Since the laterite is fine grain and plastic, it will provide the needed plasticity that will blend with the spent ore which is coarse grain and non-plastic.

Table 3. Summary Properties of Laterite

Property	Value	MRT Requirements	
		Base	Subbase
LL (%)	42	25 max	30 max
PI (%)	25	10 max	12 max
Max size (mm)	0.43	53	63
Max Fines Content	0.001	15	22
OMC (%)	5.3	-	-
MDD (g/cm^3)	1.52	-	-
CBR (%)	10.6	80 min	60 min
Soaked CBR (%)	5.2	80 min	60 min
Swell (%)	0.08	0.25 max	0.5 max
Specific Gravity	2.6	-	-
Gravel%	0	-	-
Sand%	11.1	-	-
Silt%	62.9	-	-
Clay%	26.8	-	-

3.5 Atterberg Limits of the Composites

The summary of the results of the Atterberg Limits conducted on composites are presented in Table 4 and the graphs are presented in Figure 5. The results show a gradual increase in the Atterberg Limits of the spent ore with the addition of the laterite. The effect of the laterite on the Atterberg Limits of the spent ore is presented in subsequent paragraphs.

Table 4. Summary of Atterberg Limits

Item	Composite %	LL%	PL%	PI%
1	100S0L	0	0	0
2	90S10L	20	18.7	1.3
3	80S20L	22	17.6	4.4
4	70S30L	36	29.1	6.9
5	60S40L	42	30	11.3
6	50S50L	50	33.2	16.8

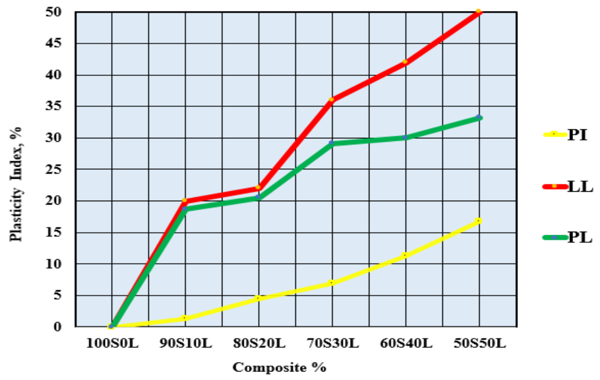

Fig. 5 Atterberg Limits of Composites

3.5.1 Liquid Limits of Composites

The Liquid Limit is the moisture content at which the soils moves from the solid state into the liquid state with addition of water. Fine grain soils such as clay and silt have high LL due to their ability to absorbed water, coarse grain soils however have less LL due to its free draining nature. Figure 5 shows a graph of LL against the composites. The graph shows a direct increase in the liquid limit (LL) from 0% to 50% with the addition of the laterite from 10% to 50. The results is expected since the addition of the laterite which contains clay fractions will impact some LL characteristics to the spent ore which is non-plastic. The results indicates that, the laterite can provide fines that can increase the LL of the spent ore for road base and subbase materials.

3.5.2 Plastic Limits of the Composites

The effect of the laterite on the Plastic Limits (PL) of the spent ore is presented in Figure 5, the graph shows an increment in the PL of the spent ore with a decrease in the PL on 20% addition of the laterite. PL is an indication of the moisture content at which the soil moves from the liquid state to the plastic state with the addition of water, the PL of the composites is due to the clay fractions in the laterite.

3.5.3 Plasticity Index (PI) of the Composites

The PI is the difference between the LL and the PL, the PI is a very important parameter of soil since it directly affect the engineering behavior of soils. The PI is related to the type and fraction of clay particles and minerals in a particle soil mass. The effect of the laterite on the PI of the composites are presented in graphical form in Figure 5. It can be observed from the graph that, the PI of the composites increase with increment in the percentage of the laterite. The higher the percentage of the laterite, the higher the PI. The results show that, the addition of laterite from 10% to 40% resulted in PI values that are within the GHA specification for PI values for based and subbase materials (10% maximum for base and 12 for subbase materials.

3.6 Compaction Properties of the Spent Ore

The results of the compaction tests conducted on the composites of the spent and the laterite are summarized and presented in Table 5.

Table 5. Summary of Compaction Tests

Item	Composite %	MDD (g/cm^3)	OMC (%)
1	100S0L	1.30	10.0
2	90S10L	1.48	5.0
3	80S20L	1.59	7.4
4	70S30L	2.01	7.5
5	60S40L	1.56	8.4
6	50S50L	1.55	9.6

3.6.1 MDD of the Composites

The graph presented in Figure 6 shows the effect of the laterite on MDD of the composites of the spent ore and the laterite. The graph shows a gradual increase in the MDD of the spent ore with addition of the laterite, the MDD ranges from 1.3g/cm^3 to 2.01 g/cm^3. The composite 70%S:30%L resulted in the highest MDD of 2.01 g/cm^3. The trend in the results can be attributed to increasing laterite content in the composites, compaction is a densification process where air is expelled from the soils by applying loads. The grading of the spent ore indicates that, the material consist of gravelly sand which is coarse grain, the laterite is also made up of clayey silts which is fine grain. The addition of the laterite to the spent ore is a blend of coarse grain soils and fine grain soils, the fine grain particles will fill in the voids spaces between the coarse particles which when compacted at the optimum moisture content will results in higher MDD. The trend as presented in Figure 8 shows an increment in the MDD up to composite 70%S30%L and decrease to composite 10S90L. It means that, the optimum amount of the laterite to produce the highest MDD is 30% and any subsequent increment in the laterite content will amount to excess fines in the composites that will decrease the MDD.

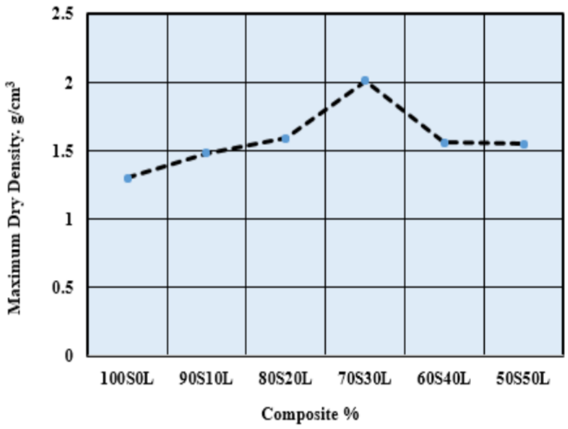

Fig. 6 Graph of MDD against Composites

3.6.2 OMC of the Composites

The effect of the laterite on the OMC of the composites is presented in Table 3, the results shows direct increase in the OMC of the composites with the laterite content. The least OMC was recorded by composites 90S10L and the highest was by 505%S50%L. The amount of water added during the compaction process is very important since it acts as a lubricant and aids the soil particles to slide over each for effect compaction. The laterite is fine grain and requires more water for effective compaction with increasing laterite content. As the percentage of the laterite is increased, more water is needed for the compaction and accounts for the higher moisture content with increasing laterite percentage.

3.7 CBR of the Spent Ore of the composites

Summary of the CBR results conducted on the composites are presented in Table 6. The Table shows the soaked and unsoaked CBR values with the corresponding swell values of the composites.

Table 6. Summary of CBR Tests

Item	Composite %	CBR %		Swell
		Soaked	Unsoaked	
1	100S0L	4.1	5.2	0
2	90S10L	35	41	0.01
3	80S20L	39	46	0.02
4	70S30L	62	64	0.06
5	60S40L	23	34	0.07
6	50S50L	14	31	0.08

3.7.1 Swell values of the Composites

The swell values of the composites are show in Table 4, the values show a gradual increase in the swell value with the increment in the laterite percentage. The Composite 50%S50%L resulted in the highest swell value of 0.08. The swell value relates to the clay content in the laterite, as the laterite is increased, the amount of clay in the composite also increased and accounted for the trend observed in the results. Based on the results, the addition of laterite between 10% and 50% will result in swell values that are within the GHA Specifications.

3.7.2 CBR values of the Composites

The effect of the laterite on the CBR values of the composites are presented in graphical form in Figure 9, the results shows variations in the CBR values with the various composites. It can also be observed that, the unsoaked CBR values are higher than the soaked CBR. The composites 70%S30%L recorded the highest soaked and unsoaked CBR values. This results is expected because it recorded the highest MDD for the compaction tests. Based on the results and the GHA Standards, the composite 70%S30%L can be used as a subbase material for road construction.

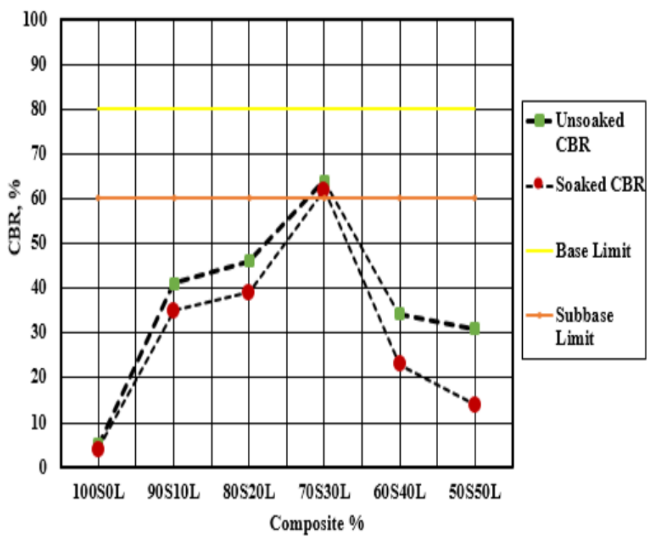

Fig. 7 Graph of CBR against Composites

4.0 Conclusions

The Atterberg Limit tests conducted on the composite materials show a general increase in the LL, PL and the PI with increasing percentage of the laterite. The results show that addition of laterite from 10% to 20% resulted in LL between 20% and 22%. The values are within the specifications for the GHA standards for base and subbase materials. The soaked CBR values of the composite materials were between 32% and 62%, the unsoaked values were between 31% and 64%. The composite 70%S30%L recorded the highest soaked and unsoaked CBR value of 62% and 64%. Combination of 70% of the spent ore and 30% of the laterite would produce a composite material that can be used as subbase material for road construction.

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