Geosciences 2012, 2(5): 107-111
DOI: 10.5923/j.geo.20120205.01

Engineering-Geological Evaluation of Rock Materials from Bansara, Bamenda Massif Southeastern Nigeria, as Aggregates for Pavement Construction

Ndukauba Egesi*, **Akaha C. Tse**

Department of Geology, University of Port Harcourt, Nigeria

Abstract In this work, the properties of some basement rocks in Bansara area in the Nigerian sector of the Bamenda massif which determine their suitability for the production of aggregate for construction works were assessed to evaluate their performance as pavement materials. The rock materials evaluated were from Biotite-Granite, Granite-Gneiss, Schist and Greenstone rocks. The Biotite-Granite gave Aggregate Abrasion Value (AAV) of 22.0%, Aggregate Crushing Value (ACV) of 23.3%, Aggregate Impact Value (AIV) of 18.5% and water absorption of 0.54% while Granite-Gneiss has 27.0%, 26.1%, 22.8% and 0.73% and the Greenstone has 45.2%, 55.9%, 49.6% and 3.90% respectively. Although the Biotite-Granite and Granite-Gneiss possess the necessary criteria for use as construction aggregates, the Biotite- Granite is of better quality because of its exceptionally high strength value and low water absorption. The high resistance of Biotite-Granite and its low water absorption could be attributed to its mineralogical composition with interlocked grain boundaries. Greenstone has no value as aggregate material due to its high pore volume.

Keywords Rock strength, Engineering properties, aggregates, pavement, Basement Complex, SE Nigeria

1. Introduction

Natural construction aggregate is one of the most abundant natural resources and one of the most widely used. Construction aggregate is the sized, or crushed and sized, rock material used in concrete and asphalt, which make up most of highways, bridges, houses and other engineering works. Aggregates range in size from large boulders (rip rap) used as fill in large construction projects to finely-ground flour-sized particles used in paint, glass, plastic, medicine, agricultural feed and soil conditioners, and many other industrial and household products. Construction aggregates are also used in water purification, emissions control, soil erosion control, and other environmental improvement products.

More than 90% of asphalt pavement and 80% of concrete consist of construction aggregate. The remainder is a binder such as asphalt or cement. About 52% of all construction aggregate is crushed stone, while 48% of the remaining is sand and gravel. (Bolen, 2005).

Aggregates are essential not only as a foundation for pavements, but also constitute the cement that makes the road itself. When a road is finished, the upper layers provide protection for the sub-base. Nevertheless, water can freely pass through the open structure, so the constituent rock must be able to maintain its properties when in the wet state. It must be able to resist the mechanical and chemical weathering processes. During the construction process, the sub-base is used as track along which heavy construction machinery can run; it must therefore be able to withstand the weight and impact of such vehicles. Selecting the right aggregate material is imperative to overcome the frequent problem of pavement failure. In the various ways in which aggregate is used, it is exposed to a variety of stresses, and the response of the structure in which it is used will largely depend upon the properties of the aggregate. It need to resist heavy loads, high impacts and severe abrasion, and it needs to be durable in the prevailing environmental conditions. These properties will need to be tested and assured before the road is built. Similarly, after the initial trafficking and removal of any surface bituminous coating, vehicle will be traveling on the actual aggregate used in the mixture for the bulk of the life of the road surface. Thus they undergo substantial wear and tear throughout their life. In general, they should be hard and tough enough to resist crushing, degradation, and disintegration from any associated activities. Furthermore, they must be able to adequately transmit loads from the pavement surface to the underlying layers, and eventually the subgrade, otherwise premature structural failure could occur. Therefore, selecting aggregates with the necessary characteristics for a particular

* Corresponding author:
ndukauba.egesi@uniport.edu (Ndukauba Egesi)
Published online at http://journal.sapub.org/geo

site is imperative. Increase in road construction projects in Nigeria demands the location and development of suitable quarries that will provide aggregates close to their end market. This is because long haulage distance from existing production areas are not only cost-prohibitive and infeasible, but also initiate early deterioration or failure of existing roads which did not factor in heavy duty vehicular traffic during their design. This work was carried out to provide some geological information about some basement rocks of Obudu Plateau and the engineering properties of aggregates produced from them for use in civil engineering construction, especially pavements.

2. Location and Description of Rocks

Rock materials used in this study were obtained from rock masses in the Bansara area which is occurs at the terminal end of the Bamenda highlands of Cameroon in south-eastern Nigeria. It lies between latitude 6° 10′ to 6° 30′ N and longitude 8° 40′ to 9° 00′ E. It is bounded in the north by the Geological Survey of Nigeria sheet 290 (Ogoja) , sheet 305 (Mukuru) in the east, sheet 315 (Ikom) in the south, while the famous Obudu Plateau sheet 291 is in the north-eastern part of the study area. The area has elevation of about 1000m to 1500m above sea level. Thick equatorial rainforests and the rugged Obudu Plateau topography have limited detailed geological studies of Bansara area. In the past, the rocks in the Bansara area, have been classified as undifferentiated basement and granulites terrain (Ekwueme 1990, 1994; Umeji 1991; Iliya and Bassey, 1993; Ejimofor 1998; Ukaegbu 2003; Ukaegbu and Oti, 2005 and Nigeria Geological Survey Agency, GSDA, formerly Geological Survey of Nigeria;2006) together with other rocks in the Obudu Plateau. The rocks are predominantly migmatite-gneiss-schist complex and charnockite-enderbite-granite plutons while the subordinate rock units are amphibolites, quartzites, cataclasites, mylonites, gabbros, pegmatites, aplites and dolerites(Ukaegbu, 2003). Recent geologic mapping by the authors of Bansara sheet 304 NE/SE also show that the area is underlain by igneous and metamorphic rocks (Fig.1). The metamorphic rocks are gneisses, schists, amphiboites, quartzites and phyllites. The gneisses consist of several varieties, including granite gneiss, augen gneiss and migmatitic gneiss. They form several hills in the form of stocks and bosses and in some restricted, exposed and eroded lowlands, relicts of fractured and weathered schists were observed. Migmatitic schists were equally observed at Kekibe hills and Kakubuk area resembling an artificial pavement. The amphibolites are rare and occur as lenses in gneisses which were difficult to sample. The presence of quartzites veins in sandstones mapped at a location called Enyi Boje suggest it is of sedimentary origin. The charnockites which are believed to be of magmatic origin (Egesi and Ukaegbu, 2011) displayed contact metamorphic aureoles at Enyi Boje, Intraba hills and steep, massive dome features above 300m at Ashuben and Katabang areas. Other rock units are amphibolites, quartzites, pegmatites, aplites, cataclasites, and mylonites.

The Pan-African orogeny seems to have left its structural imprints on the rocks of this area as observed in the field. Toteu *et al.* (1990) correlated structural orientations in the NW-SE direction to an older Pan African deformation in northern Cameroon. Opinion is however divided on the occurrence of these structural imprints in the basement rocks. Rahaman (1976) is of the view that the last Pan-African tectonothermal event was so pervasive that it erased earlier structures. Other researchers are of the opinion that though pervasive, the Pan-African event did not completely homogenize the rocks in the basement as traces of earlier structures remain (Grant,1978; Onyeagocha and Ekwueme 1982; Ekwueme 1987; Oluyide 1988; Ukaegbu 2003; Ukaegbu and Oti.,2005). Ajibade, (1988) has distinguished the early migmatites in north-western Nigeria from the Pan-African migmatites on the basis of structural features. He observed that the early migmatites are typically banded and complexly folded unlike the Pan-African migmatites which are formed by alternation of schists and granitic rocks and containing no complex folds.

3. Materials and Methods

The types, nature and distribution of rocks in the area were delineated during a geological mapping exercise of rocks in the area using Nigerian Geological Survey Agency, sheet 304 Bansara NE after which geological map showing the distribution of the rocks in the area shown in Fig 1 was produced. Rock types used for this study included Biotite-Granite, Granite-Gneiss, migmatite schists and Greenstone. They were selected for analysis out of the many other rock types because of their abundance and ease of sampling.

Both petrographic and petrologic techniques, which are systematic description of rocks based on observations in the field, hand specimen, and in thin sections, were employed during the study. In assessing the potential of a rock for use as an aggregate, the first requirement is a full petrographic study of the rocks, identifying its mineralogy, grain size, texture, fabric (sum of textural and structural features), and the weathering states which are determined by the geological processes that formed the rock. These processes decide the ways in which a rock may fail, and also help to optimize production of good-quality aggregates.

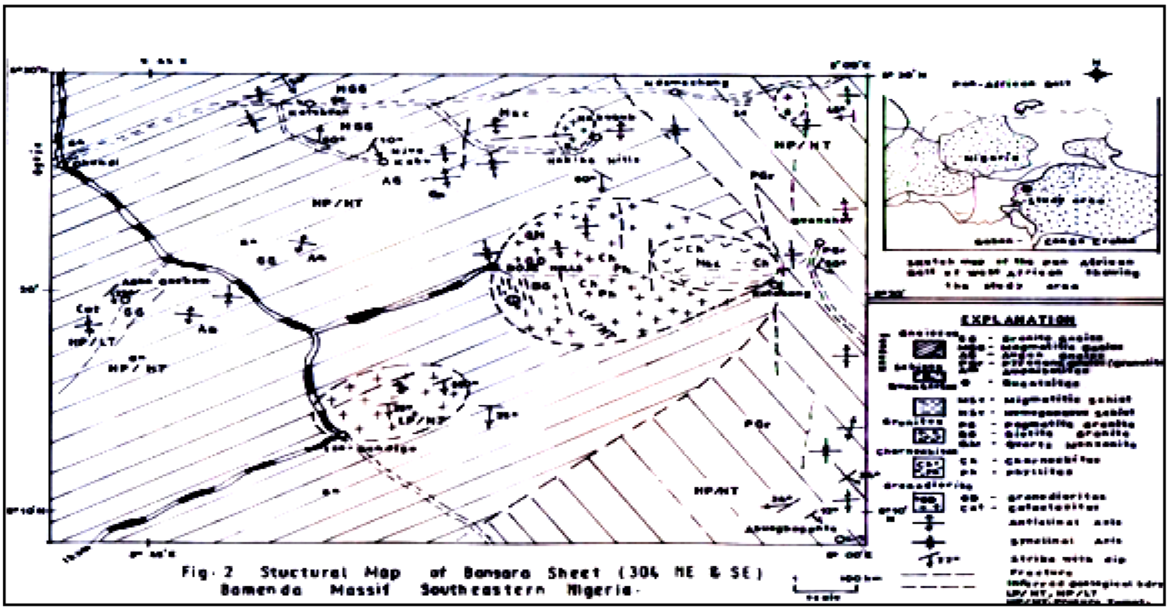

Figure 1. Geologic map of Bansara area

For road construction, there are several very important considerations as to whether a rock is suitable or not for use as aggregates. Aggregate used in the surface course (running surface) of roads must be resistant to the polishing action of vehicle tyres, otherwise the road can become slippery, especially when wet. It is essential that aggregates used in construction purposes are strong and durable. The properties used to assess the suitability of rocks as aggregate materials include the following tests: strength, water absorption, abrasion resistance, flakiness, resistance to weathering. Laboratory study included petrographic analysis of the rocks, first by thin sectioning and examination of the slides under plane and cross polarized light. The strength of the aggregates were evaluated by a series of composite tests including Aggregate Abrasion Value (AAV), Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), Specific Gravity and Water Absorption as contained in BS 812, and AASHTO T96-92. Aggregate abrasion value was determined using the Los Angeles machine.

3.1. Aggregate Abrasion Value (AAV) Determination

500g of the sample retained on the 1.70mm sieve was poured in a large rotating drum- the Los Angeles Machine with 12 balls and allowed to rotate for 500 revolutions at a speeds of 30-33 revolution per minute. The materials were then extracted and separated into materials passing the 1.70mm sieve and those retained on the 1.70mm. The retained materials were then weighed and compare to the original sample weight. The difference in weight is reported as a percent of the original weight and called the 'percent loss'. Rock materials with Aggregate Abrasion Values below 30 percent are regarded as strong, while those above 35 percent would normally be regarded as too weak for use in road surface.

3.2. Aggregate Crushing Value (ACV) Determination

The Aggregate Crushing Value is a value which indicates the ability of an aggregate to resist crushing under a gradually applied compressive load (a California Bearing Ratio (CBR) machine or concrete crushing apparatus) over a period of 10 minutes, after passing through sieve 14.0mm, and retained on 10.0mm sieve. The retained materials were poured into a mould in three layers, and tamped for 25 minutes in each layer. After compression, the fine materials (materials passing through sieve number 8 or 2.36mm) produced, expressed as a percentage of the original mass is the aggregate crushing value (ACV). The lower the value (finner particles), the stronger the aggregate, that is, the greater its ability to resist crushing. Crushing value of 30 percent and above is not good for road construction.

3.3. Aggregate Impact Value Determination (AIV)

Aggregate Impact Value (AIV) is the percentage of fines produced from an aggregate sample after subjecting it to a standard amount of impact. Resistance to impact of a sample of aggregate was measured by subjecting 14mm passing and 10mm retained materials in a 102mm diameter hardened steel mould to 15 blows from a 14kg hammer falling from a height of 380mm. The percentage mass of fines- materials passing through sieve 2.80mm BS sieve, formed in the test is known as the Aggregate Impact Value (AIV). Aggregate Impact Value (AIV) below 10 percent are regarded as strong and AIV above 35 percent would normally be regarded as too weak for use in road surface.

3.4. Water Absorption

A sample of a retained 1.75mm aggregate is immerse in water for approximately 24 hours to essentially fill the pores. It is then weighed in both the saturated surface-dry condition, submerged in water and oven-dried conditions. Strong aggregate will have a very low absorption value that is below 1.0 percent. The amount of water an aggregate can absorb tends to be an excellent indicator as to the strength or weakness of the aggregate. Therefore, the aggregate moisture content will affect the water content (and thus the water-cement ratio also) and the water content affects aggregate proportioning because it contribute to aggregate weight.

4. Results

The average modal composition of rocks from Bansara is shown in Table 1 while the strength indices are summarized in Table 2. The high resistance of Biotite-Granite to pressure, and its low water absorption value could be attributed to the fact that granite is an intrusive igneous with quartz (SiO_2), potassium feldspar (orthoclase $KAlSi_3O_8$), and biotite mica ($K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$) as the major mineralogical composition. The rock is formed from silicate melts, in which the silica content is greater than 66%. It is even-grained and entirely crystalline with grain boundaries interlocked. There is therefore, no plane of weakness in the rock mass.

Table 1. Average modal composition of rocks from Bansara

Mineral	Migmatitic gneiss	Granite gneiss	Schist	Biotite Granite
Quartz	25	27	30	30
K-feldspar	20	30	10	29
Plagioclase	22	20	25	15
Biotite	10	7	8	8
Muscovite	5	5	25	7
Chlorite	-	-	-	-
Horublende	6	6	-	-
Orthopyroxene	-	-	-	-
Clinopyroxene	-	-	-	-
Garnet	8	-	5	-
Olivine	-	-	-	-
Kyanite	-	-	-	-
Sillimanite	-	<1	<1	-
Myrmekite	-	-	-	7
Perthite	2	3	-	<1
Opaque minerals	2	2	3	3

Table 2. Strength tests results of the rock

Rock Samples	AAV (%)	AIV (%)	ACV (%)	Water Absorption (%)
Biotite Granite	22.0	18.5	23.2	0.54
Granite Gneiss	27.0	22.8	26.1	0.73
Migmatitic Schist	32.7	28.2	29.3	0.96
Greenstone	45.2	49.6	55.9	3.7
Standard specifications for aggregates.	< 30	< 35	< 30	< 1.0

Average values for 4 test results

The granite-gneiss on the other hand, although having similar mineralogical composition to biotite-granite (quartz, feldspar, and ferromagnesian minerals (biotite and hornblende), gave comparatively lower strength indices. The differences in result may not be unconnected to the fact that gneiss is a high grade regional metamorphic rock formed from either sedimentary or igneous rocks. It has a foliated texture of light and dark bands; the light bands are quartz and feldspars, while the dark bands are biotite, amphibole and magnetite. The parallel layers produce a banded structure which acts as a plane of weakness in the rock mass. The folded structures in the rock are also an indication stresses it had been subjected to in the past. The poor performance of the greenstone under the same test conditions with the other rocks is due to its geologic history. Greenstone is an extrusive igneous rocks formed when a lava solidifies and trapped gases escape, creating a distinctive vesicular texture. It actually contains more pore space than rock due to the relatively low amount of silica (SiO_2). Much of the silica is bonded to iron and magnesian to form ferromagnesian minerals such as Olivine (Forsterite, Mg_2SiO_4) and Fayalite, Fe_2SiO_4) and Pyroxene (e.g. Augite $(Ca,Na)(Mg,FeAl)$ $(Si,Al)_2O_6$.) The remaining silica and aluminum is bonded predominantly with calcium to form calcium rich plagioclase (Anorthite $CaAl_2Si_2O_8$). Greenstone does not contain quartz because no silica is left over after other minerals have been formed. The results indicate that other than the greenstone, all the other rock types yielded aggregates whose strength indices are satisfactory for use in pavement construction. For some of the samples, e.g. migmatitic schist, , the impact value and the crushing value are often numerically very similar, and indicate similar aggregate strength properties. The quality of rock aggregate depends on the presence of lithological variations in the rock deposit (van de Wall and Ajalu, 1997) and the structural inhomogeneities. Results indicate that Biotite-Granite posses higher strength value when compare to Granite- Gneiss, although they both posses the requirements necessary for production as construction aggregates in accordance with standard specifications (AASHTO 2001; ASTM 1975, 1988; BS 1975, 1981) as against the Greenstone which has low strength value and high water absorption capacity.

5. Conclusions

Aggregates are principal materials in pavement. They are often used in either stabilized or unstabilized base or sub-base courses. Knowledge of aggregate properties is crucial to designing a high quality pavement. Aggregate produced from Biotite- Granite and Granite-Gneiss because of their low porosity, and high crushing strength, possess the necessary characteristics for use in pavement construction in accordance with AASHTO, ASTM and BS standards. Results of this work will be useful in selecting the rock types to quarry for the production of aggregates for optimum use in sustainable road construction .

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