Columbite Tailings-Reclaimed Asphalt Pavement Blends As Highway Material

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Abstract
Columbite tailings generated from extraction process of separating valuable fractions from particular ore are found disposed in large quantities at mining sites and/or premises of mining companies. Massive highway reconstruction and maintenance works also generates large volume of reclaimed asphalt pavements waste. This paper present results of the laboratory evaluation of of reclaimed asphalt pavements-columbite tailings blends with a view to determine its suitability for use as flexible pavement material. The mixtures were subjected to Reduced British Standard light (Reduced Proctor), British Standard light (standard Proctor), West African Standard and British Standard heavy (Modified Proctor) compactive efforts to determine the moisture-density relationship, California bearing ratio, durability and water absorption of the blends. The reclaimed asphalt pavements waste improved with columbite tailings treatment. The maximum dry density increased while the optimum moisture content decreased with higher columbite tailings in the blends. The peak California bearing ratio values of 27.5 % (unsoaked) for 40% RAP + 60% CT using the BSL (SP) compactive effort and 24.4 % (soaked for 24 hours) for 50% RAP + 50% CT using the BSH (MP) compactive effort. The optimum blends satisfied durability requirements with insignificant water absorption and can be used as subgrade material in flexible pavement construction. Further work may be encouraged to assess resilient modulus of this material under cyclic load.

Keywords: Nigerian economy, petroleum industry, corrosion deteriorations, previous data, statistical analysis

INTRODUCTION
The life of a road can be prolonged through good design, construction and maintenance practice. Road maintenance and reconstruction however, generate large volume of the wasted scarified surfacing material otherwise referred to as reclaimed asphalt pavement that are disposed along pavement alignments, thus constituting environmental hazard. The needs for reconstruction of failed roads have lead to increased demand for good quality materials that are not readily available along the road alignment. Hence, the need to generate alternative treated waste materials that can withstand traffic loads and satisfy every requirements for usage as highway pavement material. This will encourage environmentally sustainable practices.

Columbite is the main important mineral form of nobium (Ayeni et al., 2012). They are associated with radioactive minerals as impurities such as monazite, zircon among others. These minerals cause hazards to human health during mining and milling (Mangset and Sheyin, 2009). Columbite [(Fe, Mn Nb₂O₅)] contains more percentage of the oxides of Nobium (Nb₂O₅) than Tantalum (Ta₂O₅) (Ogbonna et al., 1999). The characteristics of columbite tailings depends greatly on the ore mineralogy together with the physical and chemical processes used to extract the columbite tailings. Previous study of columbite tailings from Jos Rayfield dump site show the particle size analysis result to contain about 99.6 % coarse size aggregates with 76.5 % gravel size, 21.9 % sand size and 0.4 % silt size. The chemical analysis result of the Rayfield tailings passing 1 mm sieve aperture shows 40.3 % silica, 12.9 % iron oxide, 7.8 % zirconia and 12.5 % columbite as its major constituents (Ayeni et al., 2012). It has not found any known application as highway material.

Reclaimed asphalt pavement (RAP) is produced by milling, ripping, breaking, crushing, or pulverizing types of equipment and is mostly generated during pavement rehabilitation and reconstruction, and contains high-quality, well-graded aggregates coated with asphalt cement when properly crushed and screened (Osinubi et al., 2012). Majority of RAP are obtained from scarified surfacing and wearing course of existing road while undertaking pavement repairs and reconstructions. The aged bitumen present in a RAP has physical properties that make it undesirable for reuse without modification (Chen et al., 2007). This has caused the recycling of pavement materials to become a viable alternative to be considered in road maintenance and rehabilitation.
Previous works consider the treatment of RAP with coal fly ash and other pozzolans, and RAP with fresh aggregates. The results show that the use of class C and off-specification coal fly ash for stabilization promotes sustainable construction and improves the pavement structure prepared from road surface gravel (RSG) and reclaimed asphalt pavement materials (RPM) (Edeh et al., 2013).

The work is significant in that it presents alternative material of RAP-CT blends as highway pavement material thereby reducing the amount of waste materials requiring disposal and providing construction material with significant savings over new materials.

MATERIALS AND METHODS

Materials

Reclaimed Asphalt Pavements

Reclaimed asphalt pavement (RAP) was obtained from the scarified road surfacing and wearing courses spoiled along Makurdi-Otukpo road at Makurdi (latitude: 9° 55’ 06’’ N) and (longitude: 8° 29’ 18’’ E) in Benue State, North Central Nigeria. The RAP was crushed using a hand-hammer, from its “lump” state to smaller sample sizes passing through a 20 mm aperture sieve in accordance to ASTM C702-98 (2003) and air-dried before use for the test. The RAP consists of high-quality, well-graded aggregate coated with asphalt cement.

Columbite Tailings

Bulk samples of the columbite tailings (CT) were obtained from the stockpiles at P and H Global Services site along Alheri-Zaria road at Jos (latitude: 9° 56’ 00’’ N, longitude: 8° 53’ 00’’ E) in Plateau State, North Central Nigeria. The columbite tailing passing through 1.18 mm aperture sieve in accordance to ASTM C702-98 (2003) were oven-dried in the geotechnical laboratory of the Univ. of Agriculture, Makurdi, before use for the test.

Methods

Samples of RAP, CT and RAP-CT blends were tested to determine the index properties, particle size distribution, soil classification, specific gravity, water absorption and compaction characteristics in accordance with procedures outlined in standard ASTM codes. CT in increasing stepped concentration of 10% was mixed with RAP in decreasing stepped concentration of 10% and the optimum mix was determined during the preliminary mix design tests. The specification relating to the use of these indices for highway design and construction in Nigeria are given in FMW&H (1997).

**RAP-QW Mix Design and the Determination of Atterberg Limits**

The mix ratio adopted for this work was to alternately vary the RAP and CT contents with the increase of one component in the mix and the other was decreased in order to establish the blending ratio of RAP to CT mixes that is needed to provide adequate bearing capacity. A summary of the RAP-CT mix ratios used in the study are given in Table 1.

<table>
<thead>
<tr>
<th>RAP, %</th>
<th>CT, %</th>
<th>Resulting combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
<td>100% CT</td>
</tr>
<tr>
<td>10</td>
<td>90</td>
<td>10% RAP + 90% CT</td>
</tr>
<tr>
<td>20</td>
<td>80</td>
<td>20% RAP + 80% CT</td>
</tr>
<tr>
<td>30</td>
<td>70</td>
<td>30% RAP + 70% CT</td>
</tr>
<tr>
<td>40</td>
<td>60</td>
<td>40% RAP + 60% CT</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>50% RAP + 50% CT</td>
</tr>
<tr>
<td>60</td>
<td>40</td>
<td>60% RAP + 40% CT</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
<td>70% RAP + 30% CT</td>
</tr>
<tr>
<td>80</td>
<td>20</td>
<td>80% RAP + 20% CT</td>
</tr>
<tr>
<td>90</td>
<td>10</td>
<td>90% RAP + 10% CT</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
<td>100% RAP</td>
</tr>
</tbody>
</table>

**Physical Properties**

The particle size distribution of RAP, CT and the various RAP-CT blends were determined in accordance with ASTM D6913-04 (2009). Test mix proportions for the Atterberg limit determinations were prepared on a percent by dry weight basis using the material passing the 0.425 mm sieve in accordance with ASTM D4318-10 (1994). These tests were carried out on all RAP, CT and RAP-CT blends and the results show that the blends were non-plastic and possess no cohesion.

About 50-100g of air-dried sample of RAP, CT and the various RAP-CT blends were passed through a sieve with a 2.36 mm sieve aperture, and the specific gravity determined in accordance with ASTM C 127 (1994).

**Compaction Test**

The compaction characteristics of RAP, CT and the various RAP-CT blends were assessed using the reduced British standard light, RBSL (reduced Proctor, RP), British standard light, BSL (standard Proctor, SP) compaction, achieved using a 2.5 kg rammer falling through 30 cm onto three layers, with each layer receiving 15 and 25 uniformly distributed blows, respectively, West African standard, WAS and British standard heavy, BSH (modified Proctor, MP), achieved using a 4.5 kg rammer falling through 45 cm onto five layers, with each layer receiving 10 and 25 uniformly distributed blows, respectively (ASTM D698-07e1, 1994).

**California Bearing Ratio (CBR) Test**

The California bearing ratio (CBR) test was performed on RAP, CT and RAP-CT blends in accordance with ASTM D1883 - 07e2, (1994). Some of the specimens compacted for the CBR tests were
wrapped in an air and water-tight cellophane bags for 24 hours (unsoaked condition) while the other specimens were completely soaked in water for 24 hours (soaked condition) before the CBR tests.

**Durability Test**

Durability test was performed on all the specimens of RAP, CT and the various RAP-CT blends, using the aggregate impact value (AIV) method following the procedures described in BS 812-112 (1990). The compacted specimens were cured under uniform moisture distribution (UMD) for 7 days after which a part of each compacted mix proportion is then partially immersed in water for another 7 days. The specimens were then subjected to aggregate impact test in accordance with BS 812-112 (1990). This action breaks the aggregate to a degree that is dependent on the impact resistance of the material. This degree was assessed by sieve analysis on the impacted specimen and is taken as the aggregate impact value (AIV).

The AIV analysis method was used to assess the comparative resistance to loss in strength in terms of the AIV of the mixes after the impact because of the non-plastic properties of the RAP-CT blends. The degradation in terms of increased percent passing sieve 2.36 mm aperture, of the blends after impact represent the loss in strength of the RAP-CT blends when the composite material is cured under uniform moisture distribution (UMD) for 14 days, and for the mix samples cured under UMD for 7 days and immersed in water for another 7 days. The AIV corresponding to 100 – AIV (%) resistance to loss in strength (RLS) for the two test conditions were compared.

The water absorption characteristic was assessed as the difference in weight of the samples before immersion in water and the weight of the same samples after 7 days immersion in water, expressed as percentage of the original weight of samples before immersion in water.

The specification relating to the use of these indices for highway design and construction are given in Ola (1974).

**RESULTS AND DISCUSSION**

**Oxide composition of columbite tailings**

The oxide composition of the CT is given in Table 2. The calcium oxide (CaO) content is 1.40 % and the silicon oxide (SiO₂) content is 16.00 %. The CaO/SiO₂ ratio, which is indicative of the cementing potential, is 0.0875, SiO₂ + Fe₂O₃ = 46.82 %, with no Al₂O₃ in the tailings. Loss on ignition (LOI), which is the indication of the amount of unburned carbon in the columbite taings is 1.01 %. According to ASTM C 618-92a (1994) specification for coal fly ash, the columbite tailings used for this study falls under class F and like coal fly ash, is not self-cementing.

<table>
<thead>
<tr>
<th>Oxides</th>
<th>CaO</th>
<th>SiO₂</th>
<th>Nb₂O₅</th>
<th>Fe₂O₃</th>
<th>Nb₂O₅</th>
<th>Ta₂O₅</th>
<th>Ag₂O</th>
<th>TiO₂</th>
<th>K₂O</th>
<th>MnO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration (%)</td>
<td>1.40</td>
<td>16.00</td>
<td>0.15</td>
<td>30.82</td>
<td>4.20</td>
<td>0.54</td>
<td>1.60</td>
<td>36.50</td>
<td>1.40</td>
<td>1.28</td>
</tr>
<tr>
<td>Oxides</td>
<td>ZnO</td>
<td>ZrO₂</td>
<td>Y₂O₃</td>
<td>Nb₂O₅</td>
<td>Ta₂O₅</td>
<td>H₂O₂</td>
<td>PbO</td>
<td>Bi₂O₃</td>
<td>WO₃</td>
<td>LOI</td>
</tr>
<tr>
<td>Concentration (%)</td>
<td>0.095</td>
<td>3.50</td>
<td>0.12</td>
<td>0.40</td>
<td>0.31</td>
<td>0.19</td>
<td>0.19</td>
<td>0.15</td>
<td>0.07</td>
<td>1.01</td>
</tr>
</tbody>
</table>

**Particle Size Distribution**

The particle size distribution curves of RAP, CT and the various RAP-CT blends are shown in Fig. 1. The gradation of 100 % RAP is composed of 99.6 % coarse particles (97 % gravel and 2.6 % sand) and 0.4 % fines with coefficient of uniformity, C_u = 5.7 and coefficient of curvature, C_c = 1.5, and falls under the American Association of State Highway and Transportation Officials (AASHTO) classification of A-1-a (granular materials). Because 100 % RAP satisfy the requirements C_u>4 and 1<C_c<3, it is described as well graded sandy GRAVEL. 100 % CT is composed of 99.18 % coarse particles (31.8 % gravel and 67.38 % sand) and 0.82 % fines with coefficient of uniformity, C_u = 2.2 and coefficient of curvature, C_c = 0.92, and falls under the AASHTO classification of A-3 (granular materials). 100 % CT does not satisfy the requirements of well graded sandy soil (C_u>6 and 1<C_c<3), hence, it is described as poorly graded gravelly SAND. The particle size distribution of RAP-CT blends shows that it is composed of 85.1 - 99.6 % coarse aggregates (42.4 – 92.4 % gravel and 7.2 – 56.99 % sand) with 0.4 – 0.62 % fines, coefficient of uniformity, C_u in the range 1.2 – 45.5 and coefficient of curvature, C_c in the range 0.08 – 7.3, and falls under the AASHTO classification in the range of A-1-a to A-3 (granular materials). The various RAP-CT blends can be described in the range of poorly graded gravelly SAND – poorly graded sandy GRAVEL and are rated to be excellent highway material (Das, 1998). The improved particle size grading of the RAP-CT blends may be due to the better packing of RAP-CT particles (Grubb et al., 2006).
3.3. Specific gravity

The specific gravity of 100% RAP, 100% CT and the various RAP-CT blends are given in Fig. 2. The specific gravity values of 100% RAP and 100% CT are 1.99 and 4.91, respectively. The specific gravity of RAP falls within the recommended values in the range of 1.94 – 2.30 stated in FHWA (2008). The specific gravity values of the various RAP-CT blends show increased value with increased CT content in the blends. The specific gravity values are in the range 2.29 – 4.13 with a peak value of 4.13 recorded for 10% RAP + 90% CT blend and the least value of 2.29 recorded for 90% RAP + 10% CT blend. The increased specific gravity of the RAP-CT blends with increased CT content in the mix may be due to fine particles of the CT filling the void spaces between the larger particles of RAP, leading to increased density of the soil matrix (Osinubi and Edeh, 2011).

Compaction Characteristics

Compactions of the samples were carried out using RBSL (RP), BSL (SP), WAS and BSH (MP) energies to obtain moisture – density relationships. The test results show a trend of increase in the maximum dry densities (MDD) of the RAP-CT blends with a corresponding decrease in the optimum moisture contents (OMC) as the CT contents of the mixes increased (see Figs. 3 and 4).

For the various RAP-CT blends, the MDD increased from; 1.37 to 2.52 Mg/m$^3$ for RBSL (RP), 1.41 to 2.54 Mg/m$^3$ for BSL (SP), 1.59 to 2.55 Mg/m$^3$ for WAS and 1.68 to 2.74 Mg/m$^3$ for BSH (MP), as the CT content of the blends increased from 10 to 90% and the proportion of RAP decreased from 90 to 10% in the blends. The corresponding OMC values decreased from; 39.10 to 18.10 % for RBSL (RP), 38.30 to 16.80 % for BSL (SP), 36.20 to 16.00 % for WAS and 32.80 to 15.10 % for BSH (MP), respectively.

The observed trend of MDD and OMC with higher CT contents in the RAP-CT blends may be attributed to the higher specific gravity of CT as compare to
that of RAP and the better packing of the RAP–CT blends (Grubb et al., 2006).

**California Bearing Ratio**

The California bearing ratio (CBR) of 100% RAP, 100% CT and the various PAP-CT blends are shown in Fig. 5.

![Fig. 5](image)

The unsoaked (UCBR) and soaked CBR (SCBR) values for 100% RAP and 100% CT are 3.1 and 4.3 %, and 11 and 18.4 % for RBSL (RP); 2.5 and 2.5 %, and 14.1 and 20.2 % for BSL (SP); 5.5 and 4.6 %, and 8.0 and 12.8 % for WAS; 11.0 and 10.1 %, and 9.8 and 18.9 % for BSH (MP), respectively (see Fig. 5) while the variations of CBR with the various RAP + CT blends are in ranges; 3.7 – 15.3 % (Unsoaked) and 3.1 – 17.1 % (soaked) for RBSL (RP), 2.8 – 27.5 % (Unsoaked) and 4.6 – 20.8 % (soaked) for BSL (SP), 5.5 – 22.6 % (Unsoaked) and 3.1 – 21.4 % (soaked) for WAS, and 8.0 – 17.7 % (Unsoaked) and 9.2 – 24.4 % (soaked) for BSH (MP). The peak unsoaked and soaked CBR values of 27.5 % (BSL) and 24.4 % (BSH) were recorded for 40% RAP + 60% CT and 50% RAP + 50% CT blends respectively.

The variation in the CBR is more likely due to agglomeration of the heterogeneous materials of the RAP–CT blends (Hatipoglu et al., 2008), the uniform distribution of the CT in the mixture (Li et al., 2009), and the particle-to-particle interactions between the particles of RAP and CT that dominate strength behavior (Grubb et al., 2006).

**Durability Characteristics**

The aggregate impact values (AIV) for 100% RAP, 100% CT and the various proportions of the all-in-aggregates RAP-CT blends, compacted using RBSL (RP), BSL (SP), WAS and BSH (MP) compactive efforts, at their respective OMCs and subjected to AIV analysis are shown in Fig. 6. The conventional criterion of a maximum allowable loss in strength of 20 % which correspond to 80 % resistance to loss in strength (RLS) reported by Ola (1974) was adopted for 100% RAP, 100% CT and the various proportions of the RAP-CT blends. The results show that RLS (resistance to loss in strength) for samples of 100% RAP and 100% CT cured under uniform moisture distribution (UMD) for 14 days, and for samples cured under uniform moisture distribution (UMD) for 7 days and immersed in water for another 7 days are 64 and 118.4 %, and 100 and 100 % that correspond to 36 and -18.4 %, and 0 and 0 % AIV respectively for RBSL (RP), 97.8 and 92.6 %, and 100 and 100 % that correspond to 2.2 and 7.4 %, and 0 and 0 % AIV respectively for BSL (SP), 88.1 and 93.3 %, and 100 and 100 % that correspond to 11.9 and 6.7 %, and 0 and 0 % AIV respectively for WAS and 95.6 and 83.5 %, and 100 and 100 % that correspond to 4.4 and 16.5 %, and 0 and 0 % AIV respectively for BSH (MP) compactive efforts. RLS (resistance to loss in strength) for the various samples of RAP-CT blends cured under UMD for 14 days, and for samples cured under UMD for 7 days and immersed in water for another 7 days are in the ranges; 98.6 – 111.1 and 99 – 108.3 % corresponding to -11.1 – 1.4 and -8.3 – 1 % AIV respectively for RBSL (RP), 99 – 118.5 and 89.2 – 115.5 % corresponding to -18.5 – 1.0 and -15.5 – 10.8 % AIV, respectively for BSL (SP), 98.2 – 105.6 and 91.7 – 105.5 % corresponding to -5.6 – 1.8 and -5.5 – 8.3 % AIV, respectively for WAS, and 92.2 – 127.9 and 91.7 – 113.6 % corresponding to -27.9 – 7.8 and -13.6 – 8.3 % AIV, respectively for BSH (MP) compactive efforts. 100% RAP with 64 % (14 days UMD) resistance to loss in strength corresponding to 36 % AIV did not satisfy the durability requirement (Ola, 1974) among all the mixes.

The results did not present any particular trend of RLS (resistance to loss in strength) for the mixes. The lower resistance to loss in strength values for the blends cured under UMD for 7 days and immersed in water for another 7 days as compared to the values for blends cured under UMD for 14 days may be due to increased contact areas between the coarse aggregates of various content of the RAP-CT blends, leading to increased finer particles of the mix proportions (Osinubi et al., 2012) while the higher resistance to loss in strength values for the blends when cured under UMD for 7 days and immersed in water for another 7 days as compared to the values for blends cured under UMD for 14 days is more likely due to agglomeration of the heterogeneous materials of the RAP-CT blends (Hatipoglu et al., 2008) and the uniform distribution of the CT in the mixture (Li et al., 2009), facilitating cohesion and frictional resistance between the particles in contact.
Water Absorption Characteristics

The water absorption characteristics for 100% RAP, 100% CT and the various RAP-CT blends, subjected to RBSL (RP), BSL (SP), WAS and BSH (MP) compactive efforts at their respective OMCs and MDDs are shown in Fig. 6.

The water absorption (WA) values for 100% RAP and 100% CT are 2.2 and 4.4 % respectively for RBSL (RP), 3.2 and 1.7 % respectively for BSL (SP), 2.8 and 3.1 % respectively for WAS and 1.8 and 2.5 % respectively for BSH (MP), while the variations of WA with the various RAP-CT blends are in ranges; 0.2 – 1.9 % for RBSL (RP), 0.3 – 3.9 % for BSL (SP), 0.1 – 3.2 % for WAS and 0.2 – 3.4 % BSH (MP) compactive efforts (see Fig. 6). The observed trend in water absorption may be due to agglomeration of the heterogeneous materials of the RAP-CT blends (Hatipoglu et al., 2008) and the uniform distribution of cement and CT in the mixture (Li et al., 2009).

CONCLUSIONS

The RAP + CT blends were prepared and evaluated in the laboratory to assess the suitability of RAP-CT blends as highway pavement materials. The particle size distributions of the RAP-CT blends improved with the addition of CT in the blends and falls under AASHTO classifications in the range A-1-a and A-3 described in the range of poorly graded gravelly SAND – poorly graded sandy GRAVEL.

The compaction characteristics were affected by the proportions of CT in the blends. The MDD increased as the OMC decreased with increased CT in the blends. The optimum CBR of 27.5 % (unsoaked) recorded for the 40% RAP + 60% CT blend using BSL (SP) compactive effort and 24.4 % (soaked) recorded for the 50% RAP + 50% CT blend can be used as subgrade material in road construction, and are durable as highway construction material with insignificant water absorption.

The experiments are based on local waste materials of RAP-CT blends generated and disposed in large quantities resulting in environmental problems. The evaluations of the blended wastes are limited to laboratory experiments whose results can be used as a control to field results. The empirical strength parameter of California bearing ratio is still used as a basis for characterizing road construction materials in developing countries of the world. Further work may be encouraged to assess resilient modulus of this material under cyclic load.

REFERENCES


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