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The Effect of Spent Carbide on the Geotechnical Characteristics of Two Lateritic Soils from the Kumasi Area

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Abstract

The effects of spent carbide on the geotechnical properties of two lateritic soils were evaluated. The lateritic soils were collected from Ayeduase and Fumesua and blended with spent carbide contents of 3%, 5%, 7% and 10% by weight of dry soil. The composite materials were then subjected to geotechnical tests namely: the grading, Atterberg limits (liquid limit, plastic limit and plasticity index), specific gravity, compaction and California Bearing Ratio. Results of the study showed that the addition of spent carbide significantly affected the fines contents of the soils which resulted in the reduction of clay size content and an increase in silt contents. There was also a general reduction in the plasticity characteristics of the soils resulting in a change in the classification from inorganic clay of high plasticity (CH) for the natural soils to inorganic silt of intermediate plasticity (MI) for 10% spent carbide content. The maximum dry densities of both soils decreased with increasing spent carbide content. The optimum moisture content of the Ayeduase soil increased whereas the Fumesua soil reduced with spent carbide content. The California bearing ratio values increased with increasing spent carbide contents for both soils. General reductions in CBR-swell values were also observed. It can be concluded that the spent carbide improved significantly the geotechnical properties of the lateritic soils studied and hence has the potential for use as stabilizer.

Introduction

Lateritic soils constitute the most important tropically weathered materials which are extensively used in road construction in Ghana. Sometimes these naturally occurring lateritic materials although readily available, seldom possess some characteristics that render them unsuitable for road construction. Some laterites may contain some amount of clay such that their strength and durability can not be determined under loading especially in the presence of moisture [1]. They may also have poor grading characteristics, high plasticity, low bearing strengths (CBR), high CBR swell etc. Reference [2] has reported that poor grading characteristics of some laterites, for instance, have resulted in premature failures of road foundation. Under such circumstances where the laterites are unsuitable and good quality materials do not occur within economic haulage distances, the highway engineer may improve the problem soils through stabilisation.

Traditionally, lime, cement and bitumen have been the main stabilising agents for improving problem soils, however, the increasing cost of producing these stabilisers partly due to the high cost of energy, and the high demand for these stabilisers [3] and the high cost involved in incorporating these stabilisers [4] could render a project prohibitive. The utilisation of these traditional stabilisers have been identified by [5] and [4] to have kept the cost of construction of stabilized road financially high, which hitherto have continued to deter the underdeveloped and poor nations of the world from providing accessible roads in rural areas.

Subsequently, researchers are focusing attention on the identification and development of local stabilisers from agricultural, industrial and commercial waste materials for improving these problem soils. For instance, studies on the stabilisation of soils using calcined-agricultural waste materials such as sugar cane or bagasse ash [6], groundnut shell ash [7]; rice husk ash ([8]; [9]), coconut shell ash [1]; egg shell ash [10], industrial waste such as fly ash [11], saw dust ash [12] , etc.

Spent carbide is a residue from acetylene manufacturing plants. This residue has high calcium oxide content and traces amounts of magnesium oxides, alumina, silica and iron oxides and its composition is similar to high calcium lime used for soil stabilization [13]. There were three acetylene manufacturing plants in Ghana located in Tema, Takoradi and Kumasi owned and operated by Air Liquide Ghana Limited, however, only Tema and Takoradi plants are still in operation as at 2013. Although there is no current estimation of the amount of spent carbide generated, the three production plants at as 1988 produced 300 tonnes of this spent carbide in slurry form annually which were dumped near the premises of the plants.

The purpose of this study is to evaluate the effect of spent carbide on the geotechnical properties of two lateritic soils from the Kumasi area with the view to obtaining a cheaper alternative for the traditional stabilisers.

Materials and Method

Materials

The lateritic soils used in the study were collected from depths between 0.5m-1.6m and 0.75m-1.4m below ground level from Ayeduase and Fumesua respectively in the Kumasi area. The sites are underlain by the Birimian granites [14]. The carbide was obtained from Air Liquide Factory in Tema.

Method

The lateritic soil samples were air-dried and pulverized before use. The air-dried soils were then mixed with 0%, 3%, 5%, 7% and 10% of spent carbide by weight of dry soil. The natural and composite materials were then subjected to chemical and geotechnical engineering tests.

The chemical composition of the materials was determined using the X-ray florescence analysis at the Ghana Geological Survey Department, Accra. The geotechnical tests carried out were the index and engineering property test. The index properties conducted were particle size distribution analysis, Atterberg limits (liquid limit, plastic limit, and plasticity index) and specific gravity based on test procedures stipulated in [15] standard specification, whereas the compaction and California bearing tests were the engineering tests performed using with Modified AASHTO standards [16]. The CBR values were determined on soil samples compacted at optimum moisture content and soaked for 4-days prior to testing.

Results and Discussion

Chemical composition of the materials

The chemical compositions of the materials are presented in Table 1. It is found that the two lateritic soils have similar chemical composition with the dominant oxides being silica, alumina and iron oxides constituting about 66% and 75% for the Ayeduase and Fumesua lateritic soils respectively. The silica-sesquioxide ratios were 1.13 and 1.05 for the Ayeduase and Fumesua soils respectively. This indicates that the soils are true laterites according to [17] classification.

The primary constituent of the spent carbide is calcium oxide (lime) which constitutes 81% of the total oxide. This value is higher than those reported by [18] for high calcium quikelime which generally contain between 72 to 74 percent calcium oxide.

Table 1 Chemical composition of the materials

Major oxides	Concentration (% weight))		
	Ayeduase soil	Fumesua soil	Spent carbide
SiO_2	35.23	38.35	6.73
Al_2O_3	25.65	27.06	2.62
Fe_2O_3	5.44	9.45	0.15
Na_2O	0.81	0.64	0.41
MgO	0.86	0.92	0.08
K_2O	0.83	1.27	0.61
CaO	0.09	0.10	81.54
P_2O_5	0.10	0.10	0.01
MnO	0.02	0.02	0.01
TiO_2	0.73	0.59	0.04
SO_3	0.07	0.07	0.54

Geotechnical characteristics

The summary of results on the spent carbide stabilization of the lateritic soils is presented in Table 2 and is discussed as follows.

Effect of spent carbide on the Particle size distribution

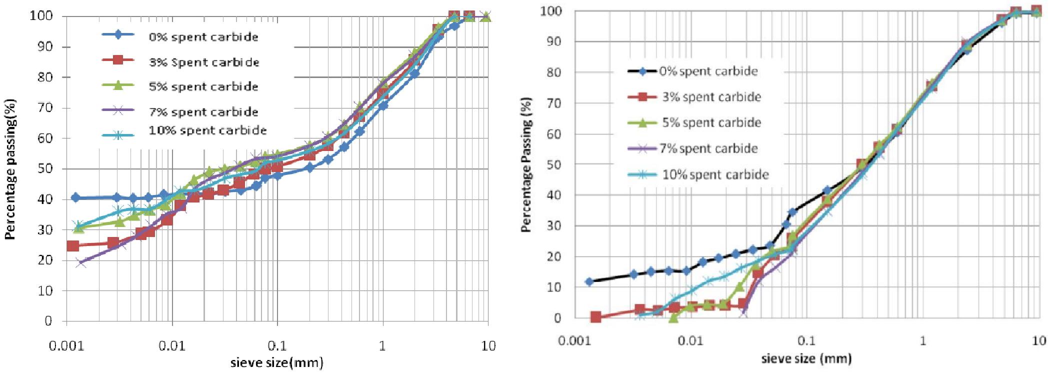
The particle size distribution curves of the natural and stabilised lateritic soils are shown in Figure **1**. Generally, there were reductions in the clay content of both soils whereas silt content increased with increasing spent carbide content.

The reduction of clay contents in the Fumesua soil to 0% at spent carbide content greater than 3% was significant and worth noting. The general reduction in clay size fraction and increase in silt size content may be due to the pozzolanic reaction between the calcium oxide (lime) in the spent carbide and the clay fraction of the soil resulting in flocculation of clay particles.

Table 2 Geomechanical characteristics of spent carbide stabilised soils

Sample ID	Ayeduase soil + spent carbide					Fumesua soil + spent carbide				
	0%	3%	5%	7%	10%	0%	3%	5%	7%	10%
Grading										
Gravel (%)	19.00	14.60	12.00	16.00	15.80	15.50	15.00	14.00	13.50	14.00
Sand (%)	36.00	37.30	36.00	37.30	36.20	56.50	63.50	63.50	68.50	64.50
Silt (%)	4.50	23.40	20.00	25.50	14.00	15.00	20.50	22.50	18.00	21.50
Clay (%)	40.44	24.80	32.00	21.00	32.05	13.00	1.00	0.00	0.00	0.00
Atterbergs										
Liquid Limit (%)	59.74	60.99	60.15	54.47	45.94	58.00	53.80	55.00	51.80	46.80
Plastic Limit (%)	23.74	35.42	37.65	34.90	33.60	27.40	31.70	31.50	32.90	34.30
Plasticity Index (%)	36.00	25.57	22.50	19.57	12.34	30.60	22.10	23.50	18.90	12.50
Compaction										
Max. Dry Density (g/cc)	2.15	1.99	1.97	1.995	1.81	1.51	1.50	1.48	1.45	1.42
Opt. Moisture Cont. (%)	12.60	13.3	14.03	14.2	16.5	13.10	13.00	12.40	12.10	12.60
CBR (%)	25.71	97.57	109.06	48.3	96.21	3.02	11.77	14.51	37.55	43.65
CBR Swell (%)	0.55	-2.00	-0.50	-2.20	-9.00	5.17	4.77	3.61	2.98	1.49
Classification										
USCS	CH	MH	MH	MH	MI	CH	MH	MH	MH	MI

Reference [19] found that during pozzolanic reaction, base-exchange occurs with the strong calcium ions of lime replacing the weaker ions such as sodium on the surface of the clay particle. Further, adsorption of non-exchanged calcium ions also leads to an increase in ion density, which results in a change of soil texture through flocculation of clay particles that reduces clay content and increases the percentage of coarse particles.



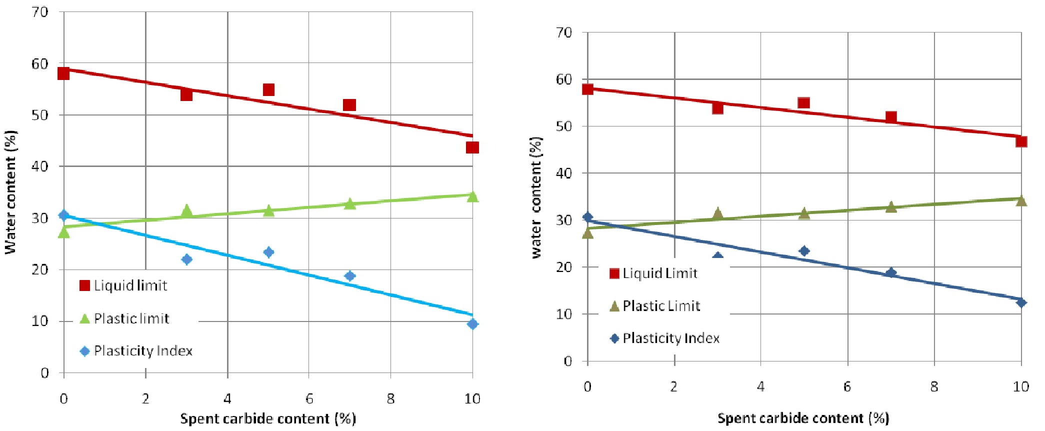
Ayeduase soil Fumesua soil

Figure 1 Particle size distribution curves of the spent carbide stabilised soils

Effect of spent carbide on the Atterberg limits and Plasticity Characteristics

The results of the variation of Atterberg limits test with spent carbide content determined on raw and stabilised soils are shown in Figure **2**. The liquid limit (LL) of the Ayeduase soil reduced by 23% whereas there was a 19% reduction in that of the Fumesua soil for 10% spent carbide content. There were 9% and 7% increases in the plastic limits of the Ayeduase and Fumesua soils respectively.

The reduction in liquid limits and increase in the plastic limits of the soils resulted in about 67% reduction in the Plasticity indices (PI) for both soils with increasing spent carbide content.

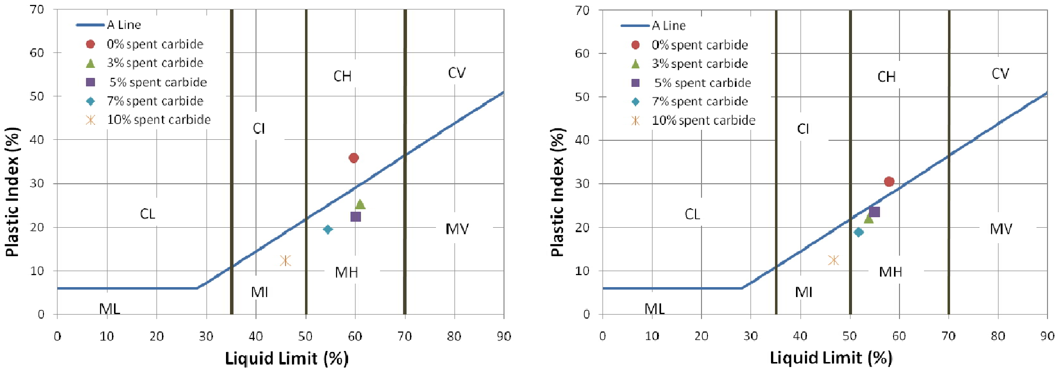


Ayeduase soil Fumesua soil

Figure 2. The variation of Atterberg limits with spent carbide content

The reduction in plasticity characteristics of the soils could be due to the reaction between the clay size fraction of the soils and the calcium oxide (lime) in the spent carbide. Reference [19] found that the addition of pozzolanic materials to soils cause base exchange and adsorption of additional non-exchanged calcium ions. He noted that flocculation also takes place increasing the percentage of coarse particle which results in reduction in the plasticity index.

The reduction in the plasticity index resulted in a change in the plasticity classification of the soil (Figure 3). The addition of 3%, 5% and 7% of spent carbide changed the classification of both soils from inorganic clay with high plasticity (CH) for the natural soils to inorganic silt with high plasticity (MH) and further addition resulted in the soil classification as inorganic silt with intermediate plasticity (MI) at 10% spent carbide content.



Ayeduase soil Fumesua soil

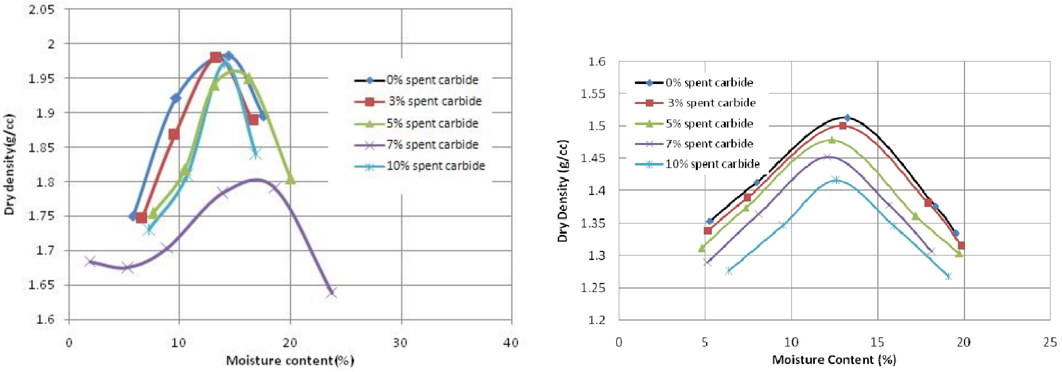
Figure 3. Plasticity classification of the stabilised soils

Effect of spent carbide on the compaction characteristics

The density-moisture relationship of the natural and carbide waste stabilised soils are presented in Figure **4**. The variation of maximum dry density (MDD) with spent carbide content of the soils is shown in Figure 5. It is found that MDD decreased with increasing spent carbide content. The maximum density of 2.1g/cc was recorded at 0% spent carbide whereas the minimum of 1.8g/cc was recorded for 10% spent carbide content for the Ayeduase soil.

The MDD of the Fumesua reduced from 1.5g/cc for the natural soil to 1.4g/cc for 10% spent carbide content. This reduction in maximum density could be partly due to the addition of a low density spent carbide material (specific gravity 2.4) to the lateritic soils (specific gravity 2.6 and 2.7 for Ayeduase and Fumesua soils respectively) which reduced the net density of the composite materials.

Reference [20] in a study of soil stabilisation by lime, have indicated that the decrease in the maximum dry density could be due to the formation of cementitious products which reduce the compactibility of the treated soil and thus the dry density.



Ayeduase soil Fumesua soil

Figure 4. Compaction characteristics of the stabilised soils

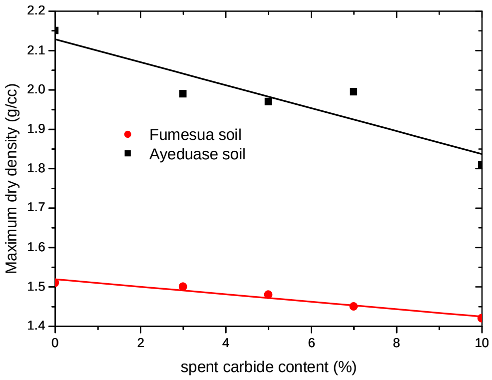


Figure 5 Variation of MDD with spent carbide content

The variation of optimum moisture content (OMC) with spent carbide stabilised soils is shown in

Figure **6**. There is an increase in OMC of the Ayeduase soil but that of the Fumesua soil reduced with increasing spent carbide content.

The increase in OMC of the Ayeduase soil may be due to the increasing demand of water by the clay size particles in the soil and the spent carbide system for the hydration process. As the spent carbide content is increased more water is required to achieve the same level of lubrication and workability and thus the OMC is increased. The Fumesua soil on the other hand had no clay size fraction upon addition of spent carbide contents greater than 3% and as such reducing the water content required for the pozzolanic reaction and hence the reduction in OMC.

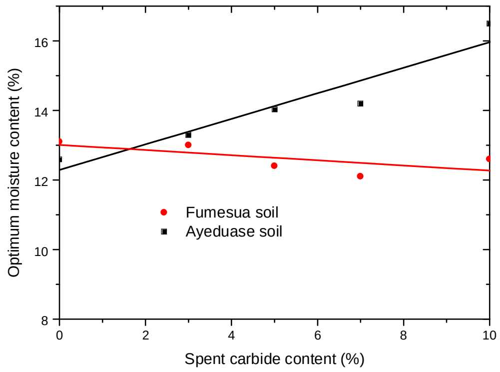


Figure 6 Variation of OMC with spent carbide content

Effect of spent carbide on the California bearing ratio vales and swells

The variation of the California bearing ratio values (CBR) with spent carbide content of the natural and stabilized lateritic soils is presented in

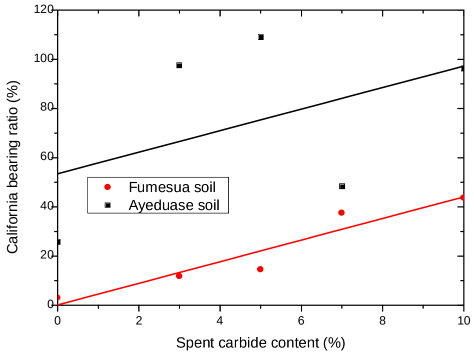


Figure 7. It is noted that CBR values generally increase with increasing spent carbide content. The CBR of the Ayeduase soil increased from 26% for the natural soil to 109 % at 5% spent carbide and then to 96% at 10% spent carbide whereas the Fumesua soil also increased from 3% to 44% for 0% and 10% spent carbide contents respectively.

The increase in the CBR value could be due to the reaction between spent carbide (lime) and clay mineral or with any other fine, pozzolanic components such as hydrous silica to form a tough water soluble gel of calcium silicate which cements the soil particles together [21]. This therefore increases the resistance to penetration thereby increasing the CBR value.

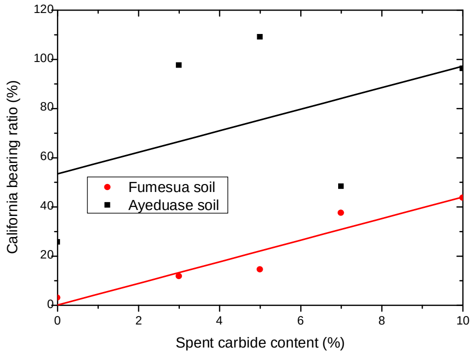


Figure 7 Variation of CBR value with spent carbide content

The variation of CBR swell with spent carbide content is shown in Figure **8**. It is observed that as spent carbide content is increased CBR swell decreases. The swell of the Ayeduase soil reduced from 0.6% for the natural soil to -9% at 10% spent carbide whereas the Fumesua soil also reduced from 5% to 1.5% for 0% and 10% spent carbide contents respectively. Negative swells were recorded for the Ayeduase soil which indicates that the soil samples shrunk with increasing spent carbide content.

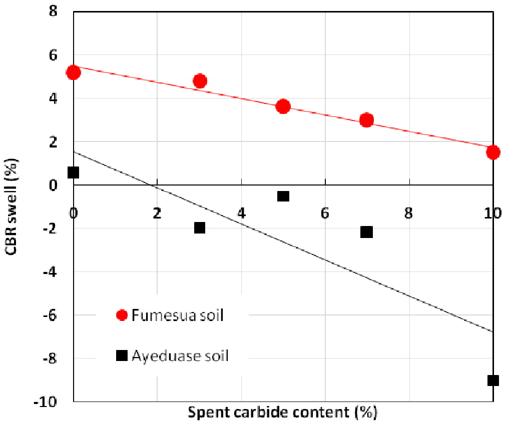


Figure 8 Variation of CBR swell with spent carbide content

Conclusion

From the study the following conclusions may be drawn:

- The addition of spent carbide significantly affected the fines contents of the soils which resulted in the reduction of clay size content and an increase in silt contents.
- There was also a general reduction in the plasticity characteristics of the soils

resulting in a change in the classification from inorganic clay of high plasticity (CH) for the natural soils to inorganic silt of intermediate plasticity (MI) for 10% spent carbide content.

- The maximum dry densities of both soils decreased with increasing spent carbide content.
- The optimum moisture content of the Ayeduase soil increased whereas the Fumesua soil reduced with spent carbide content.
- The California bearing ratio values increased with increasing spent carbide contents for both soils.
- There were general reductions in CBR-swell values.
- From the forgoing the spent carbide has the potential for use as stabilizer because it is capable of improving the geotechnical characteristics significantly.

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