Technical Feasibility of Direct Application of the Nigerian Tar Sand Deposits as Road Asphalt.

A. Akinmosin, Ph.D.[*] and A.O. Shoyemi, B.Sc.

Olabisi Onabanjo University, Ago Iwoye, Ogun State, Nigeria.

[*]E-mail: waleakinmosin2001@yahoo.com

ABSTRACT

Tar sand samples were collected at five locations in parts of Southwestern Nigeria, and were analyzed to determine their direct application as road asphalt surfacing material. Seven samples were selected out fifteen samples collected in the field for this analysis using the Marshall test method. The test involved determination of bitumen saturation, stability, flow, density, specific gravity, etc. on the samples. The stability values ranged from 14.0% to 40.0%; density ranged from 1.70kg/m^3 to 1.92kg/m^3, and general specific gravity values of 1.01 and 1.92 were obtained for the bitumen and mixed aggregate, respectively.

The Marshall test result indicates that two out of the seven samples (AG20 and AG8) can be applied directly, having flow values of 13mm and 15mm, respectively, and with a reasonably high bitumen saturation (>30%). Other samples with low stability and low bitumen saturation (<30%) require further analysis on Design Mix which was carried out in order to increase their stability. This involved the addition of certain materials like coarse aggregate and fillers to increase the stability and wearing course of the samples. Result of the Design Mix showed increase in specific gravity, density and stability values that are favorable for direct application.

(Keywords: asphalt, bitumen, tar sand, aggregates, mix, stability)

INTRODUCTION

Bituminous sands which are also commonly called tar sands are deposits of loose sands or particularly consolidated sandstone that are saturated with highly viscous bitumen. These occur within a belt cross Ogun, Ondo, and Edo states in southwestern Nigeria extending about 140km, (MSMD, 2006).

Several researchers have studied the tar sand deposits of Nigeria. Among these are the works of Ako, et al. (1983) which highlighted the relevant aspects of the bituminous sands as well as exploration strategies. Enu (1985) and Ekweozor (1985) summarized the physical and chemical characteristics of the oil sand deposits. Akinmosin, et al. (2005) worked on the provenance of the bituminous sand using quartz varieties and heavy mineral composition. Some other works include Akinmosin. et al., 2006 and Nwachukwu, 2003.

The usefulness of tar sands for the direct manufacture of road asphalts lies in the quality of the bitumen content as a binder for the solid aggregates in the job mix formula (JMF) of the produced asphalts. The JMF consists of bitumen and solid aggregates with various size ranges and it is for this cause that the direct utilization of tar sands for good quality road asphalts requires to a large extent some certain conditions to be met. The bitumen content must be sufficiently high and have the appropriate properties. The mineral matter content must also fall within designated size ranges and the mineral matter must be of appropriate quality. In view of these issues, the present work is designed to determine the suitability of the tar sands being applied directly in the manufacture of road asphalts and carrying out mix analysis to determine the amount of upgrading for deposits that cannot be applied directly for use as road asphalt.

GEOLOGY/STRATIGRAPHY OF THE DAHOMEY BASIN

The area of this research is located between the latitudes N6^{0}40^1 to N6^{0}43^1 and longitudes E4^{0}22^1 to E4^{0}30^1 of Southwestern Nigeria (Figure 1). The Benin (Dahomey) Basin constitutes of part of a system of West African peri-cratonic (margin sag) basin (Klemme 1975; Kingston et al. 1983)

developed during the commencement of the rifting, associated with the opening of the Gulf of Guinea, in the Early Cretaceous to the Late Jurassic (Burke et al., 1971;Whiteman, 1982).

The crustal separation, typically preceded by crustal thinning, was accompanied by an extended period of thermally induced basin subsidence through the Middle–Upper Cretaceous to Tertiary times as the South American and the African plates entered a drift phase to accommodate the emerging Atlantic Ocean (Storey, 1995; Mpanda, 1997).

The Ghana Ridge, presumably an offset extension of the Romanche Fracture Zone, binds the basin to the west while the Benin Hinge Line, a Basement escarpment which separates the Okitipupa Structure from the Niger Delta basin binds it to the east. The Benin Hinge Line supposedly defines the continental extension of the Chain Fracture Zone (Figure 2).
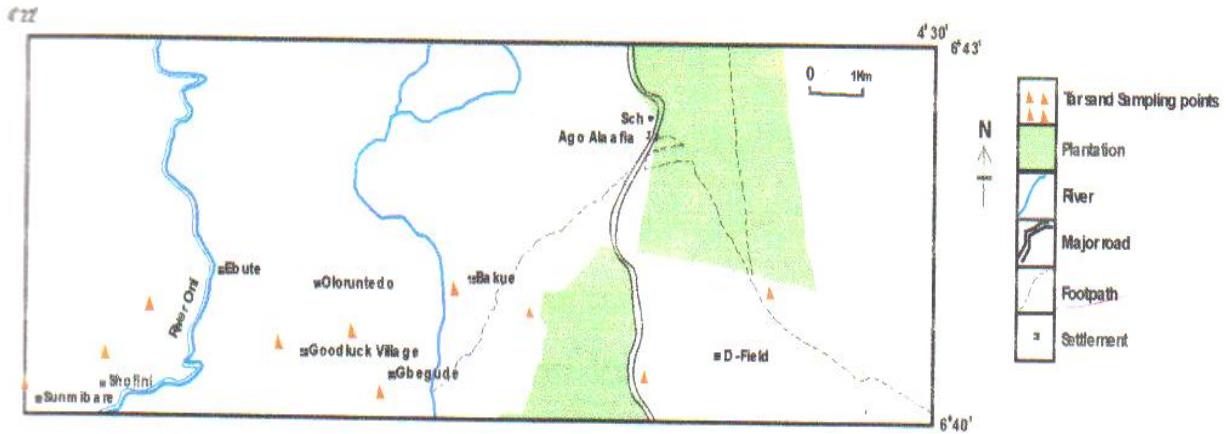

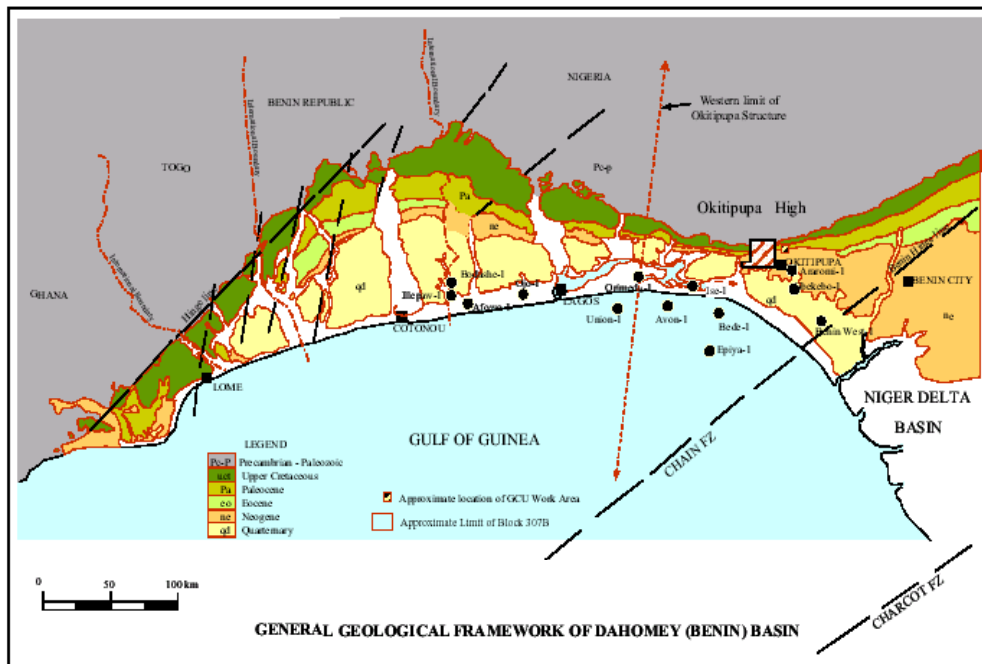**Figure 1:** Location Map of the Study Area, Showing Sampling Points.

Figure 2: General Geological Framework of the Dahomey Basin. (Modified from Bilman, 1992).

The onshore part of the basin covers a broad arc-shaped profile of about 600 km^2 in extent. The onshore section of the basin attains a maximum width, along its N-S axis, some 130 km around the Nigerian–Republic of Benin border. The basin narrows to about 50 km on the eastern side where the basement assumes a convex upwards outline with concomitant thinning of sediments. Along the northeastern fringe of the basin where it rims the Okitipupa high, is a brand of tar (oil) sands and bitumen seepages (Ekweozor and Nwachukwu, 1989).

The lithostratigraphic units of the Cretaceous to Tertiary sedimentary sequence of eastern margin of Dahomey basin according to Omatsola and Adegoke, 1981, are as follows:

Ise Formation: The oldest formation in the Abeokuta Group is referred to as Ise and is uncomfortably overlaps the Precambrian basement complex. It has basal conglomerate, gritty to medium-grained loose sand, capped by kaolinitic clay (Omatsola and Adegoke 1981, Agagu, 1985). The maximum thickness of the member is about 1865m and more than 600m of it was penetrated by Ise - 2 borehole. The age has been given to be Neocomian.

Afowo Formation: Afowo Formation based on the palynomorph content is Neocomian. Afowo Formation succeeds the Ise Formation. Afowo Formation indicates the commencement of deposition in a transitional environment after the entire basal and continental Ise Formation. The sediments are composed of interbedded sands, shales and clays, which range from medium to fine grains in sizes (Omatsola and Adegoke, 1981; Agagu, 1985). It has been found to be bituminous in both surface and sub-surface sections. The age is Mastrichitian.

Araromi Formation: Araromi Formation, the topmost unit of the Abeokuta Group. Sediments of the Araromi Formation represent the youngest topmost sequence in the group. The formation is composed of shales, fine-grained sand, thin interbeds of limestone, clay and lignite bands (Omatsola and Adegoke, 1981; Agagu, 1985). It is an equivalence of a unit known as Araromi shale by Reyment (1965). The shales are grey to black in colour, marine, and rich in organic matter. The age ranges from Maastrichtian to Paleocene.

Imo Group: This group consists of the two lithostratigraphic units which are: Ewekoro Formation and Akinbo Formation. Ewekoro Formation directly overlies the Abeokuta Group as it has been observed from the sections at Ewekoro and Sagamu quarries as well as the cored sections at Ibeshe. It is made up of grayish white and occasionally greenish limestone which is sandy toward the base and having a thickness that varies between 15-30m. This formation is dated Paleocene age. Akinbo Formation is mostly found in the western part of the Imo Group, directly overlying the Ewekoro Formation. It constitutes the upper part of the Imo Group. It is essentially greenish, highly fossiliferous and thickly laminated. The age of Akinbo Formation is considered Paleocene.

Ilaro Formation: It consists of coarse to fine grained sands, clays and shales with occasional thin bands of phosphate beds being observed at Ilo. The formation is Eocene in age.

Coastal Plain Sands (Benin Sand Formation): The coastal plain sand overlies the Ilaro Formation but evidence for this is lacking (Jones and Hockey, 1964). The coastal plain sands consist of very poorly sorted, clayey, pebbly sands, sandy clay and rare thin lignite. They are the basal continental beds of the Abeokuta Group. Coastal plain sands range in age from Oligocene to Pleistocene.

Recent Alluvium: This is the youngest unit in the Eastern Dahomey basin. It has been thought to overlie the Ilaro Formation, but convincing evidence for this is lacking (Jones and Hockey, 1964). The exposure at the road cuttings between Ofada and Mokoloki on the Ogun River reveals coarse clayey sorted sands with clay lenses and occasional pebble beds.

METHODOLOGY

Compositional Analysis of Tar Sands

Bitumen was extracted from the mineral matter (sand + clay) by soaking the samples in toluene reagent. The quantity of the extracted bitumen was later determined by the centrifuge method. The left over mineral matter was air dried and weighed. Each quantity was reported as a percentage of the original tar sand samples.

Sieve Analysis of Mineral Matter

Following the separation of the mineral matter, the quantity of each sample was weighed and placed inside a set of sieves with different mesh seizes. The shaker was then turned on until a fairly constant weight was retained on each sieve tray. The weight retained on each sieve is determined and reported as a percentage of the total weight of original mineral matter.

Marshall Test Method

The Marshall Test procedure was developed to simulate the quality of the responses of an asphaltic job mix to traffic conditions. In essence, it measures the strength level and flexibility of a job mix when subjected to stress. The levels of these two properties were obtained through the Marshall Test procedure which involved taking cylindrical briquettes (4 Inches diameter * 2.5 Inches high) made from each job mix through compression. The results were subsequently recorded as stability and flow, respectively.

Stability measures the maximum load that a sample briquette can carry when tested in compression and the strength of the briquette must be such that it can carry the load without shearing aggregate particles (i.e., structural integrity must be maintained).

Flow indicates the brittleness or flexibility of the briquette parameters and road made from asphaltic job mixes must be flexible. They must be able to deflect slightly under each load without cracking.

Design Mix

The size of materials composition ranges from coarse to fines aggregates.

Coarse Aggregate: The function of the coarse aggregate asphaltic concrete mix is to give stability by the interlocking of the aggregate particles by their frictional resistance to displacement. Both the shape and surface texture of the stone therefore contribute to the stability and the ideal aggregate is a hard angular stone with a rough surface texture such as crushed rock or crushed slag.

In order for the mix to be able to withstand the stress of traffic there is however, a limit to softness of stone which should be used and it is suggested that for surfacing work one of the following might be adopted.

- Crushing strength 25,000 Ib/in^2 (1750kg/cm)
- Los Angeles abrasion test 25max
- Aggregate crushing value 23max
  Aggregate should be free from dirt, clay and other foreign material.

Fine Aggregate: The fine aggregate adds to the stability of the mix through the interlocking of the particles at the same time it reduces the voids in the coarse aggregate. It is desirable that fine aggregate should be well graded from 8mesh down to 200mesh and should consist of natural sand, fresh screenings or a mixture of the two.

The finer fraction from 30-200 mesh on the other hand is equally important in that it increases the surface area of aggregate in the mix and hence enables the latter to carry a higher bitumen content which will give the mix the necessary durability.

Filler aggregate: The function of the filler in an asphaltic concrete mix is to act as a final void filling material as well as means of stiffening the bitumen film on the aggregate particles. Suitable materials for use of filler are limestone dust, cement, hydrated lime or other fine mineral dusts having not less than 65% passing a 200 mesh sieve.

The criterion as regards the suitability of filler is its fitness, but there are some indications that hydrated lime and possibly other active fillers provide some addition structure effect which increases the stability of paving.

RESULTS AND INTERPRETATION

Compositional Analysis Of Tar Sand Samples

Seven tar sand samples were analyzed for their bitumen constituents, water and mineral matter (sand + clay). The results obtained for each sample as well as the location and brief description are shown in Table 1.

Table 1: Analysis of Tar sand Samples from the Study Area.

Sample No	Location	Description	% Bitumen	%Mineral Matter	% Water
GB 3	Gbegude	A massive deposit with shaly unit beneath and thin overburden. A nearby spring aquifer present	14.0	82.0	4.0
AG 8	3Km Southeast of Ago Alafia	Low lying outcrop. A river nearby.	40.0	58.0	2.0
SH 12	Few Kilometers northwest of Shofini	Solidified seepage, flows during the dry season.	25.0	72.8	2.2
SH 13	Few Kilometers North of Shofini	Low lying outcrop. Forms the bed of a stream	25.5	71.2	3.3
EB 14	Few Kilometers West of Ebute	Solidified seepage, flows during the dry season	27.2	70.4	2.4
DF 18	D-Field of Michelin Rubber Plantation	Low lying outcrop. Surrounded by shrubs and plantation	27.0	72.2	0.8
AG 20	Few Kilometers Southwest of Ago Alafia	Solidified seepage, flows during the dry season	30.0	70.0	0.0

Bitumen Content

It can be readily observed from Table 1 that the bitumen content of tar sands are quite low with the exception of samples AG 8 and AG 20.This is probably due to the fact that majority of the samples are located on river banks or areas where substantial washing off actions of flowing water have drastically reduce the bitumen content of the deposits. This implies that the assayed bitumen content is not necessarily indicative of the quality of the deposits at greater depths farther away from the washing off actions of water.

In considering a given tar sands deposit for direct production of road asphalt, high bitumen content is desirable, for it implies a lower amount of mined tar sands to supply the appropriate low bitumen content implies the carrying of an excessive amount of the mineral matter into the aggregate component of the Job Mix Formula (JMF).

The percentages of bitumen content of these samples are relatively high ranging from 14%-40% as seen in Table 1. This was determined using centrifuge extraction method.

Mineral Matter Content and the Job Mix Formula (JMF)

It is to be noted that all tar sands deposits that have been successfully utilized for direct application are those that do not suffer a mineral matter disability (i.e., the mineral matter content must fall within designated size ranges and the mineral matter must be of appropriate quality).

The existence of mineral matter in the tar sands represents a preloading of the potential bitumen binder with aggregate materials over which the manufacturer has no control. The overwhelming proportion of mineral matter in Nigerian tar sands generally fall in the fine aggregate filler category with only a small amount qualifying for the medium/coarse designation.

MARSHALL TEST RESULTS

The Marshall Test method covers the measurement of the resistance to plastic flow of a cylindrical specimen of bituminous paving mixture by means of the Marshall apparatus. Strength and flexibility are two important properties of asphalt for use in pavements; this test measures the load that the sample can carry when it is under stress.

Stability: The result of the stability test as recorded from the Marshall method of testing show that it ranges from 0.2KN-0.5KN when it is under compression, American Standard Test Method (ASTM) D 1559.

Flow: The compacted specimen molded into briquette form is tested simultaneously when deformation occurs on the sample and it is expressed in millimeter as the flow. This increases along with the bitumen content since friction between particles decreases with thicker bitumen films.

Bulk Specific Gravity: This is determined from the percentages of the bitumen recorded from the extraction test and the percentages of the aggregate in the mix in relation to the specific gravity of the bitumen and the aggregate from the test result. This ranges from 1.52-1.68.

Density: The density of the molded specimen is recorded according to the volume determined from the mass of the sample in air and in water respectively, expressed in m/v. The density ranges from 1.70-1.95g/ml

Void: The percentage of air void decreases as bitumen content increases and vice versa, for instance, bulk of the void is occupied by the bitumen. Likewise the void obtained in the total mix will decrease as the bitumen increases, although voids are present in the bitumen itself, but this is inconsequential to the total volume of void present in the tar sand. Void filled with bitumen ranges from 174% to 210%, while void in mix ranges from 15%-23%.

Void in mix aggregate (VMA), Void filled with bitumen (VIB), Void in mix (VIM) and flow all report values that are mostly lower than the standard specification. The data in Table 2 provides information on the values of those parameters that ultimately determine the quality of the job mix used in the test. The table only indicates whether or not the values are within specifications.

Table 2: Marshall Test Design Summary for the Study Area.

Sample No	Density (g/ml)	V.I.M %	V.M.A %	V.I.B %	Stability (KN)	Bitumen Saturation (%)	Flow (mm)
GB3	1.92	16.22	18	190.1	1.1	14.0	11.1
SH12	1.88	21.9	28.72	176.2	0.95	25.0	12
SH13	1.88	23.32	30.2	177.4	0.5	25.5	11.5
EB 14	1.87	23.36	31.44	174.3	2	27.2	5.5
DF 18	1.89	23.72	28.92	179.8	0.9	27.0	10
AG 20	1.7	12.27	13.02	132.8	0.5	30.0	13

The inference that can be made from the data is that the lower the VMA, the higher the VIB and vice versa. Too low a VIM implies that too much of the air space has been filled with bitumen binder, a situation that may lead to loss of flexibility and seepage of the bitumen onto the surface of the road on a hot day or under abnormal stress.

Ordinarily, the remaining void spaces should be available for the expanding bitumen. Similarly, too high a VIM result in too high a void space yet to be filled and may lead to oxidative actions of air and ground water, the two main agents of asphalt hardening and ageing.

DESIGN MIX ON TAR SAND TO MEET THE WEARING COURSE OF ASPHALTIC STANDARD

Samples AG 8 and AG 20 from these analyses show that they could be applied directly, Smith 1990, while other samples (GB 3, SH 12, SH 13, SH14, and DF 18) have to be upgraded to meet the desired standard for wearing course of asphalt.

The sizes of material composition ranges from coarse to fillers. The coarse sizes of aggregates in the wearing course consist of ½ sizes of aggregates (12.7mm) as the biggest sizes of aggregates, follow by the 3/8 sizes of aggregates (9.5mm).

The analysis of this coarse size is within the specified sizes of aggregates (Table 3 and Figures 3 and 4) meant for wearing course of asphalt including the specific gravity by pychnometer method of testing.

The fines added to the mix consist of quarry dust in which the analysis ranges from 5mm and above. The filler is a powdered material derived from the quarry dust in process of vibration in batching plant. The percentages of filler included in this mix design are very small due to the nature of the tar sand.

Table 3: Design Mix (Wearing Course) Result for Tar Sand Samples that can be Applied Directly.

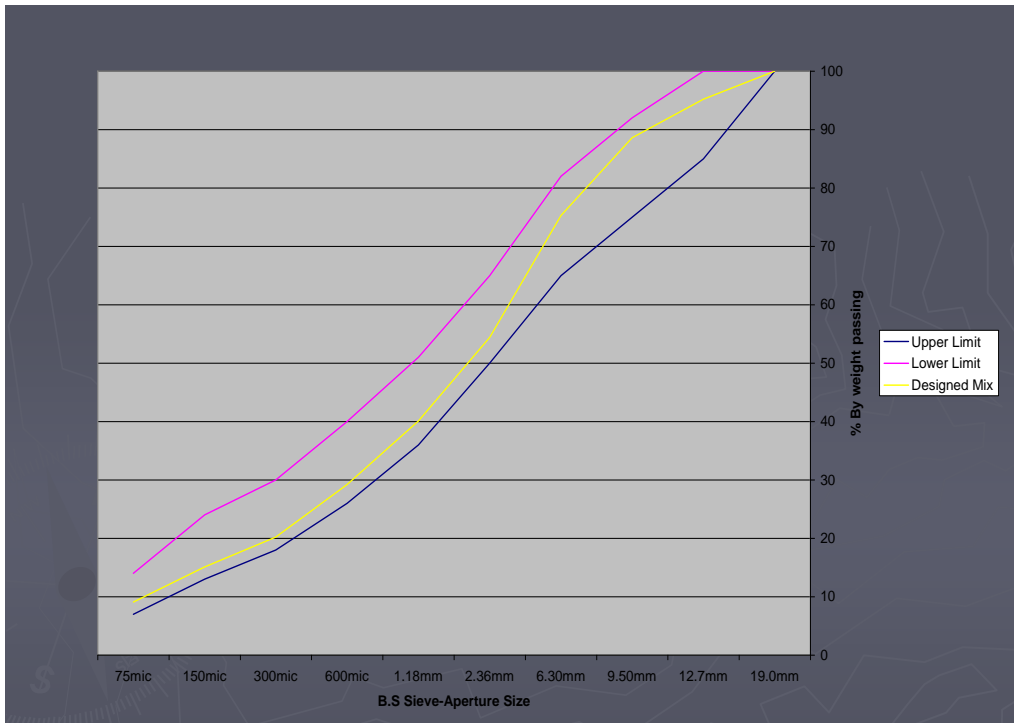| B.S sieves	% Passing	PWD Specification*
19.0mm	100	100
12.7mm	95.2	85 – 100
9.50mm	88.6	75 – 92
6.30mm	75.3	65 – 82
2.36mm	54.4	50 – 65
1.18mm	40.1	36 – 51
600mic	29.2	26 – 40
300mic	20.2	18 – 30
150mic	15.1	13 – 24
75mic	9.1	7 – 14
Pan	-	-

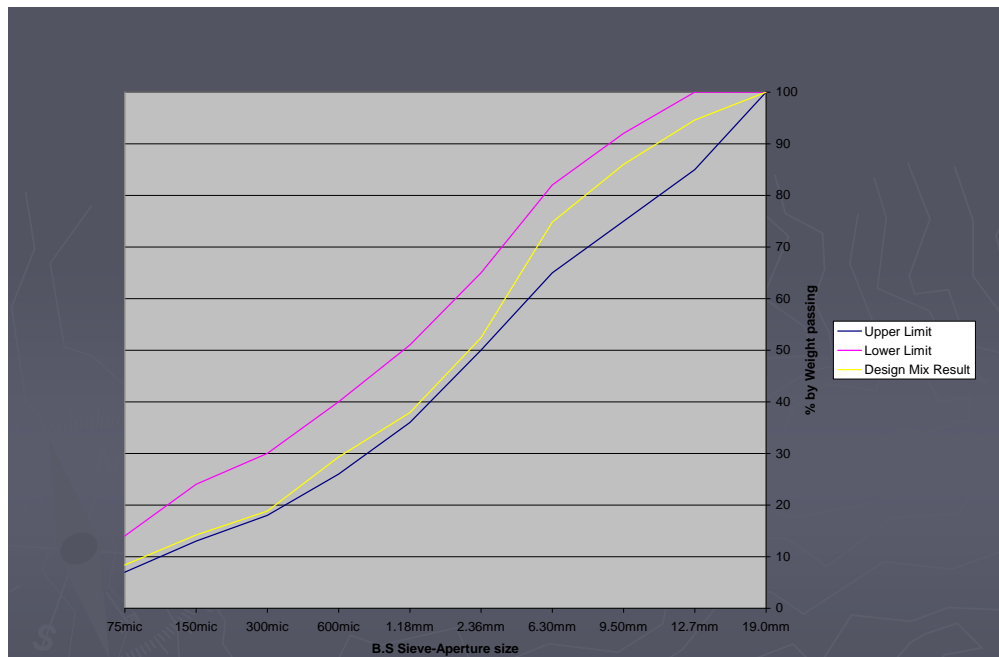**Figure 3:** Plot of the Design Mix in the Standard Chart (Direct Application).

Figure 4: Plot of the Design Mix in the Standard Chart for those that cannot be Applied Directly.

The design mix generally shows an improvement in the stability, density, and other strength parameters of the tar sand samples. The result of this design mix analyses is shown in Table 4.

CONCLUSION

The results of the tests conducted on surface and near surface samples of tar sands collected from Gbegude area indicates their low potential viability for direct utilization as road asphalt. The results from stability and flow of the tar sands show clearly that an asphalt of high quality in terms of strength and flexibility cannot be produced except without adjustment in relative quantities of aggregates.

The result however also indicates that the tar sand samples with low bitumen content and very high content of mineral matter may be technically unviable given that some processing (steps) may be required prior to their direct utilization for road asphalt manufacture.

RECCOMENDATIONS

It must be noted that favorable Marshall Test results for strength and flexibility of a job mix do not exhaust the required tests for the evaluation of its quality. The two other tests of durability and skid resistance must be implemented in order to acquire the requisite confidence level.

In addition to completing the full quality test procedures, it is recommended that the following programs are implemented before commercial level operation commences.

- Implementation of the present study on deeper lying deposits.
- Determination of the overall size of roads that the present deposit of interest can cover.

Table 4: Summary of the Strength Properties of the Tar Sand Samples after Upgrading (Design Mix).

Sample No	Density (g/ml)	V.I.M (%)	Stability (Kg/N)	Flow (mm)
GB 3	2.33	8.11	1210	4
SH 12	2.32	11.17	1229	3
SH 13	2.34	11.73	1230	4
EB 14	2.33	11.87	1200	3
DF 18	2.31	11.90	1230	5
AG 20	2.35	11.91	1231	4
AG 8	2.31		1230	3

Key: V.I.M = Void in Mix, V.M.A= Void in Mix Aggregate, V.I.B= Void in Bitumen

Note: Sample AG 8 has very high bitumen content and has been left out.

REFERENCES

1. Agagu, O.K. 1985. "A Geological Guide to Bituminous Sediments in Southwestern Nigeria". Unpublished Report. Department of Geology University of Ibadan: Ibadan, Nigeria.

2. Ako, B.D., Alabi, A.O., Adegoke, O.S., and Enu, E.I. 1983. "Application of Resistivity Sounding in the Exploration for Nigerian Tar Sand". *Energy Exploration and Exploitation*. 2(2).

3. Akinmosin, A., Olabode, O.T., and Bassey, C.E. 2005. "Provenance Study of Bituminous Sands in Eastern Dahomey Basin, Southwestern, Nigeria Based on Heavy Mineral and Quartz Varieties". *Ife Journal of Science*. 7(1).

4. Akinmosin, A., O.S. Oredein, and A.A. Odewande. 2006. "Sedimentological and Reservoir Description of Afowo Oil Sand Deposits, Southwestern Nigeria". *Ife Journal of Science*. 8(1):35 – 45.

5. ASTM. 1994. "ASTM D 1559 – 89, Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures using Marshall Apparatus". *1994 Annual Book of ASTM Standards*. Vol. 04.03. American Society for Testing and Materials: Philadelphia, PA. 19103 - 1187.

6. Bilman, H.G. 1992. "Offshore Stratigraphy and Paleontology of the Dahomey (Benin) Embayment, West Africa". *NAPE Bull.* 7(2):121-130.

7. Burke, K.C.B., Dessauvagie, T.F.J., Whiteman, A.J. 1971. "The Opening of the Gulf of Guinea and Geological History of the Benue Depression and Niger Delta". *Nature Phys. Sci.* 233(38):51-55.

8. Ekweozor, C.M. 1985. "Nigerian Tar Sands. Bitumen Chemical Properties and their Relation to Origin, Production, and Processing". *Book of Abstracts: 21st Ann. Conf. Nig. Min. & Geosc. Soc.* Jos, Nigeria. 11-15 March 1985.

9. Ekweozor, C.M. and Nwachukwu, J.L. 1989. "The Origin of Tar Sands of SouthWestern Nigeria". *NAPE Bull.* 4(2):82-84.

10. Enu, E.I. 1985. "Textural Characteristic of the Nigerian Tar Sands". *Sedimentary Geology*. 44:65-81.

11. Jones, H.A. and Hockey, R.D. 1964. *The Geology of Southwestern Nigeria.* Bulletin, Geological Survey, Nigeria: Lagos, Nigeria. No 31-pp 100.

12. Kingston, D.R., Dishroon, C.P., and Williams, P.A. 1983. "Global Basin Classification System". *AAPG. Bull.* 67:2175-2193.

13. Klemme, H.D. 1975. "Geothermal Gradients, Heatflow and Hydrocarbon Recovery". In: A.G. Fischer and S. Judson (eds). *Petroleum and Global Tectonics*. Princeton University Press: Princeton, NJ. 251-304.

14. Mpanda, S. 1997. "Geological Development of East African Coastal Basin of Tanzania". *Acta Universities, Stockholmiensis*. 45:121.

15. Ministry of Solid Mineral Development (MSMD). 2006. "Technical Paper on Nigerian Bitumen Deposits". www.msmd.org

16. Nwachukwu, J.I. 2003. "Exploitation of the Bitumen Deposits of Nigeria". In: A.A. Elueze (ed). *Prospects for Investment In Mineral Resources of Southwestern Nigeria: Proceedings of the workshop on Investment Opportunities in Solid Minerals in Southwestern Nigeria*. 4-7 November, 2001. Nigerian Mining and Geosciences Society, Ibadan Chapter: Ibadan, Nigeria. 67-74.

17. Omatsola, M.A. and Adegoke, O.S. 1981. "Tectonic Evolution and Cretaceous Stratigraphy of the Dahomey Basin". *J. Min. Geol.* 18(1): 130-137.

18. PWD. 1992. "PWD General Specification1987 (with amendments 1992)." Public Works Department: Singapore.

19. Reyment, R.A. 1965. *Aspects of the Geology of Nigeria.* Ibadan University Press: Ibadan, Nigeria.

20. Smith, H.R., J. Rolt, and J.H.G. Wambura. 1990. "The Durability of Bituminous Overlays and Wearing Courses in Tropical environments". *Proc. 3rd Int. Conf. on the Bearing Capacity of Roads and Airfields*. The Norwegian Institute of Technology: Trondheim, Norway.

21. Storey, B.C. 1995. "The Role of Mantle Plumes in Continental Break-Up: Case History from Gondwanaland. *Nature*. 377:301 – 308.

22. Whiteman, A.J. 1982. *Nigeria: Its Petroleum Geology, Resources and Potential, Vol. 2.* Graham and Trontman: London, UK.

ABOUT THE AUTHORS

Adewale Akinmosin is a Lecturer at the University of Lagos, Nigeria. He is a registered member of the Nigerian Council of Mining Engineering and Geosciences. He holds a Ph.D. degree in environmental geology from University of Ibadan, Nigeria. His research area is in geology of tar sands.

Omolola Shoyemi is a geologist practicing with one of the geological institutions in Nigeria. She holds a Bachelor of Science degree in geology and she is in the process of commencing her Master of Science in petroleum geology.

Pacific Journal of Science and Technology