

TECHNICAL EVALUATION OF ONDO BITUMEN FOR DIRECT ASPHALT CONCRETE MIX DESIGN

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Abstract

The suitability or otherwise of the abundant Nigerian Ondo bitumen as a binder in hot mix asphalt concrete mix design for roadmaking has not been established. Samples of Ondo bitumen (as-received and as-refined) were tested for specific gravity, softening point and penetration. Concrete mixes were also prepared with standard proportions of aggregates with Ondo bitumen (as-received and as-refined) and standard bitumen as binders. The concrete mixes were then compacted to standard cylindrical specimens for Marshall stability indices tests. The results of physico-chemical tests gave the specific gravity, softening point and penetration for the Ondo bitumen as-received as 1.12, 77°C and 44.3 mm, while the values for the refined product were 1.03, 52°C and 67 mm, respectively. The Marshall stability tests for Ondo bitumen (as-received) at 5.8% of the weight of aggregate yielded 25.5 KN, 15 mm, 77.4%, while that of Ondo bitumen as-refined gave 13.03 KN, 35 mm, 77.4%; respectively. When the physico-chemical properties Ondo bitumen (as-received and as-refined) were compared with those of standard bitumen, only the refined product was found to satisfy the requirements for concrete mix design. The Marshall stability results however showed that Ondo bitumen concrete mixes (as-received and as-refined) do not meet the standard specifications for stability and flow. The results obtained thus suggest that Ondo bitumen may not be useable alone for direct asphalt mix design.

Keywords: Bitumen; aggregate; concrete; penetration; Marshall, stability.

1. Introduction

Bituminous sands which are also commonly called tar sands are deposits of loose sands or particularly saturated sandstone saturated with highly viscous bitumen. These occur within a belt across Ogun, Ondo and Edo states in South Western Nigeria extending about 140 km ^[1].

The most important reason for studying asphaltic materials is to gain a better understanding of how we can design and make long lasting pavements. This is because if poor asphalt is used in making flexible pavements, it will eventually lead to road deterioration ^[2]. Hot mix asphalt concrete (HMAC) is a composite material consisting of asphalt binder and mineral aggregates mixed together and then laid down in layers and compacted. It must resist deformation and cracking, be durable over time, provide a good tractive surface and yet be inexpensive, readily made and easily placed. The factors that affect road/pavement deterioration include mix proportions, mix properties, mix production/transportation and pavement construction ^[3]. Asphalt pavements are used for highways, airports, parking lots and driveways. HMAC is produced by heating asphalt in order to decrease its viscosity and drying the aggregates to remove moisture prior to mixing ^[4].

HMAC design is the process of determining which aggregates/asphalt binder to use and their optimum combination. The most common approaches to do this are Hveem, Marshall and Superpave mix design methods ^[2]. The purpose of asphalt concrete mix design is to determine the design asphalt content using the available asphalt and aggregates. Typical design asphalt content ranges from 4 to 7% by weight of the total mix ^[5]. Asphalt mixture consists of aggregates, asphalt binders and air voids leading to the three important parameters of percentages of air voids (that is, voids in total mix), voids in the mineral aggregates and voids filled with asphalt ^[6]. The end result of a successful mix design is a recommended mixture of aggregate asphalt binder which is often called job mix formula (JFM).

The aim of this research is to determine the suitability or otherwise of tar sand sourced from Ondo state, Nigeria as an asphaltic binder in making hot mix asphalt concrete for road construction.

2. Materials and Methods

2.1 Materials

The basic material used in this study was lumps of tar sand obtained from Ondo state, Nigeria.

2.1.1 Sample collection

The dark coloured and semi-solid tar sand was collected from Gbeleju Loda village in Irele Local Government area of Ondo State. The naturally occurring tar sand of Ondo State deposit was found to occur in two basic forms on site namely; Bitumen seepage and outcrops of bitumen impregnated sand from which bitumen can be extracted by suitable process. The bitumen impregnated sand was collected in lumps at a shallow depth of about 20 cm. After sampling in the field, the tar sand was placed in a polythene bag. The sample was later thoroughly homogenized.

2.2 Methods

Samples of the homogenized bitumen were then subjected to various tests as described by Toriola [7].

2.2.1 Sieve analysis

The test was done according to ASTM C136. Representative sample of the gravel was dried in the oven at about 110°C and put on a tray. About 500 g of the dried filler sample was placed on a nest of sieves with apertures 12.5, 9.5, 4.75, 2.36, 1.18, 0.6, 0.3, 0.15 and 0.075 mm in that order and set on a pan at the bottom. The nest of sieve was then placed on a sieve shaker and subjected to shaking for about 20 minutes. The material obtained on each sieve was weighed and calculated as a percentage of the total sample mass. The procedure was repeated but with 1000, 2274, 2179.7 and 1000 g of river sand, chippings (10-16 mm), chippings (5-8 mm) and quarry dust, respectively. The asphalt mix was done with specified proportions of the sieved materials as described below.

2.2.2 Solubility test

1 g of bitumen was weighed and placed in a 250 ml beaker with 5 ml of toluene for 20 minutes. The bitumen was dissolved in the reagent and was decanted, washed with distilled water and later filtered. The sand left in the filter paper was dried and weighed. The procedure was then repeated but for 10, 15, 20 and 25 ml toluene.

2.2.3 Specific gravity

The test procedure was according to ASTM C 128. The test density bottle was cleaned with distilled water, dried and cooled in the desiccators and weighed with its stopper. About 10 g of the soil sample was placed in the bottle with air free distilled water added to cover and soak it for about 2.5 hours. Water was then added to fill the bottle to about half its volume. The density bottle was heated in a water bath to remove entrapped air. The bottle (without the stopper) was then kept on vacuum desiccators for about 1.5 hours until there was no further loss of air. The soil in the density bottle was gently stirred with a clean glass rod and the adhering sand particles was carefully washed away with drops of distilled water. The process of trapped air elimination was repeated until all entrapped air was removed. The temperature of the slurry in the bottle was then taken. The stopper was inserted into the density bottle and it was wiped clean and weighed. The bottle was now emptied, thoroughly cleaned and filled with distilled water at the same temperature determined for the slurry. The stopper was again inserted in the density bottle and it was wiped dry outside and weighed. The specific gravity, G , was determined with the formula:

$$G = \frac{(m_2 - m_1)}{(m_2 - m_1) - (m_3 - m_4)} \quad (1)$$

Where: m_1 =mass of empty bottle, m_2 = mass of bottle + dry soil, m_3 =mass of bottle + soil + water only, m_4 = mass of bottle filled with water.

2.2.4 Softening point

The quantity of bitumen sample used was such that it was sufficient to fill the test ring to the brim. The sample was heated to temperature in the range 75 and 100°C and stirred to remove air bubbles and water. The ring was heated, glycerin applied and the ring further filled with the sample. The heated sample-filled ring was allowed to cool for 30 minutes. Excess sample material was removed using a warmed, sharp knife. A 9.53 mm diameter steel ball was then placed on the bitumen sample in the steel ring and immersed in a water bath. Heat was applied to the water and its temperature was raised until a value was obtained when the sample was sufficiently softened and allowed the ball to fall. The temperature at which the ball touched the bottom of the beaker was noted, which is the softening point of the sample.

2.2.5 Penetration test

The bitumen sample used was just sufficient to fill the test container to a depth of at least 15 mm in excess of the expected penetration. The sample was then heated to a temperature of 25°C and a needle weighing 100 g was made to bear on the surface on the bitumen for five seconds. The penetration was defined as the distance, in units of mm that the needle penetrates into the bitumen sample. And the value was noted and recorded.

2.2.6 Bitumen extraction

The bitumen lumps were placed in a container and heated on an electric oven at 160°C for 4 hours. The bitumen molten bitumen was then removed from the oven and about 3 litres of petrol was added to form oil sand slurry that was decanted leaving behind sand and other gangues in the container. The filtrate was left outside to allow the petrol used as solvent to evaporate thereby leaving bitumen in the container.

2.2.7 Asphalt mix design

The amount of each size fraction required to produce a batch that will give the desired number of compacted Marshall specimens was weighed into pans. The pans with their contents were placed in the oven and heated to about 150°C and the heated aggregate was then charged into the heated mixing bowl and thoroughly mixed. The mixing formed a crater in the dry blended aggregate and the required percentage of bitumen at 130°C was added. The asphalt mix was designed to contain 25.98, 34.64, 27.64, 8.98 and 2.76% of chippings (10-16 mm), chippings (5-8 mm), quarry dust (<5 mm), river sand (< 5 mm), filler (0.075 mm) as aggregates, respectively and standard bitumen extract, as 5.8% of the weight of the aggregates. The procedure described was repeated but with 5.4, 5.6, 5.8, 6 and 6.2% standard bitumen. The whole procedure was further repeated for Ondo bitumen as-received and as-refined with bitumen as 5.8 weight % of aggregates.

2.2.8 Marshall test

The asphalt binder was heated separately and added to the aggregate. A mechanical mixer was used for the proper mixing of the aggregate and the binder. The aggregate-standard bitumen mixture was poured inside the Marshall specimen mould. The mixture was well spaced inside the mould using a heated spatula. Fifty compacting blows were then applied on both sides of the specimen with the Marshall hammer with a load capacity of 44.9 N and a free fall of 45.72 cm. The specimen was then removed and allowed to cool for 24 hours before the test was done. The specimen was immersed in water for 15 minutes before weighing in air and in water to obtain their mass, volume and density.

The inside surfaces of the test heads and the lubricated guide rods were cleaned so that the upper test heads slides freely over them. The specimen was removed from the water bath and placed in the lower segment of the breaking head. Between tests, the testing head temperature was maintained between 20 and 60°C using a water bath when necessary. The upper segment of the breaking head was placed on the specimen and the complete assembly was placed in a position on the testing machine. The flow meter was placed in position over one of the guide rods and the sleeve was held firmly against the upper segment of the breaking head while the load was applied to the specimen at a constant rate of 50.8 mm per minute until the maximum load was reached and the load began to decrease. The maximum load was recorded and the flow was subsequently measured. The test head was removed from its position over the guide rod the moment the load began to decrease. The indicated flow value was noted. The procedure described was

again repeated for aggregate-Ondo bitumen as-received and aggregate-Ondo bitumen as-refined.

3. Results and Discussion

3.1 Results

The results on solubility test, Marshall tests for Ondo bitumen as-received and as-refined and properties of concrete mix aggregates are presented in Tables 1, 2 and 3, respectively. Figures 1 show the basic physico-chemical properties of Ondo bitumen(as-received and as-refined) and standard bitumen, while the variation in the Marshall parameters of HMAC obtained at varied percents of standard bitumen binder is presented in Fig. 2.

Table 1 Particle size analyses of the aggregates for asphalt mix design

BS 410 sieve (mm)	Wt% pass (A)	Wt % pass (B)	Wt % pass (C)	Wt % pass (D)	Wt % pass (E)
12.5	-	-	53.9	100	-
9.5	-	-	12.8	99.7	-
4.75	-	99.5	0.4	70.2	-
2.36	-	94.3	0.3	10.3	77.4
1.18	-	80.9	0.2	6.7	54.2
0.6	-	49.2	0.2	5.0	40.2
0.3	100	7.7	0.2	3.9	28.2
0.15	100	14	0.2	2.8	15.8
0.075	79.5	0.6	0.1	1.6	4.2
Weight (g)	500	1,000	2,274	2,179.7	1,000

LEGEND: A = Filler material, B = River sand, C = Chippings 1, D = Chippings 2, E = Quarry dust

Table 1 Solubility test on Ondo bitumen as-received

Toluene (ml)	Average weight of residue (g)	Mass of bitumen dissolved (g)	% of dissolved bitumen
5	0.629	0.371	37.1
10	0.553	0.447	44.7
15	0.535	0.465	46.7
20	0.54	0.46	46.0
25	0.561	0.439	43.9

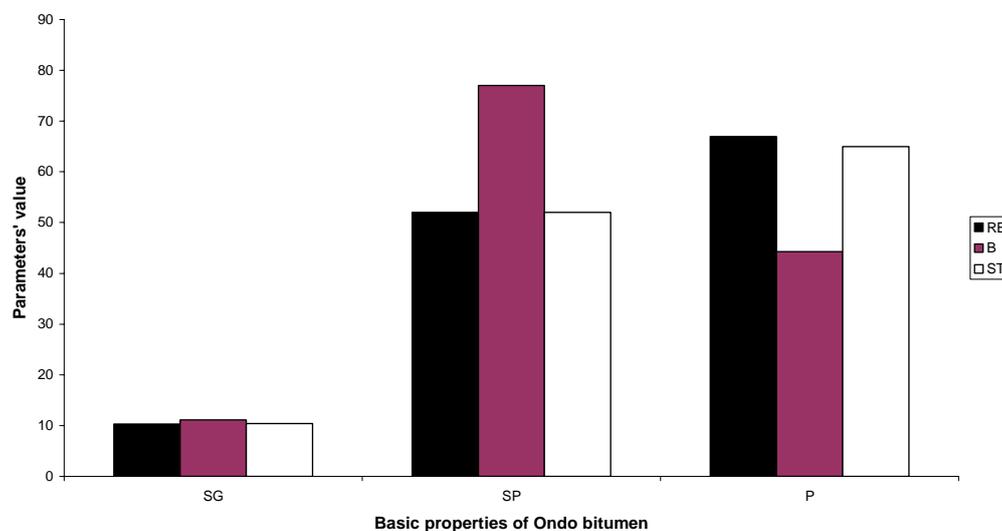


Fig. 1: Comparison of the specific gravity (SGX10), softening point (SP) and penetration (P) of Ondo bitumen as-received (B) and refined (RB) with standard (ST)

Table 2 Marshall test results

Property	Refined	Unrefined (Ondo bitumen)
Stability (KN)	13	25.5
Flow (mm)	35	15
Unit weight (g)	2.4	3.5
Specific gravity	2.5	2.8
Voids filled with bitumen (%)	77.4	77.4
Bitumen content (%)	5.8	5.8

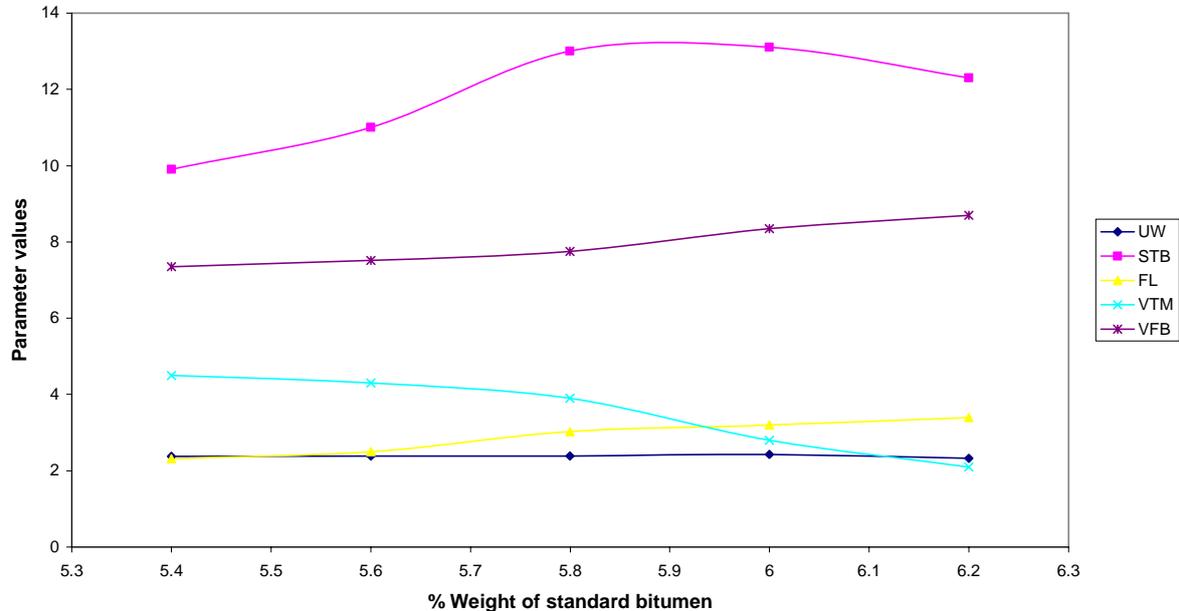


Fig.2: Variation of unit weight (UW), stability (STB), flow (FL), % voids in total mix (VTM) and % total voids filled with bitumen (X0.1 VFB) in HMAC with % bitumen

Table 3 Properties of concrete mix aggregates

Property	Requirements B.S 812	Test results
Crushing value	Max. 30 %	23.9 %
Flakiness index	Max. 35 %	28.7 %
Absorption factor	Max. 0.5 %	0.42 %

3.2 Discussion of Results

The solubility test showed that the Ondo bitumen as-received contains about 46.7% bitumen. The bitumen content of the deposit is higher than 30 and 40% for South Western Nigerian samples AG8 and AG20 reported by Akinmosin and Shoyemi [1]. The relatively high bitumen in the Ondo bitumen tested implies a low content of mineral matter thus making it a possible candidate for direct asphalt mix making.

The penetration value of 44.3 mm determined for the Ondo bitumen as-received is much lower than the average of 65 mm for the standard shell bitumen and 67 mm for Ondo bitumen as-refined. These results obtained indicate that Ondo bitumen as-received needs to be refined for it to be useable in concrete mix design in the tropics. The penetration value of the refined Ondo bitumen falls within the standard specification of 65 to 70 mm. The results obtained suggest that the refined Ondo bitumen may be a substitute for the standard bitumen in asphalt mix preparation.

The softening temperature of 77°C determined for the Ondo bitumen as-received is much higher than the specified shell bitumen range of 48 to 56°C. However, the softening temperature of 52°C for the refined Ondo bitumen falls within the specified range. The results thus indicate that Ondo bitumen as-received will require more heat to convert it from its semi-solid state to liquid. In addition, it will not flow easily when subjected to stress until at a much higher temperature. The higher softening point of the as-received bitumen might be due to its higher content of mineral matter impurities. The results obtained thus further suggest that only the refined Ondo tar sand can serve in HMAC preparation.

The specific gravity value of 1.12 obtained for the Ondo bitumen sample as-received far exceeds the shell bitumen standard grade of between 1.01 and 1.06. The value of 1.03 for the refined Ondo bitumen however falls within the specified range. The results obtained imply that Ondo bitumen is denser than its refined form and the standard bitumen grade. The bulk specific gravity of 1.52 to 1.68 determined on some South Western Nigerian bitumen samples are much higher than those of Ondo bitumen as-received and refined [1].

The stability value of 25.5 obtained for the Ondo bitumen as-received asphalt mix is far higher than 13 for mixes from its refined product and the standard bitumen. The control concrete sample reported by Toriola [7] had an average stability of 10.9. The stability value for the refined bitumen mix is similar to those for mixes of samples AG20 and AG8 from the South Western Nigeria recommended by Akinmosin and Shoyemi [1]. The results obtained thus suggest that the refined Ondo bitumen mix may be a suitable asphalt mix design. The very high stability of the as-received Ondo bitumen mix may be due to the high content of mineral matter in the as-received bitumen. Since the Marshall stability is a measure of the crushing strength of the concrete mix, a high value may be an advantage if coupled with a good flow.

The results presented in Figure 2 shows that the Marshall parameters obtained for asphalt concrete mixes obtained at varying percents of standard bitumen binder generally increases with increasing bitumen content except for percent voids in total mix that later decreased. The flow of 15 mm determined for Ondo bitumen as-received mix is much lower than 35 mm obtained for the mix of its refined form. The flow values of the two are however higher than the standard range of 5 to 10 mm. Since flow is measure of how much plastic deformation the concrete undergoes before it fails at the interfaces, the results obtained suggest that the concrete mixes with Ondo bitumen as-received and as-refined may have excessive plastic deformations at the interfaces with the aggregates. These results thus suggest that the both the as-received and as-refined Ondo bitumen may not be suitable for direct asphalt mix making. The un-necessarily high stability of Ondo bitumen as-received and its low flow indicate further it can only be adopted for rigid pavement construction. A flexible road made with asphalt mix including the un-refined Ondo bitumen will be susceptible to untimely failure due to alligator crack under axle load movement. The percents voids filled with bitumen/binder determined as about 77.5% for the three concrete mixes satisfy the specified range of 70 to 80 by the Asphalt Institute [8].

4. Conclusions

Samples of Ondo bitumen (as-received and as-refined) have been analyzed for physico-chemical properties and their concrete mixes specimens for Marshall stability indices tests. The results of physico-chemical tests showed that only the refined product satisfy the requirements for concrete mix design, while the Marshall stability results also showed that Ondo bitumen concrete mixes (as-received and as-refined) do not meet the standard specifications for stability and flow and thus may not be useable alone for direct asphalt mix design.

References

- [1] Akinmosin, A. and Shoyemi, A. O., 'Technical feasibility of direct application of the Nigerian tar sand deposits as road asphalt'. *Pacific Journal of Science and Technology*, Vol. 11, No. 1, 1-13 (2010)
- [2] Garrick, R. J., CE222 Materials: Asphaltic Materials, Lecture 1-4, 24th January 2007 <http://www.eng2.uconn.edu/~garrick/courses.htm>
- [3] Roberts, F.L., Kandhal, P.S., Brown, E. R. Lee, D.Y. and Kennedy, T.W., *Mechanical test for bituminous mixes*. New York: Chapman and Hall. 1997.
- [4] Somayaji, S., *Civil Engineering Materials*. New Jersey: Prentice Hall. 2001.
- [5] Mamlouk, S.M. and Zaniewski, J.P., *Material for Civil and Construction Engineers*. California: Addison Wesley. 1999.
- [6] Atkins, H.N., *High Materials, soils and Concretes*. Prentice Hall, 1997.
- [7] Toriola, A.E., *Effects of proportions of crushed aggregates on some mechanical properties of asphalt concrete*. Unpublished Thesis, B.Sc. Materials Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria. 2008.
- [8] Asphalt Institute, 'The Asphalt Handbook', MS-4, Lexington, KY.1989.