# Performance of Lateritic Soils Stabilized with Both Crushed Rock Aggregates and Carbon Black as a Pavement Base Layer

Brian Tugume, Isaac Owani, Samuel Jjuuko(✉), and Denis Kalumba

Uganda Christian University, Mukono, Uganda
sjjuukol@gmail.com

**Abstract.** The increased crushed rock aggregate consumption resulting from road construction has greatly contributed to the depletion of national rocks in Uganda, hence environmental degradation. The purpose of this study was therefore to investigate the use of carbon black in reduction on the amount of crushed rock aggregates used in mechanical stabilization of unsuitable lateritic soils for road base construction. Preliminary tests on the lateritic soil were carried out to determine if the soil required stabilization. The test results classified the soil as Clayey Gravel with Sand of high plasticity based on the Unified Soil Classification System (USCS) and it required stabilization for use on road base. The combined effect of carbon black and crushed rock aggregates was investigated based on the compaction characteristics, Atterberg Limits, Particle size distribution and California Bearing Ratio tests. Results obtained were analyzed graphically and a blend of 50% lateritic soil, 40% aggregates and 10% carbon black was found to be the most effective in producing a suitable base material. It gave a CBR of 69.4 at 95% relative compaction and a plasticity index of 7 which meet the requirements of CBR above 60% as per the General Specifications for Road and Bridges (2004) of the Ministry of Works, Housing and Communication in Uganda. In relation to previous research, by Jjuuko et al. (2014) which recommended 50% aggregates and 50% lateritic soil, there is a 10% reduction in crushed rock aggregate consumption.

**Keywords:** Stabilization · Crushed rock aggregate · Carbon black
Lateritic soil

## 1 Introduction

The deterioration of roads in Uganda, since 1996, due to inadequate routine and periodic maintenance and rehabilitation led to serious economic challenges including transport inefficiency (National Development Plan 2010; Jjuuko et al. 2014). The government intervened by increasing the funding to the road sector in order to resuscitate the economy since 2005. This led to extensive improvements through the design, rehabilitation and maintenance of the road infrastructure throughout the country (Uganda National Roads Authority 2012). This, subsequently, drastically increased the quarrying sector in Uganda resulting into an increase in aggregate production throughout the country.


L. Zhan et al. (Eds.): ICEG 2018, ESE, pp. 382–388, 2019.
https://doi.org/10.1007/978-981-13-2221-1_39

Considering the historical statistics, the quarrying sector grew by 8% in fiscal year 2005-06, 14% in fiscal year 2006-07 and in 2013, the production of aggregates increased by 437% making it 109,906 metric tons (Uganda Bureau of Statistics 2014). According to Arm (2003), the road construction industry is accountable for about half of the aggregate consumption worldwide. Hence a main contributor to natural rock degradation. However, Newman et al. (2012) state that traditional aggregate materials used in the road base, such as natural rock, gravels and sands, can be replaced by recycled materials, repurposed waste, or alternative processes so as to uphold sustainability.

This research therefore sought to use carbon black in reduction on the amount of crushed rock aggregates used in road base construction in Uganda. The mechanical stabilization of suitable lateritic soils for road base construction using carbon black and crushed rock as a means of reduction in resource consumption, diversion of waste carbon black from landfill and reduced quarrying was investigated.

## 2 Materials and Methods

### 2.1 Carbon Black

Carbon black was sourced from GM Tire Recycling Plant located in Njeru in Eastern Uganda (00 22′42.9″ N 330 08′10.4″ E) which carries out pyrolysis of scrap tires. The carbon black extracted from the pyrolysis process is of very low purity and cannot be used in tire manufacturing. Its disposal is very problematic and this has triggered further research in its usage in concrete, asphalt and electrical insulation (Clark et al. 1993). According to the International Carbon Black Association (2016), the primary particles of carbon black are fused/covalently bonded together making its particle size distribution not relevant. In addition, the spheroidal particles strongly bond/fuse together to form discrete entities called aggregates which have a robust structure and are able to withstand shear forces. Furthermore, carbon black is non plastic and thus can replace the plastic fines in gravel with clay (or silty clay).

The chemical constituents of the obtained carbon black were tested from Makerere University, Department of Geology and Petroleum Studies laboratory. The sample was analyzed for Oxygen (O2), Iron (Fe), Zinc (Zn), Carbon (C) and Sulphur (S). During analysis, the sample was digested and the resultant solution analyzed. The results obtained as shown in Table 1 were expressed in parts per million (ppm). Perkin Elmer Analyst 400 equipment was used in the analysis. According to Roy et al. (1990), pyrolyzed carbon black includes 75% carbon, 9% ash, 4% sulfur, and 12% of butadiene copolymer.

### 2.2 Crushed Rock Aggregates

Crushed rock aggregates of size ranging from 0.075–37.5 mm were obtained from a quarry owned by SBI International Holdings (UG) 21 kms from Ndese town off Kayunga Road.

**Table 1.** Chemical content of the utilized carbon black

| Parameter | Content (%) |
|---|---|
| Carbon | 79.8 |
| Ash | 16.754 |
| Oxygen | 2.8 |
| Sulphur | 0.61 |
| Iron | 0.03131 |
| Zinc | 0.001298 |

## 2.3 Lateritic Soil

The soil sample was obtained from a borrow pit owned by SBI International Holdings (UG), 60 kms from Mukono town along Kayunga Road. The tests conducted on the sample showed it was a reddish brown gravel with clay (or silty clay) of high plasticity. According to the Unified Soil Classification System, the soil was classified as Clayey Gravel (GC) with Sand. The sample consisted of 50.1% gravel, 37.5% sand and 12.4% fines as shown in Table 2. The material did not meet all the requirements for base construction according to the Ministry of Works, Housing and Communication (MoWH&C) General Specifications for National Roads of 2004, (Table 4.1), in reference to Atterberg Limits and 4-days soaked California Bearing Ratio (CBR) hence the need to be stabilized.

## 2.4 Sample Preparation

The samples for laboratory testing were prepared in accordance with BS 1377 Part1:1990. On account of the fact that some tropical soils are sensitive to pre-test drying methods, air-drying was undertaken. Other pre-test sample preparation methods included pulverization, sieving and sub-sampling (coning, quartering and riffling). After air-drying, index properties tests were carried out for classification.

In order to investigate the effect of carbon black (CB) and crushed rock aggregates (CRR) on the properties of lateritic soils, specimens with specified amounts of CB, CRR and soil were prepared in different mixes; Mix I (100% soil, 0% CB, 0% CRR), Mix II (50% soil, 50% CB, 0% CRR), Mix III (50% soil, 40% CB, 10% CRR), Mix IV (50% soil, 30% CB, 20% CRR) and Mix V (50% soil, 20% CB, 30% CRR), Most specifying bodies permit the use of recycled materials as a portion of the road base. According to BS 6543 for waste materials and industrial byproducts, a maximum of 50% carbon black by weight of total mass could be used. The mixing was done mechanically on a metal tray. For consistency, soil was mechanically blended before mixing with CB and CRR. Tests of physical properties of the different blends/mixes were conducted.

**Table 2.** Physical and mechanical properties of the soil sample and requirements for base course layers of G60 materials

| Physical property | Reference | Standard (MoWH&C, 2004) | Soil sample |
|---|---|---|---|
| Sieve size (mm) | BS 1377: part 2 | Grading limits (%) passing sieve | (%) passing sieve |
| 63 | | 100 | 100 |
| 37.5 | | 80–100 | 100 |
| 20 | | 60–95 | 91.8 |
| 5 | | 30–65 | 51.8 |
| 2 | | 20–50 | 29.5 |
| 0.425 | | 10–30 | 23 |
| 0.075 | | 5 – 15 | 12.4 |
| *Classification tests* | | | |
| Liquid limit (%) | BS 1377: part 2 | 40 | 46.2 |
| Plastic limit (%) | BS 1377: part 2 | – | 21.2 |
| Plastic index (%) | BS 1377: part 2 | 12 | 25 |
| Linear shrinkage (%) | BS 1377: part 2 | 6 | 12.1 |
| *Strength tests* | | | |
| MDD kg/m$^3$ | BS 1377: part 4 | – | 2073 |
| OMC (%) | BS 1377: part 4 | – | 9.4 |
| 4 Days-Soaked CBR | BS 1377: part 4 | Minimum 60 | 31.5 |
| Swell percent | BS 1377: part 4 | Maximum 1.0 | 0.15 |

### 2.5 Tests

The following tests were carried out on the prepared specimens:

- Atterberg limits test in accordance with BS 1377:Part2:1990.
- Proctor compaction test in accordance with BS 1377:Part4:1990 for natural gravel and BS 1924:Part2:1990 for stabilized lateritic gravel.
- California Bearing Ratio test in accordance with BS 1377:Part4:1990 for natural gravel and BS 1924:Part2:1990 for stabilized lateritic gravel.

## 3 Results and Discussion

### 3.1 Atterberg Limits

The liquid limit of the lateritic soil sample of 46.2% decreased to 39.9% with a small addition of carbon black of 10% and 40% CRR. This was due to the reduction in the amount of cohesive fines since carbon black is non-cohesive. Hence less water absorbed. The increased addition of carbon black visa vi reduced CRR percentages increased the liquid limit to a maximum of 59.2% at 50% soil, 20%, CRR and 30% CB as shown in Table 3. This was due to the fact that carbon black does not readily react

**Table 3.** Atterberg limits for various blends

| Description | Atterberg limits | | | | Compaction parameters | | CBR | | |
|---|---|---|---|---|---|---|---|---|---|
| | LL (%) | PL (%) | PI (%) | LS (%) | MDD (kg/m$^3$) | OMC (%) | 93 (%) | 95 (%) | 98 (%) |
| 100% soil | 46.2 | 21.2 | 25 | 12.1 | 2073 | 9.4 | 23.5 | 31.5 | 43.4 |
| 50% soil + 0% CRR + 50% CB | 59.1 | _ | Non plastic | 1.1 | 1360 | 11.2 | 7.3 | 17.6 | 31.5 |
| 50% soil + 10% CRR + 40% CB | 58.3 | _ | Non plastic | 3.2 | 1370 | 10.8 | 9.6 | 20.1 | 35.8 |
| 50% soil + 20% CRR + 30% CB | 59.2 | _ | Non plastic | 2.6 | 1390 | 10.8 | 42.5 | 47 | 53.7 |
| 50% soil + 30% CRR + 20% CB | 51.6 | 41.6 | 10 | 4.4 | 2085 | 10.2 | 56.7 | 60.7 | 66.6 |
| 50% soil + 40% CRR + 10% CB | 39.9 | 32.9 | 7 | 3.4 | 2175 | 9.9 | 60.6 | 69.4 | 82.4 |

with water and is non-cohesive. Thus more water is needed to enable the mixture to bind together resulting in high liquid limits.

All the blends had a linear shrinkage less than 6% which is a recommended maximum for a road base material. The sample was made less expansive which is an improvement on its engineering properties. From Fig. 1.1, the Plastic Index (PI) of the stabilized soil decreased greatly with increasing carbon black content, from 25% for the neat sample to 7% at just 10% carbon black content and 40% CRR. With an increase in carbon black content, the blends became non plastic. This decrease in PI was attributed to a reduction in the clay fine content with increasing carbon black content which is non plastic. Clay fines are responsible for retaining water. This explains why the neat sample has a higher PI. The reduction in PI is considered an improvement to the engineering properties of the soil since it reduces the sensitivity of the soil to wetting and its ability to swell. Based on the general specifications for roads and bridges, all the road base materials must have a maximum PI of 12.

## 3.2 Maximum Dry Density (MDD) and Optimum Moisture Content (OMC)

From the laboratory test results, it was observed that MDD of the lateritic soil increased with increase in the percentages of crushed rock aggregates used. That is from 1370 kg/m$^3$ at 10% CRR, 1390 kg/m$^3$ at 20% CRR, 2085 kg/m$^3$ at 30% CRR, 2170 kg/m$^3$ at 40% CRR and 2278 kg/m$^3$ at 50% CRR. Adeyemi and Afolagboye (2013) state that grading is directly proportional to MDD of the material. As the coarse fraction of the mixture increases with an appropriate amount of fines in the blend, the volume of void containing air is diminished. This way the soil particles get closer due to the new arrangement hence increase in dry density.

Similarly, increment in carbon black content led to a proportionate increase in the fines fraction of the mixture. This lowered MDD of the material because as the gravel particles reduced, the fines in the material settled very fast and could not offer enough resistance on compaction hence a reduction in the dry density. It is also known that for well-graded soils, the maximum dry density tends to be higher than for poorly graded soils.

It is notorious that the increment in the fines content tends to increase the maximum dry density up to a maximum point (2175 kg/m$^3$ as for this study), followed by a reduction in the maximum dry density thereafter (1360 kg/m$^3$ in this study), (Guerrero 2004).

The OMC is the water content of a given soil sample at which its maximum dry density can be achieved after a given compaction effort. OMC of the blends increased with increase in the carbon black content, at reduced CRR percentages. That is from 9.4% for the neat soil to 9.9% at 10% CB, 10.2% at 20% CB, 10.8% at 30% and 40% CB and 11.2% at 50% CB. This increase in OMC is due to the increase in surface area resulting from increase in carbon black content. Carbon black has a large surface area of 15 to over l00m2/g (Yao and Monismith 1986). This increases the soil's affinity for water and thus small carbon black content (10%) should be considered in the stabilization of materials for a road base construction.

### 3.3 California Bearing Ratio (CBR)

The 4-day soaked CBR values increased from 31.5% for the neat soil sample to 69.4% at 10% CB and 40% CRR at 95% MDD. The results of CBR vs carbon black content are detailed in Fig. 5. The CBR values reduced with increase in the carbon black content. This can be attributed to reduced mechanical strength in the blends due to increased concentration of carbon black. Whilst as the CRR percentages increased, the 4-day soaked CBR values increased. This is because the aggregates are more resistant to crushing under gradually applied loads. This increase in the CBR values of the blends is considered a great improvement in the engineering properties of the soil in regard to road base construction.

## 4 Conclusion

A mixture containing 50% lateritic soil, 40% CRR and 10% carbon black is recommended for road base construction. It resulted into the highest CBR value of 69.4% at 95% compaction, a PI of 7 and MDD of 2170 kg/m3. Thus met all the requirements for base construction according to the Ministry of Works, Housing and Communication (MoWH&C) General Specifications for National Roads of 2004.

## References

Adeyemi GO, Afolagboye LO (2013) Mechanical stabilization of a migmatite gneiss-derived lateritic soil from Southwestern Nigeria. Electron J Geotech Eng 18:1847–1858

Arm M (2003) Mechanical properties of residues as unbound road materials. Land and Water Resources Engineering. TRITA-LWR 1007 PhD, KTH Royal Institute of Technology, Stockholm

Clark C, Meardon K, Russell D (eds) (1993) Scrap tire technology and markets. William Andrew Inc., Oxford

Guerrero AMA (2004) Effects of the soil properties on the maximum dry density obtained from the standard proctor test. University of Central Florida Orlando, Florida

International Carbon Black Association (2016) Carbon Black User's Guide. http://www.carbon-black.org/images/docs/2016-ICBA-Carbon-Black-User-Guide.pdf. Accessed 22 Feb 2017

Jjuuko S, Kalumba D, Bbira S, Bamutenda JB (2014) Blending of marginally suitable lateritic soils for use in base construction. In: Proceedings of the IV South American young geotechnical engineers conference –IVSAYGEC, Bogota, Colombia

Ministry of Works, Housing and Communications (2004) General Specifications for Road and Bridge Works, Series 3000; Earthworks and Pavement Layers of Gravel or Crushed Stone

National Development Plan (2010) Uganda's National Development Plan (2010/11-2014/15) http://www.undp-alm.org/resources/naps-least-developed-countries-ldcs/uganda%E2%80%99s-national-development-plan-201011-201415-%E2%80%93. Accessed 23 Feb 2013

Newman P, Hargroves K, Desha C et al (2012) Reducing the environmental impact of road construction. Sustainable Built Environment National Research Centre, Queensland, Australia

Roy C, Labrecque B, Caumia B (1990) Recycling of scrap tires to oil and carbon black by vacuum pyrolysis. Res Conser Recycling 4(3):203–213

Uganda Bureau of Statistics (2014) Statistical Abstract 2014 http://www.ubos.org/onlinefiles/uploads/ubos/statistical_abstracts/Statistical_Abstract_2014.pdf. Accessed on 22 Feb 2017

Uganda National Roads Authority (2012) Ongoing Projects http://www.unra.go.ug/index.php?option=com_content&view=category&id=43&Itemid=66. Accessed 23 May 2013

Yao Z, Monismith CL (1986) Behaviour of asphalt mixtures with carbon black reinforcement. In: Association of asphalt paving technologists, vol 55, pp 564–585