TECHNICAL FEASIBILITY AND ECONOMICS OF DIRECT APPLICATION OF THE NIGERIAN TAR SAND DEPOSITS AS ROAD ASPHALT

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Abstract
This study present, the technical feasibility and the Economics of the direct application of Nigerian Tar sand deposits as road asphalt. Twenty Tar sand samples were selected from nine locations in parts of Southwestern Nigeria and several engineering tests were conducted on twenty samples. The tests involved Bitumen extraction to determine the percentage of bitumen content, Sieve analysis, Specific gravity and Marshall tests which include the Stability, Flow, Density and Void determination. The percentage of bitumen saturation ranges from 5.6 to 28.6%, the stability values ranges from 2.1 to 6.3KN, the flow values ranges from 27.8 to 63.1mm10, specific gravity values ranges from 1.79 to 2.35g/ml and density values ranges from 1.75 to 2.01g/ml. The sieve analysis results indicate that none of the samples could be applied directly in road construction, though some of them possess stability and flow values that meet the standard specification for wearing course of asphalt. Design mix analysis which involves modification of mineral aggregates was carried out on ten out of the twenty samples to improve their gradation. From economic point of view, using the modified aggregates of tar sand (@₦7,000-9,500 per ton) as against current asphalt concrete (₦20,000 per ton) would have potentially large cost saving in Nigeria.

Keywords: Tar sand, Asphalt, Aggregates, Mix, Bitumen.

1.0 Introduction
Bituminous sands commonly called tar sands are deposits of loose sands or particularly sandstone that is saturated with highly viscous bitumen. They are bitumen-impregnated sands from which bitumen can be extracted by suitable processes. These deposits occur within a belt across Ogun, Ondo and Edo States Southwestern Nigeria. Bitumen is a non-crystalline, black or dark brown viscous material, which is substantially soluble in organic solvents, such as toluene and carbon disulphide, and possesses adhesive and water-proofing qualities. It consists essentially of hydrocarbons with at least 80% carbon and 15% hydrogen respectively, other components are oxygen, sulphur, nitrogen and traces of various metals.

The usefulness of tar sands for the direct manufacture of road asphalt lies in the quality of the bitumen content as a binder for the solid aggregates in the job mix formula (JMF) of the produced asphalt. The JMF consists of bitumen and solid aggregates with various size range and it is for this cause that the direct utilization of tar sands for good quality road asphalts requires that the following conditions be met: the bitumen content must be sufficiently high, the bitumen content must have the appropriate theological properties, the mineral matter content must fall within designated size ranges and the mineral matter must be of appropriate quality.

Although the greater proportion of bituminous materials used for highway and airport pavement construction worldwide is from manufactured asphalt; increasing attention is being paid to natural asphalt deposits.

It is also worth noting that Nigeria paid relatively little attention to her vast deposits and continues to expend millions of dollars to import raw materials in the form of asphalt yielding crude petroleum for the manufacture of bitumen for pavement and other construction purposes. Based on this background, there arises a need to focus greater attention on the vast naturally occurring bitumen deposits of Nigeria. It is expected that eventual utilisation of the materials will have a significant pay-off potential on cost reduction.

In view of these, the present work is designed to determine the suitability of the tar sands for direct use in the manufacturing of road asphalts; carrying out mix analysis to determine the amount of upgrading for deposits that cannot be applied directly as road asphalt; and the economic effect of using the modified tar sand aggregates against current asphalt concrete used in road construction.

2.0 Geology/Stratigraphy of the Dahomey Basin

The study area is located between the latitudes N60401 to N60431 and longitudes E40221 to E40301 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).

The onshore part of the basin covers a broad arc-shaped profile of about 600 km2 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 in age. 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 is 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.

The Abeokuta Group is overlain by the Imo Group (Ewekoro and Akinbo Formations Adegoke 1977, Jones and Hockey, 1964), the Oshosun Formation, Coastal Plain sands and the Recent Alluvium.

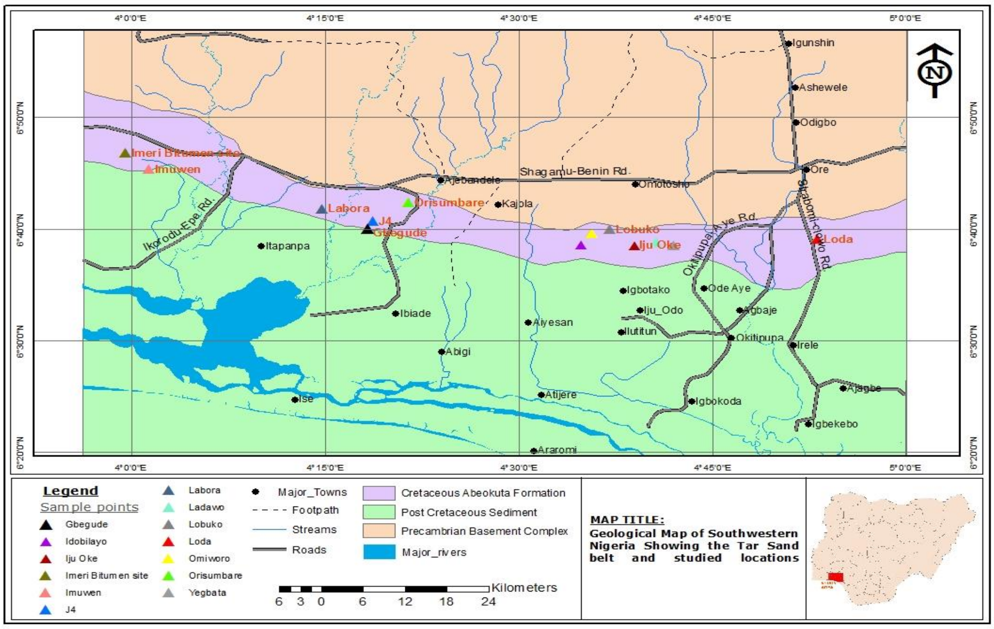

Figure 1: Geological Map of The study area showing sampling locations

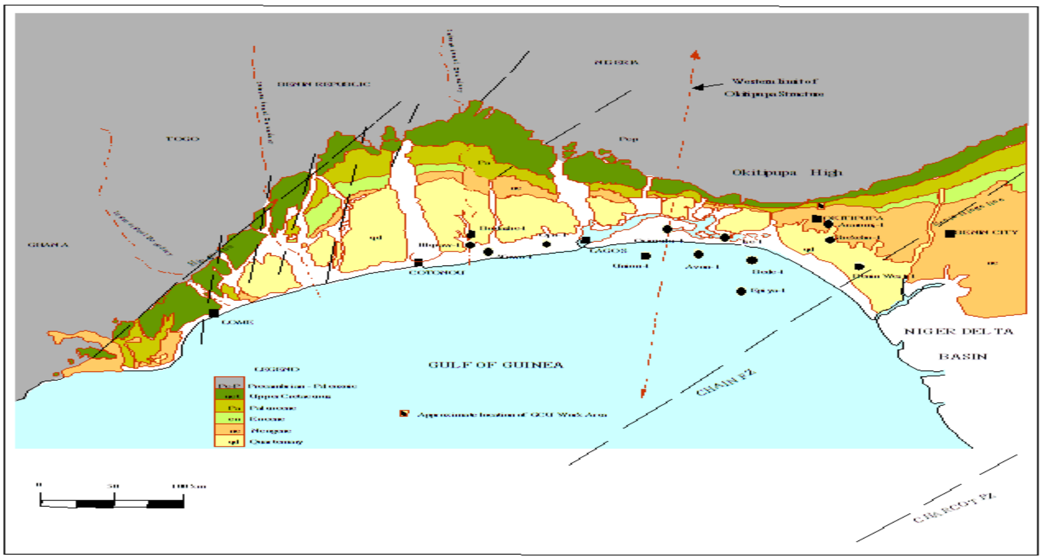

Figure 2: General Geological Framework of the Dahomey Basin (Billman 1992)

3.0 Methodology

3.1 Field Mapping

The field mapping exercise involved traversing by foot and location of outcrops and seepages with the aid of the global positioning system (GPS), compass clinometer and the base map. Other tools used for the mapping exercise include the sedimentological hammer, chisel, marker, field note, paper tape, sample bags, trowel, camera etc.

Oral interview was conducted in order to gather information from the villagers and farmers around the study area. Description and identification were noted, and all observations and sketches were made in the field note.

The Geological mapping exercise was carried out along the tar sand belt in southwestern Nigeria. The areas covered fall mainly in the Afowo Formation of the Abeokuta Group of the Dahomey Basin, while some areas showed marked characteristics of the Araromi Formation.

3.2 Bitumen Percentage Determination by Extraction

The bitumen percentage was determined by bitumen extraction. In the process, 1.5kg portion of the tar sand sample was soaked in a quantity of Tricholene (Trichloroethylene) and placed in the centrifuge extractor. This is to allow the sample to disaggregate. The sample was covered and a filter paper was placed on it with the cover plate tightly fitted on the bowl. The centrifuge extractor was put on, which revolves slowly and gradually. The speed was increased until the solvent ceases to flow from the outlet. The centrifuge extractor was then allowed to stop and tricholene was then added several times during the centrifuging process. The filter paper was removed from the bowl and the aggregates were later dried in the oven at a temperature range of 105 to 110^0c. The weight of the extracted sample was taken in order to determine the bitumen percentage.

3.3 Grading Analysis of Materials

This was carried out using different sieve sizes, and the weight of dried aggregate was shaken over a set of sieves.

The weight of material retained on each sieve size was determined and expressed as a percent of the weight of total sample. These data were plotted on the aggregate gradation chart. Such plots provide a means of visualizing the gradation characteristics of the mineral aggregate.

3.4 Marshall Test

The method uses standard test specimens of 6.35 cm height and 10.16 cm diameter. The principal features of the method are a density-void analysis and a stability-flow test of the compacted specimen. The specimens were compacted by giving 50 blows on both top and bottom of the hammer. The procedure is adequate for highway pavements designed for a tyre pressure of $0.7MN/m^2$. The Marshall Stability value is the maximum load resistance in kg or Newtons that the standard test specimen will develop at 60^0c (140^0F). A flow meter records the strain at the maximum load when failure occurs. The flow value is the total movement or strain in units of 0.25mm occurring in the specimen between no load and maximum load during the stability test.

To prepare the specimens, samples weighing 1.2kg each were used. The samples were heated before transferring to the moulds, before compaction as stated (50 blows both ways). After compaction, the specimens were extruded from the mould using extrusion jack and the extruded specimens were then placed on a smooth, level surface until ready for further testing. Normally, specimens were allowed to cool overnight before testing. The testing method was by loading the specimen in compression to failure in the Marshall testing machine. The machine measures both stability and flow that developed at failure. The measured stability values were later corrected to those which would have been obtained if the specimen has been exactly 63.5 mm high. This was done by multiplying each measured stability value by an appropriate correlation ratio.

3.5 Design Mix

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

Coarse Aggregate: Coarse aggregate is all mineral material retained on sieve size 9.5mm. It consists of crushed stone, crushed slag, or crushed or uncrushed gravel. 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.

Fine Aggregate: Fine aggregate is all mineral matter passing sieve size 9.5mm. 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.

Mineral Filler: Mineral filler is finely ground particles of limestone, hydrated lime, Portland cement or other non-plastic mineral matter, predominantly finer than 0.075mm that is added to the mix. 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 as 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 additional structural effect which increases the stability of paving.

4.0 RESULTS AND INTERPRETATION

4.1 Bitumen content

The results of the bitumen content of the twenty tar sand samples as well as outcrops description is shown in Figure 3-7.

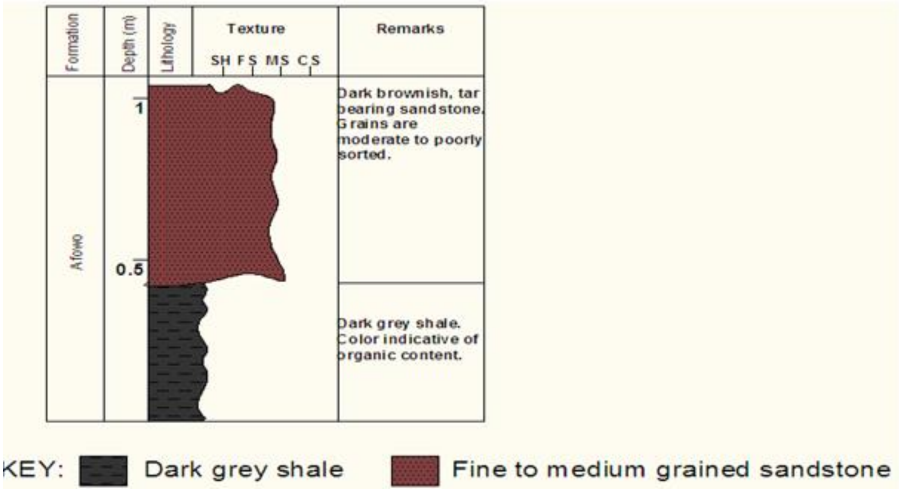

Fig 3: Lithologic section of Imeri sequence

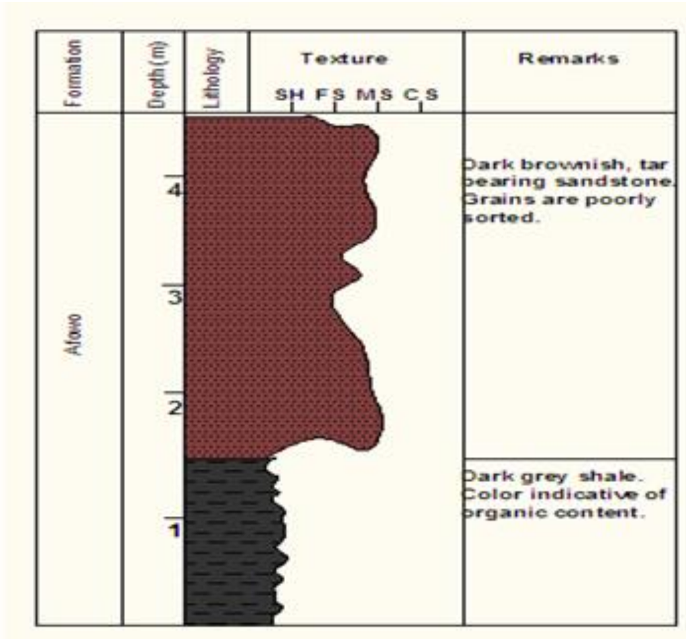

Fig 4: Lithologic section of Gbegude sequence

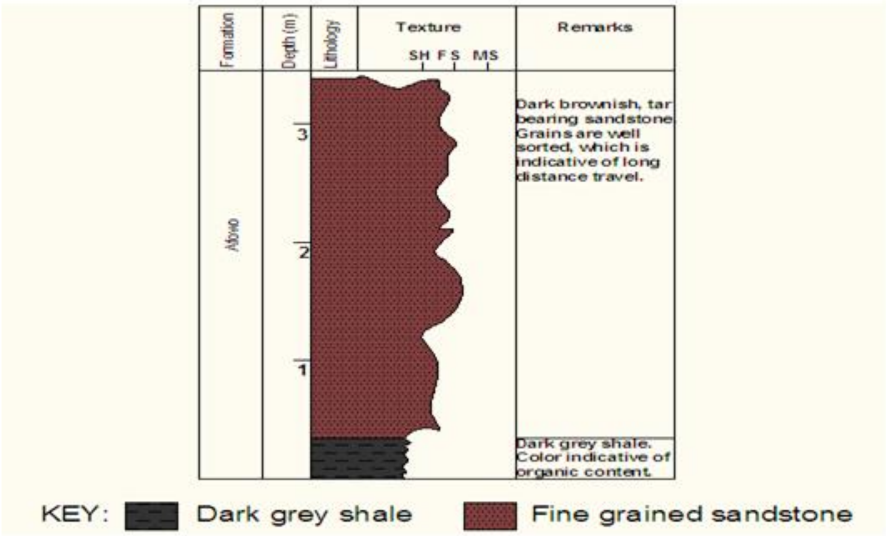

Fig 5: Lithologic section of Loda sequence

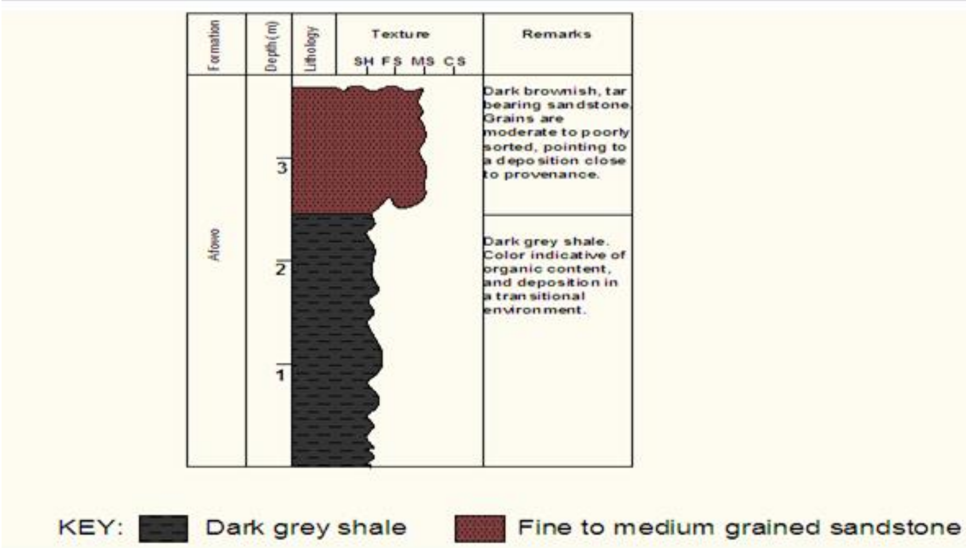

Fig 6: Lithologic section of Area J4 sequence

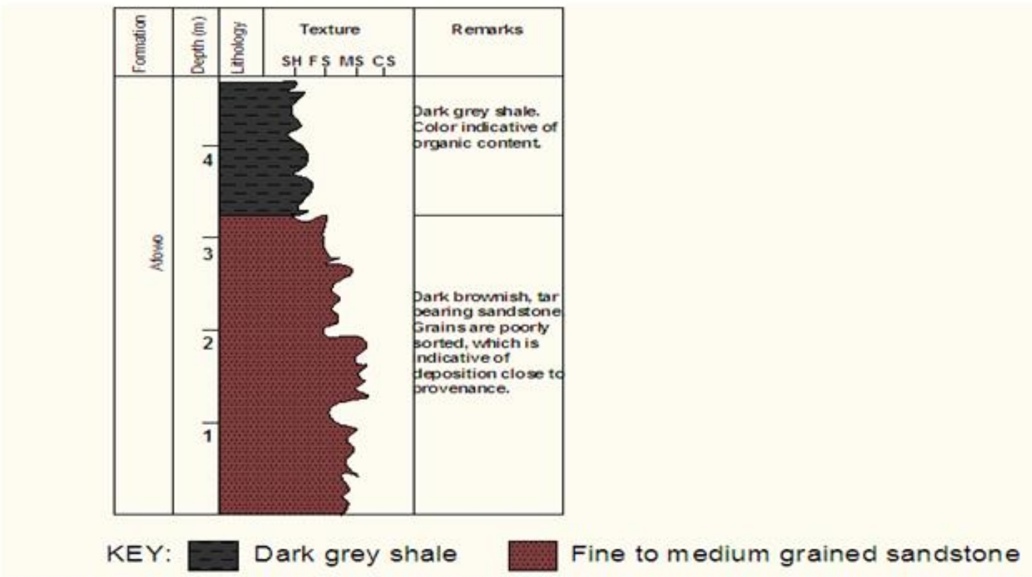

Fig 7: Lithologic section of Idobilayo sequence

The results of the bitumen content of the tar sand samples presented in table 1 show that the bitumen content of some of the samples are quite low while others have relatively high bitumen content. The percentage of bitumen content of the twenty tar sand samples ranges from 5.6%-28.6%.

4.2 Sieve analysis

The results of the sieve analysis for the twenty tar samples showed that the mineral aggregates of the samples does not meet the requirements for use in road construction as specified by the Nigerian General Specification (FMWH, 1999). It is to be noted that for natural bituminous sand to be used in road construction, the gradation of the aggregates must fall within the grading envelop. Hence, the tar sand samples need to be upgraded before use in road construction.

The result of the sieve analysis for the samples in their natural form is presented in Table 1 and the gradation result is depicted in Figure 8.

Table 1: Summary of Sieve analysis Results for All Tar Sand Samples

(BS)Sieve Size (mm)	% Passing	FMWH, 1999
19	100.0	100
12.5	100.0	85-100
9.5	99.9	75-92
4.75	98.4	60-75
2.36	95.5	50-65
1.18	85.0	36-51
0.6	68.8	26-40
0.3	37.8	18-30
0.15	12.0	13-24
0.075	5.1	7-14

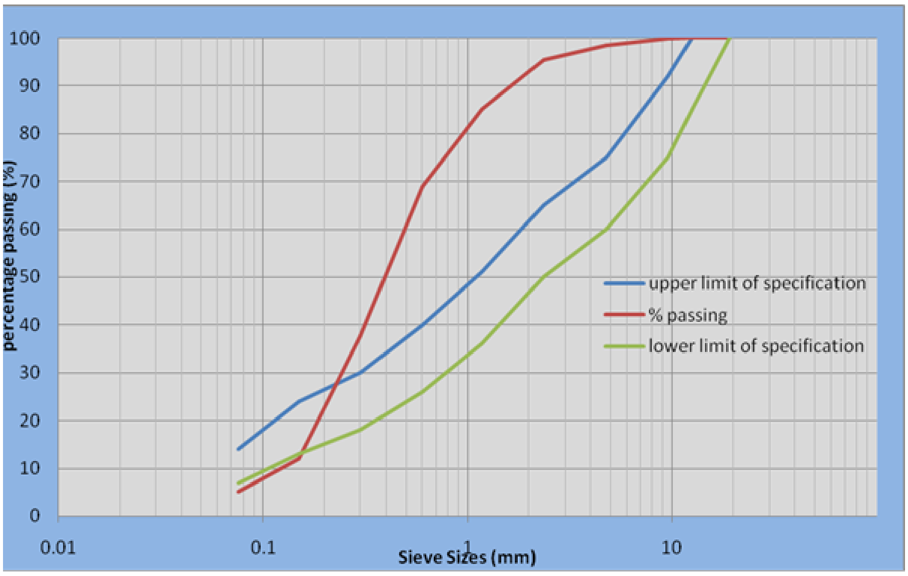

Fig 8: Gradation results for all tar sand samples

4.3 Stability Test

The stability values of the various samples as seen on Table 2 shows that four of the samples did not meet the standard specification for hot mix. These samples include IDO 3, ORI 1, IMU 1 and IMU 2. The result of the stability test as recorded from the Marshall method of testing showed that it ranges from 2.1KN-6.3KN when it is under compression, This according to American Standard Test Method (ASTM) D 1559. The stability test showed that samples that met the standard specification have a good strength when subjected to worst condition.

4.4 Flow Test

The flow values of the various samples as seen on Table 2 shows that four of the samples did not have flow value in the range of the hot mix standard specification. These samples include IDO 3, ORI 1, IMU 1 and IMU 2 which have flow values above the range. The flow test showed that samples that met the standard specification have a good strength when subjected to worst condition.

Table 2: Marshall Test results of the various samples

	standard specification				
	>=3.5	20-40	3-5	75-82	
Sample No	Stability KN	Flow mm10	Void in total mixture %	void filled with bitumen %	Density g/ml
IME 1	6.3	34.7	15.7	67	1.98
IME 2	5.4	33.8	11	77.9	2.01
GBE 1	3.8	38.9	13.4	66.7	1.78
GBE 2	3.7	37.3	15.3	62.2	1.75
GBE 3	5.4	27.8	16.9	62.6	1.78
LOD 1	6.7	33	9.4	76.4	1.91
LOD 2	6.1	31.9	15	68.4	1.9
IDO 1	3.4	40.9	5.1	88.1	1.91
IDO 2	3.4	39.4	5.7	86.5	1.94
IDO 3	2.6	42.7	5.8	86.2	1.89
ONI 1	——	——	7.6	87.9	1.98
ONI 2	——	——	1.1	98.2	2.01
ORI 1	2.2	57.1	1.4	97.3	1.96
ORI 2	4.1	36	1.2	97.4	1.98
LOB 1	3.6	35.8	12.9	74	1.76
LOB 2	4.8	32.5	14.5	69.9	1.77
IMU 1	2.5	52.9	5.1	80.6	1.89
IMU 2	2.1	63.1	5.9	77	1.9
OMI 1	——	——	13.5	43.3	1.9
OMI 2	——	——	13.7	51.2	1.93

4.5 Voids in total mixture

From Table 2, percentage voids in total mixture for the samples does not fall within the range of the hot mix standard specification.

4.6 Voids filled with bitumen

The percentage voids filled with bitumen in samples IME 1, GBE 1, GBE 2, GBE 3, LOD 2, LOB 1, LOB 2, OMI 1 and OMI 2 were seen to be below the range of the standard specification for hot mix asphalt, while for samples IDO 1, IDO 2, IDO 3, ONI 1, ONI 2, ORI 1 and ORI 2 they were seen to be above the range of the standard specification. Only samples IME 2, IMU 1, IMU 2 and LOD 1 fall in the range of the hot mix standard specification.

4.7 DESIGN MIX

From the test results, it was observed that the aggregate gradation of all the tar sand samples appeared to vary with location and cannot be applied directly for use in road construction. For this purpose, they need to be upgraded to meet the desired standard for wearing course of asphalt. Ten samples were selected for modification to improve their gradation. This modification involves the addition of aggregates. The results of the design mix on the samples is depicted in Fig 9.

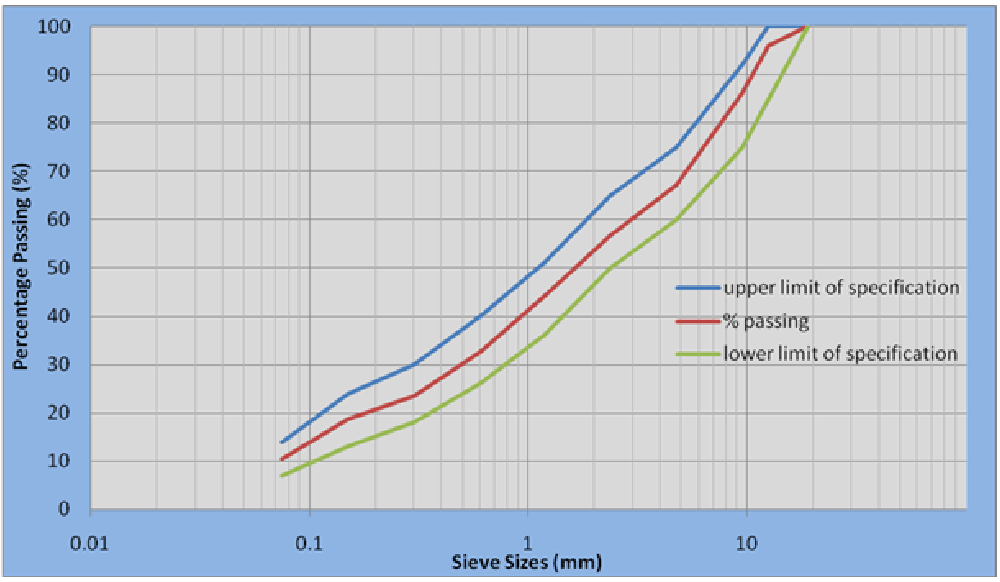

Fig 9: Gradation results for all upgraded tar sand samples

4.8 ECONOMIC IMPLICATION OF DESIGN MIX

There is a potential large cost savings associated with the use of tar sands in asphalt pavement in Nigeria. This analysis compares the costs of a ton of the current asphalt concrete to an approximate cost of a ton of upgrading aggregates of the tar sand in Nigeria. Table 3 shows the difference in cost of using upgraded tar sand aggregates versus the cost of current asphalt concrete. The table it shows that the upgraded tar sand aggregates cost about ₦7,000-9,500 per ton as against current asphalt concrete, which cost about ₦20, 000 per ton.

Table 3: Economic Effects on Using Tar Sand Aggregates

Sample No	ORI1	ONI1	IDO2	IDO3	LOD2	LOB1	IMU1	OMI2	IME1	GBE1
Current Aggregate cost (₦/ton)	₦ 20000	₦ 20000	₦ 20000	₦ 20000	₦ 20000	₦ 20000	₦ 20000	₦ 20000	₦ 20000	₦ 20000
Upgraded tar sand Aggregate cost (₦/ton)	₦ 7850	₦ 7030	₦ 8200	₦ 8340	₦ 8690	₦ 8370	₦ 8770	₦ 7830	₦ 9280	₦ 8100
Difference	₦ 12150	₦ 12970	₦ 11800	₦ 11660	₦ 11310	₦ 11630	₦ 11230	₦ 12170	₦ 10720	₦ 11900

CONCLUSION

Bitumen deposits are available in the Southwestern Nigeria in commercial quantities. These occur either as bitumen seepages or outcrops of bitumen-impregnated sands usually referred to as tar sands.

The results of the tests conducted on surface and near surface samples of tar sands collected for this study indicate their low potential viability for direct utilization as road asphalt. The results from sieve analysis of the twenty tar sand samples showed clearly that all their aggregates need to be modified before use in road construction.

The bituminous sands could form excellent base course or asphalt concrete wearing course materials for flexible pavement construction provided there is proper mixture design. Nigeria's natural bitumen deposits, if exploited, can earn the much desired foreign exchange in addition to serving as local pavement construction materials.

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