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Research Article

Analyzing an efficient mix design for the production of quality asphalt concrete: A means of reducing roads' maintenance cost

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ABSTRACT

Poor road design is the bedrock for strength deformation and formation of potholes in road pavement systems. The best choice of aggregates for asphalt concrete production contributes significantly to road pavement stability, sustainability, and durability at its serviceability lifestyle. The use of critical design and analysis techniques for the production of asphalt concrete is one of the standard means of eradicating the defect of roads' pavement deformation in the global construction industries. This study reveals the hidden knowledge about the standard formulation and mix design required for producing durable asphaltic concrete pavements. In the experiment, three different mix designs were used to make quality asphalt concrete for the road's binder pavement construction. This was done to ascertain the best quality aggregates required to produce durable asphalt concrete to construct binder road's pavement. Also, the aggregates used for the production of quality asphalt concrete for the construction of road's wearing course pavements were formulated using two mix designs. The results of the experiments proved that the asphalt concrete made with the aggregate formulated for the binder course from the first mix design yielded the best outcome, which is suggested for the global production of quality and standard asphalt concrete for road' binder pavements' construction. Although the formulated aggregates for the wearing course's asphalt production were made from the two mix designs, however, the obtained results from the first mix design were satisfactory fell within the specified limits. This made it the best mix design for industrial practice. In addition, the accuracy and efficiency of the results obtained relied so much on the standard of estimation made to produce quality asphalt concrete, which cost up to $270,830.00 at Chainages 26 + 700 to 26 + 925. All the experimental results proved that application of standard aggregates' mix design in road pavement construction helps in preventing the problems of deformation, cracks, and other defects on the roads' pavement system. Also, applying the first formulated mix design used in this study will help in maintaining the sustainable, durable, stable, and flexible road pavement in the global communities. Likewise, the government's constant expenditure on road pavement maintenance will be reduced.

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1. INTRODUCTION

Asphalt concrete is a composite mixture of aggregates with standard mineral resources banded together with asphalt and Portland cement or epoxy [1]. As investigated by [2], a material with the potential capacity to revolutionize the method of road construction is known as asphaltic cement (hot mixed). It consists of aggregates mixed uniformly with asphalt–cement coated. Asphalt concrete possesses some potential properties that make it durable and last longer. Lying of asphalt – concrete, on road courses has been improving the level of road surfaces and smoothing them against damage. The smooth road surface is commonly constructed with little expense and high-standard quality asphalt for easy transportation of goods and services [3]. In the construction industries today, asphaltic concrete surfaces (binder and wearing courses) are referred to as the most durable surfaces typically constructed for the smooth driving of automobiles and transportation of goods and services. Asphalt is a versatile material with suitable properties for construction purposes. Its suitability is the construction of durable and flexible pavements that are far better for automobile rides than other pavements built from recycle and non-durable materials such as green asphalt and cement-concrete pavements. Riding on asphalt concrete pavement reduces the effects of tear and wear on vehicles and increases the efficiency of fuel used by car riding, making it more durable [4]. In residential lodges, manufacturing companies, and construction industries, asphaltic concrete is used to construct internal roads, inside and outer access, the floor of motor park centers, and the seal of water lodge buildings.

According to [5], road pavement analysis and design were carried out from the 1950s to the 1993s using the old version of the highway design manual of the American Association of the State, popularly known as AASHTO [5]. AASHTO manual was established to control the quality of asphalt produced for road pavement construction under the American Highways and geometrical design association [6]. Although AASHTO is a good manual for road pavement construction, some of its limitations reduce its efficient performance in service. One of its limitations is that it has no complex mix design for standard asphalt concrete production like the one in the recent AASHTO design manual. In the early 1990s, a Superpave asphalt concrete mix design was introduced into the construction system organized for road binder course classification. A Superpave road system is referred to as a road pavement with highly superior performing asphalt concrete built for smooth transportation of vehicles [7]. The Superpave road system was implemented by a research programming group for highway strategic design to reduce the rate of premature failure of the road pavement and the cost of its maintenance [8]. Despite the efficient strategic mix design introduced into the system and the application of suitable aggregates for the road's binder pavement construction, aggregate load stresses were still not reduced to the expected level. Instead, they were prone to more failures, resulting in creeping, cracking, and deflection of road pavement. To remove the problem of road pavement deformation, earlier before establishing the Superpave system, the Hveem mix design was introduced into the asphalt concrete production system. This mixed design (Hveem mix design) is a design technique established by a resident engineer called Francis Hveem, who worked as a highways engineer at the highways division of California in the United States of America (USA) in 1920–1930. Hveem mix design was established to use high quantities of asphalt binder to produce firmly thick asphalt concrete. This type of concrete has less strength to withstand stress from vehicles during loading, thus resulting in pavement deformation [9, 10]. Any deformation from the pavement produced by the Hveem mix design can lead to a high cost of maintenance. The Superpave design method is far better than this method.

In further investigations to remove this problem of road pavement deformation from highway systems, [11] designed and modeled the responses of asphalt concrete aggregates against deformation. It was conducted for pavement loading stages to work against deformations reflected from high temperatures and mixes' viscoelasticity asphalt pavement. The process was achieved using the finite element model. Yet, the model's efficiency against those defects was not totally met. Most of these tests were carried out using a specified mix design of AASHTO for binder and wearing layers of the roads' pavement [12]. Having observed deviations from the expected road pavement construction standards, a better aggregate mix design is required for the road pavement system's stability, sustainability, and durability. Thus, this is the trust of this study.

From the practical point of view, most of the maintenance works on road structures these days are commonly initiated by improper mix designs of asphaltic concrete aggregates, its poor production, their inaccurate mixing, their poor methods of laying and compacting courses of asphalt on road surfaces, and its poor aggregates durability confirmation. These defects have caused much damage to global societies, organizations, and industries. Among the damages are sudden accidents, potholes formation, vehicle parts destruction, and road surface swaying. The above damages have called for other standard alternatives for the smooth transportation of goods and services globally. At that time, other available means of transportation were heavily affected, and they were too loaded and busy. This has been increasing the road maintenance culture globally, thus inflating the price of goods and services transported and increasing the sale price of goods and commodities globally, most especially in Nigeria. This study aims to develop and analyze a global standard mix design for the production of quality asphalt concrete. It also help in minimizing the high cost of asphalt concrete for road pavement construction in the global international market. In connection with the aim, this study (1) determines the quality of the materials for asphalt concrete production, (2) actualizes the accurate mix design best for the production of asphalt concrete, (3) develops a new standard method at which asphaltic concrete can be produced to fall within the limit of recommended specification. (4) ascertain the quantity, quality, and cost of

Figure 1. **(a)** Set of Sieves **(b)** Sieve Shaking Machine **(c)** Weighing Balances **(d)** Bitumen Extraction Machine **(e)** Thermometer **(f)** Marshall Testing Machine.

asphalt concrete laid on road courses through the use of leveling instrument.

2. MATERIALS AND METHODS

2.1. Materials and Equipment

The materials and equipment used in this experiment are crushed aggregates of sizes ¾", ½", and 3/8"; quarry dust, uncrushed aggregate (sharp sand), bitumen, filler (soft sand), bitumen extraction machine, Marshall Testing machine, weighing balances, scapular, set of sieves, thermometer, leveling instrument, reading staff, site record book, and asphalt production plant. Some of these equipments are shown in Figure 1. For further clarification, a set of sieves is equipment with square apertures and wire screens, rigidly woven together in a cylindrical metal frame, generally used to determine the sizes of particles such as sand, gravel, and soil [13]. A sieve shaking machine is a device upon which a set of sieves is placed for efficient sieving of particles under steady power loading. Also, a weighing balance is a machine used to determine the mass of a particle, object, or material to calculate its weight easily. A bitumen extracting machine is a device that is usually used to remove the total quantities of bitumen from asphaltic concrete at a controlled temperature by extracting solvents such as petrol and kerosene. Likewise, a thermometer is a device used to determine the degree of hotness or coldness of the body or an object. In asphalt concrete production companies, it is usually used to assess the degree of hotness of asphalt produced before laying it as pavement on the road surface.

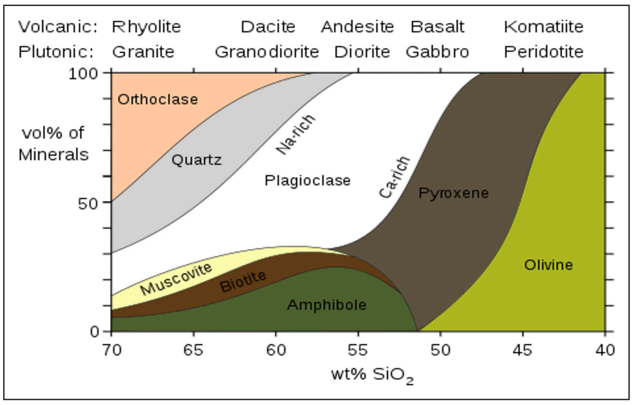

Figure 2. The levels of igneous rock assemblage of minerals [11].

2.1.1. Crushed Aggregates (Granite) of Sizes ¾", ½" and 3/8" Descriptions

Granite is a coarse-grained material extracted from hard igneous rock. It consists of microcline or orthoclase, mica, and quartz minerals. Granite is one of the most durable, oldest building materials. It is essentially used for offices and home luxuries because of its endurable beauty [14]. According to [15], granite is a grain stone called granum in Latin word. It is normally extracted from granitic rock that consists of major minerals such as amphibole, mica, quartz, and feldspar, which influence the interlocking process of the granite. Amphibole and mica formed the color minerals during the interlocking process, while quartz and feldspar formed the scattered dark biotite, often called hornblende. The coarse grain and a lighter–colored igneous rock is generally called Granitoid. A porphyritic texture granitic rock is known as granite porphyry [16]. The levels of igneous rock assemblage of minerals were presented as shown in Figure 2. The QAPF diagram of coarse-grained rocks was labeled according to the quantities of plagioclase feldspar alkali and quartz in half of the diagram. As alkali modern petrologic convention states, true granite consists of 35 to 90% of feldspar and 20–60% of quartz by volume.

The granitic rocks with more than 60% quartz are classified as quartz-rich granitoid or quartzite [17–19]. A typical granite (or metaluminous granite) is granite that is made up of alkali and aluminum metals, most especially potassium and sodium, as shown in the chemical reaction of $K_2O+Na_2O+CaO>Al_2O_3>K_2O+Na_2O$.The granite with less aluminum that developed into feldspar with alkali oxides, as shown in the chemical reaction of $Al_2O_3<K_2O+Na_2O$, is referred to as Peralkaline [20]. Granite possesses an average density of 2.65 to 2.75 g/cm^3 [21, 22]. It has over 200MPa compressive strength with a viscosity of 3 to 6 x 10^{20}Pa.S [23]. A dry granite melt at ambient pressure and temperature of 1215–1260^{0}C (2219–2300^{0}F) [24]. The melting temperature is usually reduced to 650^{0}C with the presence of water. Granite is poor in primary permeability but performs better in secondary permeability through fractures and cracks [25, 26].

2.1.1.1. Chemical Composition and Classifications of Crushed and Uncrushed Aggregates

Globally, the chemical composition of granite based on 2485 analyses was presented as shown in Table 1.

A ¾" crushed aggregate is a material for road and concrete construction with a 19.1mm size crush size. It is made of large stones and can be used to construct a base or sub-base in road pavement construction. It was classified as coarse gravel since its aggregate sizes fall between 16–64 mm and 19.1mm. It is also usually used to produce high-strength concrete [27, 28]. Likewise, the crushed aggregate of ½" size (12.5 mm) was classified as medium gravel due to its size gradation that is within 8–16 mm according to [27] and [28] classification. It is commonly used to supplement the performance of ¾" aggregate for high strength yielding during road pavement construction. With this, the base and sub-base materials of the road will be stronger and compatible. Also, the 3/8 crushed aggregate was classified into a medium gravel category ranging from 8–16 mm. Majorly, using ½" and 3/8" crushed aggregates supplements the structural function of ¾" aggregate in producing high-quality asphaltic concrete.

Moreover, the aggregates ranging from 2.36 mm to 0.6 mm were classified into coarse sand (uncrushed). ASTM classification states that 2.0 mm–0.5 mm of uncrushed aggregate is categorized and grouped into coarse sand material. The other uncrushed materials were sized to 0.30–0.075 mm and classified into fine sand and quarry dust. According to [28], the specified limit for these groups (other uncrushed materials) ranged from 0.25 mm–0.06 mm.

The mixture of these aggregates for asphalt production for road construction has highly increased the strength of the road surface pavement, especially the binder course. The classification of the aggregates used in this study proved to be of high quality and fit for experimental investigation and road courses" construction (binder and wearing courses). A quarry dust is defined as a waste obtained when the coarse aggregate (crushed granite) from rock material is being processed into sizes at the quarry [29]. The quarry dust used in this study was classified into 2.0–0.5 mm due to its presence of fine particles. They usually replaced sand (fine aggregate) for asphalt and concrete productions. It is gray and of grade A standard. It has no packaging type, but its formation is in the form of chips [28, 30]. The uncrushed material produced by asphalt concrete in this study is sharp sand. Sand is a granular loose material generally obtained from the disintegration of rock, which consists of smaller particles than gravel but has coarseness than silt and can be used to produce abrasive, mortar, and foundry molding [31]. The size of sand used in this experiment is 2.36–0.6 mm. Figure 3 shows the images of granite, sharp sand, and quarry dust used in this study.

Table 1. Chemical composition of granite [15]

Composition	SiO_2 (Silica)	Al_2O_3 Alumina	K_2O	Na_2O	CaO	FeO	Fe_2O_3	MgO	TiO_2	P_2O_5	MnO
% Constituent (%)	72.04	14.42	4.12	3.69	1.82	1.68	1.22	0.71	0.30	0.12	0.05

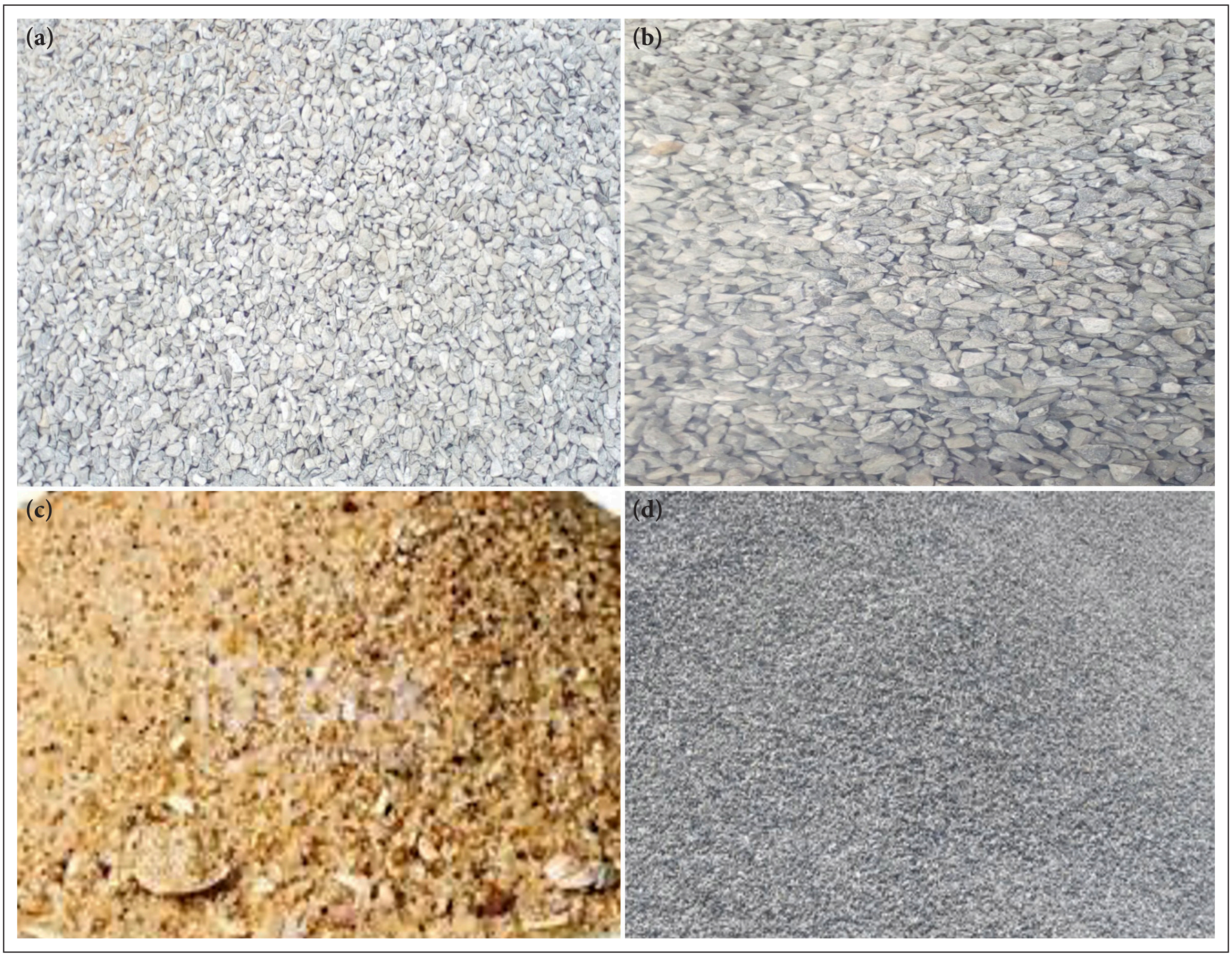

Figure 3. **(a)** Crushed Aggregate (1/2” granite) **(b)** Crushed aggregate (3/4” granite) **(c)** Sharp Sand **(d)** Quarry Dust.

2.1.2. Aggregates and Their Treatments

The crushed aggregates (sizes ¾", ½", and 3/8") used in this investigation were obtained from a quarry site very close to Okin, Oko, Ogbomoso, Oyo State, Nigeria. The obtained crushed aggregates were air-dried for four weeks in a cool, dry place around the quarry site. The air-dried aggregates were oven-dried again under 105 ^{0}C temperature to remove its optimum moisture content. The dried aggregates were removed from the oven, allowed to cool, and sieved to remove the clay particles and broken bottles. The sieved aggregates were stored around the quarry site in a cool, dry place. Also, the quarry dust used to produce asphalt concrete in this study was obtained from a quarry that belongs to Dutum Company Nigeria Limited at Okin, Oko, Ogbomoso, Oyo State, Nigeria. The same crushed aggregate treatment (granite) procedure was adopted for quarry dust treatment. Furthermore, the sand used in this research was obtained from a stream close to Dutum Company's quarry site at Okin, Ogbomoso. It was also Sun-dried for two weeks (14 days) like granite to dry its moisture content completely. The dried sand was sieved and kept in a cool, dry place until its usage. Likewise, the soft sand (filler) used in this investigation was to supplement the binding properties of asphalt aggregates for better production of quality asphalt. The soft sand was obtained around the Okin quarry site. The soft sand was treated as that of sharp sand. For standard production of asphalt concrete, the quality of bitumen supplied from the market were determined using the specified limit of 60–70 mm, 80–100 mm, 40–50 mm, 130–150 mm, and 180–200 mm.

2.2. Methodology

2.2.1. Determination of Quality of Bitumen Supplied for Asphalt Concrete Production

The higher the quality of bitumen is, the greater the quality of asphalt concrete that will be produced from it. Also, the more complex the needle penetration into the bitumen supplied, the higher the quality of the provided bitumen for asphalt concrete production. As conducted in the experiment, the quality of the provided 60–70 mm grade of bitumen with a heating temperature limit of 160–175 ^{0}C was determined through the bitumen penetration testing method. The small bitumen was taken into a small Can and heated to 150 ^{0}C on a Bunsen burner. The heated bitumen was poured into two or more Cans in equal quantities and cooled at 20 ^{0}C to 25 ^{0}C. The bitumen penetration machine was set in a good position for the experiment. The hap of plumb was attached to a penetrometer (penetration machine) at the base to maintain stability. The pin-tip of the penetration needle was well-positioned for easy penetration. The penetrometer

Table 2. First asphalt mix design for road binder course laying

Aggregate used with sizes (in inches)	Constituent (%)
¾” Aggregate (granite, crushed)	27
½” Aggregate (crushed)	18
3/8” Aggregate (crushed)	11
Quarry dust (uncrushed)	31.1
Sharp sand (uncrushed)	8
Bitumen content	4.9
Total	100

Table 3. Second asphalt mix design for road binder course laying

Aggregate used with sizes (in inches)	Constituent (%)
¾” Aggregate (granite, crushed)	25
½” Aggregate (crushed)	10
3/8” Aggregate (crushed)	13
Quarry dust (uncrushed)	37.4
Sharp sand (uncrushed)	10
Bitumen content	4.6
Total	100

was set to zero (0) to avoid inaccuracy in the reading results. Then, the pin-tip of the needle was set to coincide with that of the rod from the penetration scale and set to zero (0). The penetrometer rod was then released quickly and allowed to press the bitumen in the Can for 5 seconds. Immediately, the needle penetration was stopped at precisely 5 minutes. A rod positioned at the back of the penetration machine was pressed to touch the rod from the tip of the needle. Then, the needle penetration reading was taken immediately. This procedure was adopted and followed repeatedly for all the bitumen samples tested. The penetration values were measured in millimeters and recorded accordingly.

2.2.2. Asphalt Mix Design

The three mix proportions produced asphalt concrete for the road's binder pavement construction. For the construction of wearing pavement, two mix proportions were used to experiment with the quality production of asphalt pavement for the construction of Oko – Ogbomoso - Osogbo road by Dutum Company Nigeria Limited in agreement with ASTM: D692/D692M-20, D242/D242M-19 and D1073-16(2022) standard for the use of coarse aggregates, filler and fine aggregates for the production of asphalt concrete for road pavements construction respectively [32]; following the specification of FMW (1994)'s standard. After analyzing the asphaltic concrete aggregates, the best mix proportion among the three proportions used for producing asphaltic concrete was adopted for quality asphalt production. The best mix design was also adopted for the production of asphalt concrete for the road pavement wearing course's construction from the two mix designs evaluated.

2.2.2.1. Asphalt Concrete Mix Proportion for Binder Course

The first to the third trial mixes produced concrete at a quarry site around Okin-Oko, Ogbomoso. For efficient asphalt production, the crushed and uncrushed aggregates were placed into the asphalt plant in percentages, and asphalt concrete was produced using the three-mix design. During the first mix, ¾” aggregate (crushed) was placed inside the asphalt plant's mixer, occupying up to 27% of the total aggregates. Following this, about 18% of ½” aggregate (crushed) was placed inside the same asphalt plant's mixer. The two aggregates in the mixer were thoroughly mixed and prepared for the next stage. Then, about 11% of 3/8” aggregate (crushed) was added to the mixture of the aggregates in the asphalt plant mixer, and all the aggregates were thoroughly mixed for the second time. After a while, 31.1% and 8% of quarry dust and sharp sand were also added to the mixed aggregates in the asphalt plant mixer. All the aggregates (crushed and uncrushed) in the asphalt production plant's mixer were re-mixed for the third time to have a homogeneous composite. Then, about 4.9% of bitumen was added to the mixed aggregates in the asphalt plant mixer, remixed several times, and heated at high temperatures to produce quality asphalt concrete. Concrete was produced after the aggregates with bitumen have passed through the several stages of industrial processes in the asphalt plant. The concrete produced was discharged into the Lorries, transported them to the site where the pavements will be constructed. The mix designed adopted for this asphalt production is presented in Table 2. The second and third trial mixes were experimented following the steps used to produce asphalt concrete in the first mix design. Here, the aggregate mix proportion used to produce asphalt concrete differs from that of the first trial mix. This second trial mix comprises 25%, 10%, and 13% of ¾”, ½”, and 3/8” crushed aggregates and 37.4% and 10% of quarry dust and sand res, respectively. Also, the percentage of the bitumen added was about 4.6%. This percentage (4.6%) is lower than the first mix design. The third mix design used 27%, 15%, and 11% of ¾”, ½”, and 3/8”crushed aggregate, respectively. As used in the experiment, the sand and quarry dust percentages included in the mix were 10% and 32.2%, respectively. 4.8% of bitumen was added to the mixed aggregates before the aggregate's final processed to produce asphalt concrete for the binder pavement construction. This value (4.8%) is more than the percentage used in the second mix design (4.6%) by 0.2%. Tables 2–4 present the mix proportions for the production of asphalt concrete from first to third mix designs. To produce quality asphalt concrete for road-wearing pavement construction, the above procedures used for producing asphalt concrete for binder pavement construction were adopted. During the mixing of aggregates to produce asphalt concrete for wearing pavement construction, the volume of sand included in the mix was reduced, and that of quarry dust was increased. As shown in Table 5, 20% of ¾”–½” of crushed aggregate was used for the investigation, while the ½”–3/8” of crushed aggregates used were up to 27%. For smooth concrete production, 10% of sand and 42.2% of quarry dust were mixed thoroughly with the measure aggregates in the mixer to form a uniform composite. The initial mixed aggregates were mixed again thoroughly with 5.8% bitumen for the second time, after which it passed through series of stages before the asphalt concrete was produced. The asphalt concrete produced was

Table 4. Third asphalt mix design for road binder course laying

Aggregate used with sizes (in inches)	Constituent (%)
¾” Aggregate (granite, crushed)	27
½” Aggregate (crushed)	15
3/8” Aggregate (crushed)	11
Quarry dust (uncrushed)	32.2
Sharp sand (uncrushed)	10
Bitumen content	4.8
Total	100

transported to the site where the road-wearing pavement will be constructed. The second mix design was experimented with, to produce asphalt concrete for the construction of road’s wearing course’s pavement according to the proportion stated in Table 6.

2.2.3. Extraction Test and Asphalt Grain Analysis

2.2.3.1. Bitumen Extraction Test

The extraction of bitumen content from the freshly produced asphalt concrete was carried out to ascertain the quantity and quality of bitumen used to produce asphalt concrete for the sustainability of the Oko-Ogbomoso-Osogbo road which was under construction then in Nigeria. The following procedures were adopted: extract of bitumen from the asphalt concrete produced using three different mix designs. During the investigation, a certain quantity of asphalt concrete was taken from an asphalt production plant at Okin, Oko-Ogbomoso, Oyo State, Nigeria. The collected samples were heated on the bursen burner until their heat temperature read 150 ^{0}C on the thermometer. Then, the riffle box apparatus was set out to distribute the heated asphalt concrete evenly for easy testing. In each of the extraction test carried out, 1200 g of heated asphalt was measured on a weighing balance. The weighed samples were placed on clean trays and correctly positioned for testing. Also, the filter disc paper, which was used to protect the weighed sample from losing or dropping out during the bitumen extraction was weighed on a scale. The earlier measured 1200g heated asphalt concrete sample was transferred into the rotor bowl inside the centrifuge bitumen extracting machine. The weight of asphalt, together with that of the rotor bowl, was measured before testing. At that point, the bitumen-extracting machine was well-positioned for the test. After the machine positioning, a bitumen-extracting solvent (petrol or kerosene) was poured on the heated samples, which were earlier transferred into the rotor bowl, after which a new weighed filter disc paper was placed on top of the rotor bowl to prevent it from losing aggregates content of the sample testing. Also, it was used to avoid wasting bitumen during the extraction process. At this stage, the heated samples with solvent and disc paper placed inside the rotor bowl were covered with the extraction machine’s lid. Then, the rotor bowl was keyed down with its lid using the nuts and bolts at the edge of the centrifuge bitumen-extracting machine. After properly tightening the nuts and bolts of the machine with the rotor bowl, it was powered

Table 5. Asphalt mix design for road wearing course lying (first mix design)

Aggregate used with sizes (in inches)	Constituent (%)
¾” – ½”Aggregate (crushed)	20
½” – 3/8” Aggregate (crushed)	27
Quarry dust (uncrushed)	37.2
Sharp/soft sand (Filler) (uncrushed)	10
Bitumen content	5.8
Total	100

Table 6. Asphalt mix design for road wearing course lying (second mix design)

Aggregate used with sizes (in inches)	Constituent (%)
¾” – ½”Aggregate (crushed)	18
½” – 3/8” Aggregate (crushed)	22
Quarry dust (uncrushed)	49.4
Sharp/soft sand (Filler) (uncrushed)	5
Bitumen content	5.6
Total	100

on to start the extraction process. In the extraction process, the rotor machine motion speed was controlled, and it was gradually increased. This was done to prevent the escape of extract (solvent with bitumen) from the rotor bowl to the machine operators and laboratory technicians, which can lead to injury or burning of their skin. It was also observed that the higher the speed, the hotter the mixture of asphalt and solvent can lead to a fire outbreak. After 2–5 minutes of extraction, when the solvent might have washed the bitumen from the asphalt concrete away, the extraction machine was stopped, and the dissolved bitumen was drained from the mixture of solvent and asphalt in the rotor bowl. This process was repeated, and more solvent were poured on the aggregate in the bowl until no trace of bitumen was observed in the drained solvent after the extraction. The extraction process was stopped at the total draining of the bitumen from the sample. At the final stage, the extracted solvent was drained from the rotor machine, and the bowl and aggregates remained in the bowl after extractions were brought out from the machine. All the aggregates that escaped during the extraction process from the rotor bowl to the filter paper disc were brushed off into the bowl. Also, all the aggregate in the bowl was oven-dried at a steady and controlled temperature to dry off all its moisture content. After properly drying of the aggregate in the oven, the aggregates were removed, weighed, and kept in a cool, dry place for sieve analysis. At this time, the weight of the filter disc paper was also determined after the extraction process.

2.2.3.2. Sieve Analysis of Extracted Aggregates

After the bitumen extraction, the sieve analysis of asphalt concrete’s aggregate was conducted as follows: The dry aggregate was taken from the oven and allowed to cool for some minutes. The specified sets of sieves, ranging from 3/4” (19.1 mm) to No. 200 (0.075 mm), were set as shown in Table 7.

Table 7. Sieve sizes arrangement in mm and inches

Sieve sizes in inches	3/4"	½"	3/8"	No. 7	No. 14	No. 100	No. 200
Sieve sizes in mm	19.1	12.7	9.5	2.3	1.18	0.60	0.075 or 75μm

Table 8. Set of sieve size for binder and wearing courses' asphalt aggregates

Source of aggregate	Binder and Wearing Course Aggregates												
Sieve sizes (mm)	38.1	25.4	20.0	12.7	10.0	6.35	2.36	1.18	600 μm	300 μm	150 μm	75 μm	Passing base plate

Then, the sets of sieves were placed on the electronic sieve shaking machine for sieve analysis. The oven-dried extracted aggregates were placed on a 19.1 mm sieve on top of the set. Then, a metallic cover was placed on top of the set sieve and tightened at both edges with the rods beside the sieve sets. The sieve shaker was powered on, and speeds were applied steadily to quickly sieve the aggregates. The retained aggregate on each set of sieves was measured and classified according to size. The values of aggregates from sieve analysis were compared with that of the specified standard stated by the Federal Ministry of Works (Federal Ministry of Works' Road Specification, 1994). The sizes of sieves specified for sieve analysis of the extracted aggregates from asphalt concrete for road binder and wearing course laying are shown in Table 8.

After the bitumen extraction process, the weights of aggregates observed were determined as follows:

The weight of asphalt concrete with solvent and rotor bowl in grams was represented by A, that is,

A = Weight of asphalt concrete + solvent + rotor bowl. The weight of the rotor bowl measured was represented by B, and then, the weight of the mixture (asphalt concrete + solvent) in the bowl was determined using Equation 1.

$$\text{Weight of mixture (asphalt concrete + solvent)(C)} = A - B \tag{1}$$

The weight of filter disc paper before testing was determined to be D, and its value after testing was determined to be E. Therefore, the weight of aggregate retained on the filter paper (F) was calculated using Equation 2.

$$\text{Weight of aggregate retained on the filter paper (F)} = E - D \tag{2}$$

Also, the weight of aggregates in the bowl after the bitumen extraction was G, while the weight of total aggregates in the bowl with filter paper was H. Then, the weight of bitumen in asphalt concrete tested was calculated using Equation 3.

$$\text{Weight of bitumen in asphalt concrete tested} = C - H \tag{3}$$

The percentage of bitumen used on the total weight of mixture (J) was determined using Equation 4.

Percentage of Bitumen used on the total weight of mixture (J)

$$= \frac{\text{Weight of Bitumen}}{\text{Weight of Mixture}} \text{ x } 100\%$$

$$= \frac{I}{C} \text{ x } 100\% \tag{4}$$

Also, the percentage of bitumen used on dry aggregate mixture was determined using Equation 5.

$$\text{Percentage of Bitumen on dry aggregate} \frac{\text{Weight of Bitumen}}{\text{Weight of Total aggregates in the bowl}} \text{ x } 100\% = \frac{I}{H} \text{ x } 100\% \tag{5}$$

2.2.4. Surveying Method of Determining the Cost of Asphalt Concrete Laid

The cost of asphalt concrete laid at the construction of the Ogbomoso – Osogbo – Oko Federal road was estimated for using the leveling method of measurement as prescribed by the regulation of the surveying department at Dutum Company Nigeria Limited, which is the contractor of the project. This study only considered the cost estimate of asphalt concrete laid at chainage 26 + 700 to chainage 26 + 925 of the road. During the survey measure, the road surface level was determined and recorded as the initial level before the commencement of asphalt lying. Also, after laying asphaltic concrete, the level of road pavement was retaken to determine the actual volume of asphalt concrete laid. In the leveling processes, the level instrument was fixed on its tripod stand and tight firmly as shown in Figure 4. Then, the leveling device was set accurately to cancel zero error. Then, the level instrument was put on a small pillar at chainage 26 + 700, referred to as the initial total benchmark (TBM). At the initial TBM, the first back sight of the road leveling was taken using staff and level equipment. Also, the road's high curvature (H.P.C.) was determined using a leveling device, staff, and measuring tape. A reduced internal level (R.I.L) of sights measurement was assumed to be 1012.500 for easy calculation. This value was used to determine the level of each point of the road at that location. Likewise, at chainage 26 + 700, around the TBM location, surveying staff was placed at the center of the road tip to do a reading from the level device, referred to as the first inter-sight of surveying measurement. The second inter-sight reading was taken when the staff instrument was placed at the road's right-hand side (R.H.S.), and the level device was used to take a reading from the staff. The following reading from the staff was taken at the road's left-hand side (LHS), called inter-sight reading. The values obtained were used to determine the R.I.L of all the sighted measurements. The above steps were repeated until there was a change of point in the measurement. These processes were carefully followed, and the readings were taken from Centre, RHS, and LHS until chainage 26 + 925 was reached. When there was a change in the reading level taken on the road from the staff sights, the previous foresight (FS) and the new backsight (BS) were taken for the measurement. The values obtained from the readings were tabulated as shown in Table 9.

Figure 4. **(a)** Survey Staff **(b)** Level device fixed on tripod stand **(c)** Taking of road levels by the chief surveyor.

After the asphalt concrete was laid, the above steps and methods were adopted for road leveling. This value was determined by the total volume of asphalt concrete laid (Fig. 5). The volume obtained from sight readings was used to estimate the cost of the asphalt concrete laid from chainage 26 + 700 to chainage 26 + 925, which is about 250 minutes. For accuracy of sight measurement, equation 6 was used to check the efficiency of the recorded values.

3. RESULTS AND DISCUSSIONS

The results of the investigation conducted on the three different aggregates mix designs for asphalt concrete production for binder course lying and that of two mix designs for wearing course pavements construction, together with their estimated costs obtained, are presented as follows.

3.1. Marshall Test Results on Asphalt Concrete for Binder Course

3.1.1. Marshall Test Results of Asphalt Concrete for Binder Course From First Aggregate Mix Design

The laboratory test results of the asphaltic concrete produced from the first mix design are presented in Tables 10, 11 and Figure 5. As shown in Table 10, the percentage of aggregate passing sieve sizes ¾” (19.1 mm), ½” (12.5 mm), 3/8” (9.5 mm), and ¼” (6.5 mm) were recorded as 86.4%, 66.7%, 57.88%, and 49.4% respectively. These values were within the specified limit of 70–100, 55–80, 47–70, and 40–60 percent, as stated by the Federal Ministry of Works and Housing for road-binder course pavement construction (1994). The results show that aggregates from the first mix design used to produce asphalt concrete are valuable with good structural properties to resist the stress generated through loading on road pavement during its serviceability life span (Fig. 5).

The specified limit approved for the aggregate passing sieve sizes No. 7 (2.38 mm), No. 14 (1.18 mm), No. 25 (0.60 mm), and No. 52 (0.30 mm) were ranged as 27–45, 20–34, 14–24 and 8–20 percents respectively by Federal ministry’s specification. The percentages of aggregates passing through the sieve mentioned above sizes are 35.6%, 26.2%, 18.2%, and 13.6%, respectively. These values were perfectly fixed to the specified limit stated for the binder course aggregates for road construction according to the specifications of the Federal Ministry of Works and Housing (FMWH) road. The efficiency of these aggregates in road construction (significantly, the binder course) are shown in Figure 6 and are classified as fine aggregates. Likewise, the number of aggregates that passed through sieves No. 100 (0.150

Table 9. Format of recording Level values before and after asphaltic concrete lying

Back Sight (B.S.)	Inter Sight (I.S.)	Fore Sight (F.S.)	High Point of Curvature (HPC)	Reduce Internal Level (R.I.L)	Distance	Remarks

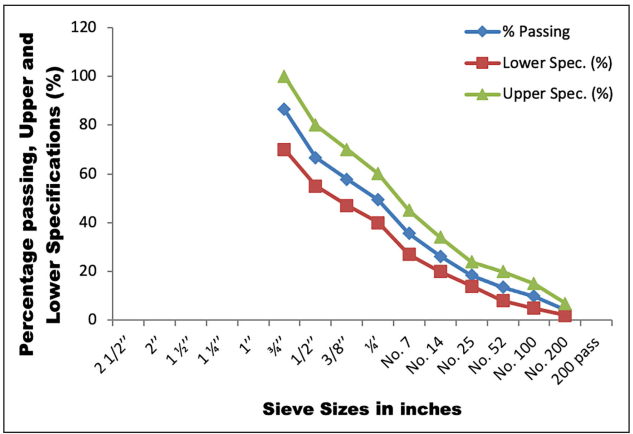

Figure 5. Chart of gradation result of asphalt concrete for road binder course laying from first mix design.

mm) and no. 200 (0.075 mm) also meet the specified limit of 5–15% and 2–7%, as stated for this classification. Aggregate passing through sieve No. 200 is referred to as clay. From the gradation result presented in Table 10, it was observed that all the aggregates used for the experiment were of high quality and suitable for asphalt concrete production for road binder pavement construction. As shown in Figure 6, all the aggregates' values presented were between the middle of the specified limit (envelope) for quality asphalt concrete production. This proves the first concrete mix design efficiently produces quality asphalt concrete for road binder course laying. Thus, this first mix design is highly recommended for global asphalt concrete production for the binder course of the road. As presented in Table 11, the bitumen content in the first mix design of asphalt concrete was calculated to be 4.9%. This is the bitumen content ex-

Table 10. Granisize analysis of asphalt concrete for road binder course laying from first mix design

Sieve size (inch)	Sieve size (mm)	Weight retained (g)	% Retained (%)	% Passing (%)	Specification
2 1/2"	63.5				
2"	50.6				
1 ½"	38.1				
1 ¼"	31.8				
1"	25.4	–	–	–	100
¾"	19.1	155	13.6	86.4	70–100
1/2"	12/7	225	19.7	66.7	55–80
3/8"	9.5	102	8.9	57.8	47–70
¼'	6.5	96	8.4	49.4	40–60
3/16"	4.76				
1/8"	3.45				
No. 7	2.36	157	13.8	35.6	27–45
No. 14	1.18	107	9.4	26.2	20–34
No. 25	0.600	89	7.8	18.4	14–24
No. 36	0.425				
No. 52	0.300	55	4.8	13.6	8–20
No. 72	0.212				
No. 100	0.150	43	3.8	9.8	5–15
No. 200	0.075	63	5.5	4.3	2–7
200 pass	0.075	49	4.3		

Contract: Ogbomoso–Osogbo–Oko Road Project; Sample Ref.: Binder Course; Location: Chainage 26+700 to chainage 26+925; Weight of total aggregate: 1141.4g

Table 11. Extracted Bitumen from asphalt concrete for road binder course laying from the first mix design

Reference	Description	Value	Unit
A	Weight of mixture+bowl	2010	g
B	Weigram bowl	870	g
C	Weight of mixture = A-B	1200	g
D	Weight of filter before testing	0.2	g
E	Weight of filter after testing	0.6	g
F	Weight of material retained by filter = E-D	0.4	g
G	Weight of aggregate in the bowl	1141	g
H	Weight of total aggregate = F+G	1141.4	g
I	Weight of bitumen = C-H	58.6	g
J	% of Bitumen on the total weight of mixture = I/C×100	4.9	%
K	% of Bitumen on dry aggregate = I/H×100	5.1	%

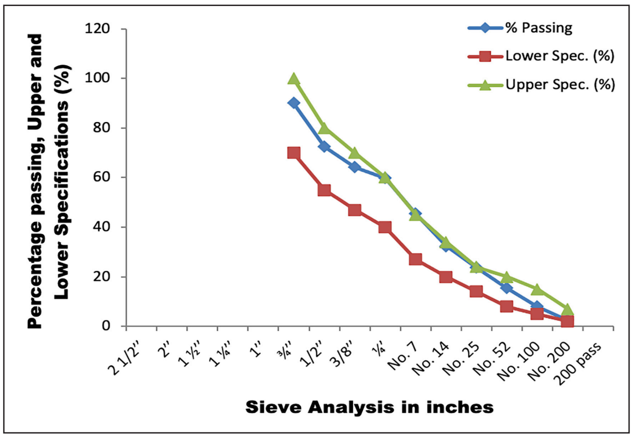

Figure 6. Chart showing the gradation result of asphalt concrete for road binder course laying formed from second mix design Grainsize.

tracted from 1200 g of asphalt concrete sample used. The result obtained is equivalent to the initial percentage used during the production of asphalt concrete (4.9%). As shown in the result, the quality of bitumen used in the first mix is accurate and efficient. The aggregates analysis and bituminous content results show that asphalt concrete produced from the first mix design is of high quality and is an efficient construction of a sustainable road's binder course layer.

3.1.2. Marshall Test Results of Asphalt Concrete for Road Binder Course Laying from Second Mix Design

The result of aggregates' analysis from the second mix design of asphalt concrete was wasted, as shown in Figure 6 and Tables 12, 13.

As shown in Table 12, the percentage of crushed aggregates passing sieve sizes ¾" (19.1 mm), ½" (12.5 mm), 3/8" (9.5 mm), and ¼" (6.5 mm) were 90%, 72.5%, 64.2%, and

Table 12. Grain size analysis of asphalt concrete for road binder course laying from second mix design

Sieve size (inch)	Sieve size (mm)	Weight retained (g)	% Retained (%)	% Passing (%)	Specification
2 1/2"	63.5				
2"	50.6				
1 ½"	38.1				
1 ¼"	31.8				
1"	25.4	–	–	–	100
¾"	19.1	114	10	90	70–100
1/2"	12/7	200	17.5	72.5	55–80
3/8"	9.5	95	8.3	64.2	47–70
¼'	6.5	52	4.5	59.7	40–60
3/16"	4.76				
1/8"	3.45				
No. 7	2.36	164	14.3	45.4	27–45
No. 14	1.18	150	13.1	32.3	20–34
No. 25	0.600	98	8.6	23.7	14–24
No. 36	0.425				
No. 52	0.300	95	8.3	15.4	8–20
No. 72	0.212				
No. 100	0.150	85	7.4	8.0	5–15
No. 200	0.075	64	5.6	2.4	2–7
200 pass	0.075	27	2.4		

Contract: Ogbomoso–Osogbo–Oko Road Project; Sample Ref: Binder Course; Location: Chainage 26+700 to chainage 26+925; Weight of total aggregate: 1144g

Table 13. Extracted Bitumen from asphalt concrete for road binder course lay from second mix design

Reference	Description	Value	Unit
A	Weight of mixture+bowl	1470	g
B	Weight of bowl	270	g
C	Weight of mixture = A-B	1200	g
D	Weight of filter before testing	1.0	g
E	Weight of filter after testing	2.0	g
F	Weight of material retained by filter = E-D	1.0	g
G	Weight of aggregate in the bowl	1143	g
H	Weight of total aggregate = F+G	1144	g
I	Weight of bitumen = C-H	56	g
J	% of Bitumen on the total weight of mixture = I/C×100	4.7	%
K	% of Bitumen on dry aggregate = I/H×100	4.9	%

Figure 7. Laying of asphalt concrete at the binder course.

59.7% respectively. Though the percentage of aggregates that passed ¾" sieve (90%) was within the specified limit (70–100%) set by FMWH on an excellent binder course of a road, the obtained values were so close to the upper limit of the specification. This implies that ¾" size aggregate has a higher volume in the third mix design formulated than other aggregates. This might cause ineffective compaction of aggregates during construction because the aggregate size is too big for perfect compatibility. The asphalt compaction quality will be improved if the aggregate percentage is reduced to 75–80% for accurate compaction. Also, the value of aggregate passing sieves ½" (72.5%), 3/8" (64.2%), and ¼" (59.7%) are within the Ministry's specified value, like 55–80%, 41–70%, and 40–60% as stated by FMWH. Although the values obtained are within the specified limit, the recorded values were too close to the edges of those specifications. As observed, some crushed aggregates are more significant than expected compared to the specified limit (Fig. 7). The aggregate values within the specified boundaries should be reduced to 65–72%, 58–62%, and 48–53% for perfect compaction of aggregates during the pavement construction at the binder course of the road. The categories of aggregates that passed through sieves No. 7, No. 14, No. 3,6, and No. 52 were found to perfectly satisfy the specified standard of uncrushed aggregate (sand) (2.4–0.5 mm,) which is in agreement with the findings of [33]. The percentage of aggregates that passed through the above set of sieves was calculated to be 45.4%, 32.3%, 23.3%, and 15.4%, respectively. Some aggregates that passed through sieve No. 7 are too big compared to others in the same category. As shown in Figure 7, the aggregate percentages specified to be within the limit of 27–45%, as stated by FMWH, are beyond the expected values. Therefore, there should be aggregate quantity reduction, which should range from 32–40%. Also, the value of aggregate passing sieve No. 14 (32.3%) is too close to the specified limit (20–34%) for perfect construction and compaction; it will be okay if it is reduced to 25–30%. Likewise, the values of aggregates passing sieves No. 25 and No. 52 have to be reduced and should fall within the range of 18–20% and 12–14% instead of 23.4% and 15.4% obtained. Percentages of other aggregates passing sieves No. 100 and No. 200 obtained (8.0% and 2.4%, respectively) are standard for producing sustainable asphaltic concrete compared with the specified limit approved by FMWH. The results analysis showed that the asphaltic concrete made from the second mix design is inefficient for the road's binder layer's construction, as the one produced from the first mix design. Therefore, the aggregate sizes formulated from the first mix design for asphalt concrete production are adopted to produce quality asphalt for the road's binder layer. Like the concrete made from the first mix design, the quantity of bitumen used to produce asphalt concrete through the second mix design was calculated to be 4.7%. This value is obtained through the bitumen extraction process. The value (4.7%) was 0.1% more than that obtained from concrete from the first mix design (4.6%).

3.1.3. Marshall Test Results of Asphalt Concrete for Road Binder Course from Third Mix Design

The aggregate analysis results and the bitumen content produced from the third mix design are shown in Tables 14, 15 and Figure 8. As presented in Table 13, the number of aggregates passing sieve sizes ¾", ½", 3/8", and ¼" were analyzed and classified as medium gravel. According to [33], the aggregates in this category were of sizes 8–16 mm. The percentages observed, 90.0%, 64.9%, 56.8%, and

Table 14. Granisize analysis of asphalt concrete for road binder course lay from third mix design

Sieve size (inch)	Sieve size (mm)	Weight retained (g)	% Retained (%)	% Passing (%)	Specification
2 1/2”	63.5				
2”	50.6				
1 ½”	38.1				
1 ¼”	31.8				
1”	25.4	–	–	100	100
¾”	19.1	108	10.2	90.0	70–100
1/2”	12/7	270	25.1	64.9	55–80
3/8”	9.5	88	8.1	56.8	47–70
¼’	6.5	79	7.3	49.5	40–60
3/16”	4.76				
1/8”	3.45				
No. 7	2.36	85	7.9	41.6	27–45
No. 14	1.18	88	8.2	33.4	20–34
No. 25	0.600	110	10.2	23.2	14–24
No. 36	0.425				
No. 52	0.300	100	9.3	13.9	8–20
No. 72	0.212				
No. 100	0.150	80	7.4	6.5	5–15
No. 200	0.075	70	6.5		2–7
200 pass	0.075				

Contract: Ogbomoso–Osogbo–Oko Road Project; Sample Ref: Binder Course; Location: Chainage 26+700 to chainage 26+925; Weight of total aggregate: 1078g

Table 15. Extracted Bitumen from asphalt concrete for road binder course lay from third mix design

Reference	Description	Value	Unit
A	Weight of mixture+bowl	1370	g
B	Weight of bowl	170	g
C	Weight of mixture = A-B	1200	g
D	Weight of filter before testing	1.0	g
E	Weight of filter after testing	2.5	g
F	Weight of material retained by filter = E-D	1.5	g
G	Weight of aggregate in the bowl	1075.0	g
H	Weight of total aggregate = F+G	1076.5	g
I	Weight of bitumen = C-H	123.5	g
J	% of Bitumen on the total weight of mixture = I/C×100	10.3	%
K	% of Bitumen on dry aggregate = I/H×100	11.5	%

49.5%, were within the specified limit of 70–100%, 55–80%, 47–70%, and 40–60% respectively, stated by FMWH for stability and durability of asphalt binder concrete. As shown in Figure 8, the quantity of aggregate passing sieve size ¾” was very close to the specified limit. A good value is expected to be within the specified envelope (lower and upper limit) as stated in the FMWH specification. This value must be reduced and should fall between the 78–85% range for quality production of asphalt concrete and efficient compassion and sustainability of the aggregates. Also, as shown in Table 14, the percentage of aggregates passing sieve sizes ½” and 3/8” (64.9% and 58.8%) were within the middle of the specified boundaries (lower and upper limit) that is 55–80% and 47–70% respectively. The values obtained were quality to produce asphalt concrete pavement. Also, the percentage of aggregate passing sieve ¼” is average, but it requires a bit of

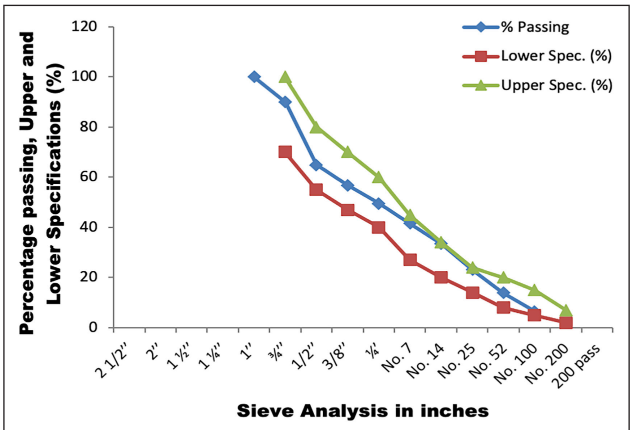

Figure 8. Chart showing the gradation result of asphalt concrete for road binder course laying from third mix design.

Table 16. Granisize analysis of asphalt concrete for road wearing course lying from the first mix design

Sieve size (inch)	Sieve size (mm)	Weight retained (g)	% Retained (%)	% Passing (%)	Specification
2 1/2”	63.5				
2”	50.6				
1 ½”	38.1				
1 ¼”	31.8				
1”	25.4				
¾”	19.1	–	–	100	100
1/2”	12/7	83	7.3	92.7	85–100
3/8”	9.5	100	8.8	83.9	75–92
¼’	6.5	121	10.7	73.2	62–82
3/16”	4.76				
1/8”	3.45				
No. 7	2.36	200	17.6	55.6	50–65
No. 14	1.18	157	13.8	41.8	36–51
No. 25	0.600	99	8.7	33.1	26–40
No. 36	0.425				
No. 52	0.300	117	10.3	22.8	18–30
No. 72	0.212				
No. 100	0.150	54	4.8	18.0	13–24
No. 200	0.075	89	7.8	10.2	7–14
200 pass	0.075	115	10.2		

Contract: Ogbomoso–Osogbo–Oko Road Project; Sample Ref: Wearing Course; Location: Chainage 26+700 to chainage 26+925; Weight of total aggregate: 1135g

adjustment (reduction) for its suitability for concrete production. Its value should be within the 50–52% range for more accuracy and compatibility.

All the aggregates that passed through sieves No. 7, No. 14, No. 25, and No. 52 were classified as fine aggregates using the size limit of 2.4–0.5 mm according to [34]. The t passed through these sieves was 41.6%, 33.4%, 23.2%, and 13%, respectively. The quantity of aggregate through sieve No.7 (41.6%) shows that the aggregates used need adjustment since their values were too close to the specified limit (27–45%). There should be a reduction in the aggregates' volume for accurate compatibility during the compaction of aggregates. The suggested reduction should be within the range of 35–39%. Likewise, the percentages of aggregates passing sieves No. 14 (33.4%) and No. 25 (23.2%) obtained were too close to the upper limit of the specification (20–34% and 14–24%). These values should be within the range of 20% for accurate and efficient compatibility. The compatibility rate of aggregate passing sieve No. 52 (13.9%) was correct compared to the 8–20% specification recommended by FMWH. Also, the obtained aggregates value (13.9%) fell within the middle of the specified limit (envelope) of 8–20% according to FMWH standards. The value of aggregate passing sieve No. 100 needs adjustment. The adjustment should be within 8.5–10% instead of 6.5%. The percentage of bitumen extracted from asphalt concrete produced from the third mix design is 11.5%. This value (11.5%) is more than the percentage of bitumen specified for average asphalt production from the third mix design, which is 4.8% (Tables 4 and 14). The increment is about 6.5%, which shows that the percentage of bitumen in asphalt concrete produced from the third mix design was not adequately controlled. For effectiveness, its bitumen is constantly controlled. Figure 7 shows the laying of asphalt concrete at the binder course.

Considering the three results of asphalt concrete obtained from the first, second, and third mix designs, the first mix design output is the best. It consists of accurate analysis results. Their aggregates were compatible and consisted of durable qualities. Therefore, the first mix design is recommended for producing concrete for road binder course construction. This experimental output is accurate and adequate for constructing global roads' binder courses with high sustainability and durability properties. Having obtained the first mix design as the best design method for stable binder pavement, this result is compared with other previous research outputs. According to [35], investigations were conducted to correct the properties of asphalt mix aggregates against fracture toughness. The results proved that applying lower asphaltic binder aggregates into road pavement construction reduced the intensity of concrete's fracture toughness but affected the stability and sustainability of its aggregate during tension. However, the output of this research negates the defect of fracture toughness as observed by [35]. In this experiment, no rutting defects were observed beneath the road binder pavement constructed with the concrete made from binder aggregate mix design.

Meanwhile, in the results of [36], there was a formation of 4% air voids and deep rutting deformation beneath the roads' binder pavement. This was increased with an

Table 17. Extracted bitumen from asphalt concrete produced for road-wearing course pavement construction using the first-wearing course mix design

Reference	Description	Value	Unit
A	Weight of mixture+bowl	2070	g
B	Weight of bowl	870	g
C	Weight of mixture = A-B	1200	g
D	Weight of filter before testing	0.2	g
E	Weight of filter after testing	0.6	g
F	Weight of material retained by filter = E-D	0.4	g
G	Weight of aggregate in the bowl	1135	g
H	Weight of total aggregate = F+G	1135.4	g
I	Weight of bitumen = C-H	64.6	g
J	% of Bitumen on the total weight of mixture = I/C×100	5.4	%
K	% of Bitumen on dry aggregate = I/H×100	5.7	%

increase in the rate of binder aggregate in the mix. Therefore, the value obtained in this study (especially from the first mix design) will significantly improve road pavement quality produced in construction industries. It was also observed that the output of this study satisfied the stability conducted through the Marshall testing. This is in line with the results of [37], which show that the application of cement aggregates improved the performance of asphalt concrete when loading during tension.

3.1.4. Granisize Analysis and Bitumen Extraction Test Results of Asphalt Concrete for Wearing Course Lying using the wearing course first mix design

The grain size analysis results and bitumen extraction test obtained from the asphalt concrete produced from asphalt mix design for the wearing course were presented as shown in Tables 16, 17 and 8. As shown in Table 16, the percentage of aggregates passing sieves ½" (12.5 mm), 3/8" (9.5 mm), and ¼" (6.5 mm) were calculated to be 92.7%, 83.9%, and 73.2% respectively. These values accurately fit the specified limits of 85–100%, 75–92%, and 62–82%, respectively, as stated by FMWH (1994). Thus, the aggregate used for the wearing course asphalt production is stable, effective, and durable. Likewise, the aggregates passing sieves No. 7 (2.36 mm), No. 14 (1.18 mm), No. 25 (0.6 mm), and No. 52 (0.30 mm), are 55.6%, 41.8%, 33.1%, and 22.8% respectively in value. These values were obtained after the grain size analysis, and they are within the specified envelope (that is, 50–65%, 36–51%, 26–40%, and 18–30%, respectively) stated by FMWH [38] for perfect asphalt concrete production for the wearing pavement. Therefore, the aggregates used in this experiment were suitable for asphalt concrete production for road construction in the global construction industries.

The experiment's output shows that aggregate passing sieves No. 100 and No. 200 possessed an excellent property for quality production of asphalt concrete for the wearing pavement construction. Considering the results, the values of aggregate passing sieve No. 100 and No. 200 (18.0% and 10.2%) were in line with the suggested specification according to FMWH (1994) standard, that is 13–24% and 7–14% respectively (Fig. 9). Also, as shown in Figure 9, it was observed that the aggregates used to produce asphalt concrete at the wearing zone of the road from the first mix design are of great potential for road construction. Therefore, it is recommended that the first mix designs used in this study be adopted to produce concrete for road-wearing pavement construction in the global construction industries. As shown in Table 17, the percentage of bitumen extracted recorded was 5.7%. This value is very close to the bitumen rate percentage or the production of asphalt concrete (5.8%). Therefore, the bitumen used to produce asphalt is excellent and efficient.

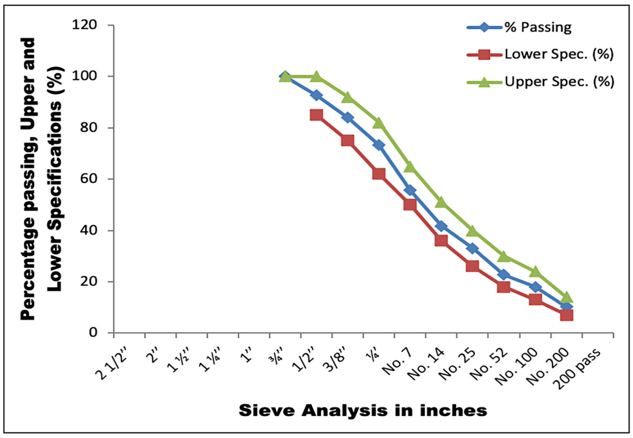

Figure 9. Chart showing the gradation result of asphalt concrete for road's road-wearing pavement construction using the wearing course mix design.

3.1.5. Grainsize Analysis and Bitumen Extraction Test Results of Asphalt Concrete for Wearing Course Lying Using the Wearing Course Second Mix Design

The results of the grain size analysis of asphalt concrete produced from the second mix design, as proportioned in Table 6, are presented in Tables 18, 19. According to Table 18, the percentage of aggregate passing sieve size 1.18 mm is more than that of the quantity specified in the 1994 asphalt production manual organized for the efficient production of quality asphalt concrete by the Federal Ministry of Works and Transportation Authority, Nigeria. This depreciation might have occurred due to the high proportions of quarry

Table 18. Granisize analysis of asphalt concrete for road-wearing pavement construction from the second mix design

Sieve Size (Inch)	Sieve Size (mm)	Weight Retained (g)	% Retained (%)	% Passing (%)	Specification
2 1/2"	63.5				
2"	50.6				
1 ½"	38.1				
1 ¼"	31.8				
1"	25.4				
¾"	19.1	–	–	100	100
1/2"	12/7	112.00	10.00	90.00	85–100
3/8"	9.5	98.56	08.80	81.20	75–92
¼'	6.5	176.96	15.80	65.40	62–82
3/16"	4.76				
1/8"	3.45				
No. 7	2.36	144.48	12.90	52.50	50–65
No. 14	1.18	4.59	0.41	52.09	36–51
No. 25	0.600	124.21	11.09	41.00	26–40
No. 36	0.425				
No. 52	0.300	256.59	22.91	18.09	18–30
No. 72	0.212				
No. 100	0.150	12.21	1.09	17.00	13–24
No. 200	0.075	42.56	3.80	13.20	7–14
200 pass	0.075	147.84	13.20		

Contract: Ogbomoso–Osogbo–Oko Road Project; Sample Ref: Wearing Course; Location: Chainage 26+700 to chainage 26+925; Weight of total aggregate: 1135g

Table 19. Extracted bitumen from asphalt concrete produced for road-wearing course pavement construction using the second-wearing course mix design

Reference	Description	Value	Unit
A	Weight of mixture+bowl	2080	g
B	Weight of bowl	880	g
C	Weight of mixture = A-B	1200	g
D	Weight of filter before testing	0.3	g
E	Weight of filter after testing	0.6	g
F	Weight of material retained by filter = E-D	0.3	g
G	Weight of aggregate in the bowl	1120	g
H	Weight of total aggregate = F+G	1120.3	g
I	Weight of bitumen = C-H	79.7	g
J	% of Bitumen on the total weight of mixture = I/C×100	5.64	%
K	% of Bitumen on dry aggregate = I/H×100	7.1	%

dust and filler (soft sand) used to produce asphalt concrete. Therefore, the second mix design is unsuitable for producing concrete with durable and flexible wearing pavement. Using the first mix design to create asphalt concrete will help the government and communities construct a durable wearing pavement against deformation, which can lead to constant maintenance and cost a lot. Also, the percentage of the bitumen content extracted from the asphalt concrete produced from the second mix design for wearing pavement construction (Table 6) was 1.5% more than its initial designed proportion, which is 5.6% (Table 19). Excess bitumen in the concrete signified that the asphalt production plant's discharge unit was poorly controlled or monitored for accurate production. From another perspective, it could be that the aggregates used for the production are very dry, leading to excess bitumen absorption to attain their satisfaction. It can be deduced that only the first design is accurate, standard, and effective for constructing quality and durable asphaltic road-wearing pavement.

3.1.6. The Importance of These Mixed Design Methods Against the Frequent Road Pavement Maintenance

The application of best mix designs used in this study for the construction of road binder and wearing pavements will be a means of controlling premature pavement deterioration, such as cracks, potholes, and pavement shrinkage, which lead to its constant maintenance. This method is one of the best methods of controlling excessive spending on road pavement maintenance because it allows the right choice of valuable materials (crushed and uncrushed) to produce quality asphalt concrete for constructing durable road pavements. Also, the application of the best mix design discovered in this study for the production of asphalt concrete for the construction of asphalt pavements (binder and wearing) in highways construction industries is an excellent solution to the problem of premature pavement construction in the globe since the concrete produced using the best mix proportion of aggregates as shown in this study will produce concrete with high rigidity and durability properties which will prolong its lifespan and prevent the issue of constant road pavement maintenance. In addition to that, roads with poor-strength pavement will have a negative impact on the people of those communities. Its constant maintenance will affect the sales of some marketers, cause road trafficking, and increase the government expenditure. All these problems will be eradicated when the new method of asphalt concrete production is implemented in the global construction system.

Most of the materials used in this study are naturally endowed. They are so valuable, rigid, and of high standard. This shows its relevancy for the construction of a durable road pavement. Our natural resource, crushed and uncrushed aggregates, has contributed significantly to constructing rigid pavement. Using artificial or natural eco-friendly materials to produce asphalt concrete for road pavement construction, especially from green asphalt concrete production, will negatively affect the community's health and cause environmental pollution. Besides, the degradation of these materials, most significantly, the bitumen and asphalt made from recycled waste materials, will result in premature deterioration, leading to frequent maintenance of the road's pavement or its total rehabilitation, thus increasing the government's budget for road construction. The other limitation of using green asphalt concrete for the construction of road pavements is its high carbon emission rate from its carbonated recycled materials used to produce green emulsion bitumen for road pavement construction [39, 40]. This is unethical and unfriendly to humans and the environment. Since the materials used in this study to produce asphalt concrete are naturally endowed, they are not made from recycled waste materials. Therefore, asphalt concrete pavements are eco-friendly and not liable to carbon emissions. This makes it one of the best methods for producing durable, eco-friendly pavements.

3.1.7. Application of this Study's Findings to Global Road Pavements Construction Practice

Practicing road pavement construction with asphalt concrete produced from the best mix designs structured for the binder and wearing pavement construction according to the design findings of this study together with the use of asphalt concrete production manual organized by the Federal Ministry of Works and Transportation 1994 will help in producing the durable, sustainable, flexible, and mature road pavements without spending on its maintenance. Using this study method for road construction will also help control the high carbon emission rate in the environment, thus preventing global warming. In addition, most of the aggregates used to produce asphalt concrete in this study are naturally endowed, rigid, and have heavy weights to withstand stress generated during the roads' loading. From another perspective, most of the materials used to construct green asphalt–concrete pavements are made from recycled materials that are very fragile and prone to deterioration, decomposition, and carbon emission, which can increase the rate of global warming. To produce concrete for the construction of binder and wearing pavement, applying the first mix designs from each category is suitable for producing durable and sustainable pavements in temperate and cool environments, following the accurate procedures as explained in this study. It is advisable to carefully examine the climatic condition of the environment where pavement construction will occur before embarking on applying this method. It is essential to produce asphalt concrete that will be friendly to the climatic conditions of its construction environment. This will prevent constant maintenance of the road's pavements, encourage smooth vehicle movement, and extend the life span of the road's pavement.

3.1.8. Response of Asphalt Pavement to Climatic Conditions

Heating asphalt concrete to about 150^{0}C before laying for pavement construction is a means of increasing its rate of aggregates' compatibility after compaction. Using a standard compacting machine will play a vital role in increasing the strength of the pavement in construction against stress disturbances from heavy vehicles, which will prevent the formation of potholes and pavement cracking. This treatment will protect the asphalt pavement against hot and cold weather deformation. Any pavement constructed using the mix designs (first mix designs from both binder and wearing proportions) and materials from this study will develop high strength to withstand stress against deformation that usually occurs due to constant expansion and contraction of asphalt pavement during the hot and cold climatic conditions.

3.1.9 Results of road leveling at chainages 26 + 700 to 26 + 875 before and after the laying of asphalt concrete: For easy and accurate calculation of the thickness of asphalt concrete laid, two standard reduced internal levels (R.I.L) of 1013.506 and 1012.50 were introduced for efficient reduction of measured road levels before and after the laying of asphalt concrete at chainage 26 + 700 to chainage 26 + 875. The results of leveling measurements taken before and after laying asphalt concrete were presented as shown in Tables 20 and 21.

All the data presented in Tables 20 and 21 were used for accurate calculation of the volume of asphalt concrete laid and for their cost estimations

3.1.10. Calculating the Volume of Asphalt Concrete Laid at Chainages 26 + 700 to 26 + 875 Using Leveling Method

The volume of the road before laying asphalt concrete was determined using the leveling instrument for data measurement, as shown in Table 20. As presented in Table

Table 20. Measured Roads' Levels from chainage 26+700 to chainage 26+875 before the laying of asphalt concrete

Back sight B/S (mm)	Inter sight I/S (mm)	Fore sight F/S (mm)	High point of curvature (H.P.C.) (mm)	Reduced internal level (R.I.L.)	Road distance (m)	Remarks
2769			1016.275	1013.506		TBM on Top of a well at RHS
	1427			1014.848	26+700	Φ (Centre of the Road)
	1505			1014.770		Shoulder LHS
	0919			1015.356		Shoulder RHS
	1331			1014.944	26+725	Φ (Centre of the Road)
	1439			1014.836		Shoulder LHS
	1061			1015.214		Shoulder RHS
	1792			1014.483	26+750	Φ (Centre of the Road)
	1638			1014.637		Shoulder LHS
	1831			1014.444		Shoulder RHS
	2400			1013.875	26+775	Φ (Centre of the Road)
	2148			1014.127		Shoulder LHS
	2029			1014.246		Shoulder RHS
	2689			1013.586	26+800	Φ (Centre of the Road)
	2353			1013.922		Shoulder LHS
	2705			1013.570		Shoulder RHS
2277		2605	1015.947	1013.670		C. P (Change of Point)
	1671			1014.276	26+825	Φ (Centre of the Road)
	1541			1012.735		Shoulder LHS
	1357			1011.378		Shoulder RHS
	2140			1009.238	26+850	Φ (Centre of the Road)
	1965			1007.273		Shoulder LHS
	1927			1005.346		Shoulder RHS
	2431			1002.915	26+875	Φ (Centre of the Road)
	2169			1000.746		Shoulder LHS
	2429			998.317		Shoulder RHS
		2441		995.876		Total Bench Mark (TBM) on top of an iron line drain

20, the breadth of the road used was 12.8 m. The distance covered (D) from chainage 26 + 700 to chainage 26+875 was calculated to be 175 m. The volumes of the road surface were calculated for at the center (ϕ), left-hand side (LHS), and right-hand side (RHS) as shown in Table 22.

The volume at the center (Φ) of the road was calculated to be 175×12.8×1.77025=3965.36 m^3; That of the LHS of the road was calculated as 175×12.8×1.61800=3624.32 m^3. Also, the volume at the RHS of the road is estimated to be 175×12.8×1.7365=3889.76 m^3. The total volume of the road surface before laying asphalt was calculated to be 11,479.44 m^3. This value was obtained by adding the volume at the center of the road, its LHS and RHS equal to 3965.36 m^3+3624.32 m^3+3889.76 m^3=11,479.44 m^3. Likewise, the volume of the road surface after laying asphalt concrete was determined using the measured data from the leveling device in Table 21 as shown in Table 23. From the calculations made, the volume of asphalt concrete measured at the center (Φ) of the road which is 175×12.8 x 1.985125=4446.68 m^3; also, that of its LHS of the road was gotten from 175×12.8×1.84475=4132.240 m^3; and that of its RHS of the road was calculated as 175×12.8×1.7785=3983.84 m^3. The total volume of the road surface after the laying of asphalt concrete=4446.68 m^3+4132.240 m^3+3983.84 m^3=12 562.760 m^3. Therefore, the actual volume of asphalt concrete laid at chainage 26+700 to chainage 26+875=12, 562.760 m^3 -11,479.44 m^3=1083.320 m^3. The cost per 1 m^3 of asphalt concrete=$250.00. Therefore, the total cost of asphalt concrete laid on the road from chainage 26+700 to chainage 26+875=$250.00×1083.320 m^3=$ 270,830.00 which is 740×270,830=#200, 414, 200:00 (Table 23).

3.1.11. Limitations of this Study and Future Suggestions on Pavement Design

To ideally make use of this method for road pavement construction, the asphalt paving machine, which is commonly used for the construction of asphalt concrete on the road's surface, is required to retain high heat temperature to be able to lay the asphalt concrete on the road's surface perfectly. The high heat generation in this method contributes to the increase in high heat affecting the Island, thus exposing it to heat deficiency. Also, the application of mix design

Table 21. Measured Levels of the road from chainage 26+700 to chainage 26+875 after the laying of asphalt concrete

Back sight B/S (mm)	Inter sight I/S (mm)	Fore sight F/S (mm)	High point of Curvature (H.P.C.) (mm)	Reduced internal level (R.I.L.)	Road distance (m)	Remarks
2621			1815.121	1012.500		TBM on Top of a well at RHS
	1226			1813.895	26+700	Φ (Centre of the Road)
	1302			1813.819		Shoulder LHS
	0619			1814.502		Shoulder RHS
	1217			1813.904	26+725	Φ (Centre of the Road)
	1139			1813.982		Shoulder LHS
	1001			1814.120		Shoulder RHS
	1625			1813.496	26+750	Φ (Centre of the Road)
	1414			1813.707		Shoulder LHS
	2312			1812.809		Shoulder RHS
	1942			1813.179	26+775	Φ (Centre of the Road)
	2000			1813.121		Shoulder LHS
	2245			1812.876		Shoulder RHS
	2671			1812.450	26+800	Φ (Centre of the Road)
	2151			1812.970		Shoulder LHS
	1708			1813.413		Shoulder RHS
1272		1825		1813.296		C. P (Change of Point)
	1251			1813.317	26+825	Φ (Centre of the Road)
	1415			1813.153		Shoulder LHS
	1149			1813.419		Shoulder RHS
	2008			1812.560	26+850	Φ (Centre of the Road)
	1761			1812.807		Shoulder LHS
	1829			1812.739		Shoulder RHS
	2222			1802.933	26+875	Φ (Centre of the Road)
	1762			1812.806		Shoulder LHS
	2029			1812.536		Shoulder RHS
		1419		1813.149		Total Bench Mark (TBM) on top of an iron line drain

All the data presented in Tables 20 and 21 were used for accurate calculation of the volume of asphalt concrete laid and for their cost estimations.

in this study requires using a standard asphalt plant and a well-trained operation to proportion the aggregates and bitumen efficiently to produce quality asphalt concrete for the best pavement construction. Any deviation from this standard can produce low-quality asphalt concrete, which cannot be recycled or reused. In addition, the gravitational values of the aggregates used, as shown in this study, can differ from one location to another. This is because these aggregates are naturally endowed and have different gravitational values. These differences in values can negatively affect the products produced from the aggregates from one country to another, thus leading to the construction of less durable pavement and increasing the cost of pavement maintenance. Therefore, it is advisable to know the integrity value of an aggregate before its use in construction.

Furthermore, most of the materials used in this study are not renewable or recyclable, though they possess high resisting capacity against stress and deformation that can occur through loading. This value increases its durability properties. In case the initial pavement constructed is faulty, the asphalt concrete from the existing pavement cannot be recycled or renewed for the reconstruction of the new pavement—the building on of the payment required using new materials for the new construction.

Uture researchers should experiment with recycling and reusing old and weak pavement concrete made from natural materials to produce new durable asphalt concrete for road pavement construction. This will reduce the cost of road rehabilitation in construction industries.

4. CONCLUSION AND RECOMMENDATIONS

This study proved that the road pavement mix design used by the American Highway Design Association (AASHTO) from 1950 to 1993 is not complex enough for rugged pavement design and construction. A new standard design method is needed. Despite the mix design used for asphalt concrete production, the efficiency of aggregates and models used to neutralize the effects of creeping, cracks, and deflection of road pavement was not met. A better aggregate

Table 22. Calculating the volumes of the road's surface at the center, LHS, and RHS before the laying of asphalt concrete

Chainages (m)	Width of the road (m)	Height of the Road Φ (center) (m)	LHS (m)	RHS (m)	Volume at Φ (m³)	Volume at LHS (m³)	Volume at RHS (m³)
26+700	12.8	1.226	1.302	0.619	3965.36	3624.32	3889.76
26+725	12.8	1.217	1.139	1.001			
26+750	12.8	1.625	1.414	2.312			
26+775	12.8	1.942	2.000	2.245			
26+800	12.8	2.671	2.151	1.708			
26+825	12.8	1.251	1.415	1.149			
26+850	12.8	2.008	1.761	1.829			
26+875	12.8	2.222	1.762	2.029			
Total	102.4	14.162	12.944	13.892			
Average	12.8	1.77025	1.61800	1.7365			

LHS: Left-hand side; RHS: Right-hand side.

Table 23. Calculating the volumes of road surface after the laying of asphalt concrete at the center, LHS, and RHS of the road; the volume of asphalt concrete laid on the road

Chainages (m)	Width of the road (m)	Height of the Road Φ (center) (m)	LHS (m)	RHS (m)	Volume before the laying of asphalt (m³)	Volume after the laying of asphalt (m³)	Volume of Asphalt concrete laid (m³)
26+700	12.8	1.427	1.505	0.919	11,479.44	12,562.76	1083.320
26+725	12.8	1.331	1.439	1.061			
26+750	12.8	1.792	1.638	1.831			
26+775	12.8	2.400	2.148	2.029			
26+800	12.8	2.689	2.353	2.705			
26+825	12.8	1.671	1.541	1.357			
26+850	12.8	2.140	1.965	1.927			
26+875	12.8	2.431	2.169	2.429			
Total	102.4	15.881	14.758	14.228			
Average	12.8	1.985125	1.84475	1.7785			

mix design for road pavement's sustainability, durability, and stability is needed, and this was evaluated for the construction of a rigid pavement system in this study.

In the construction industries globally, most of the crushed aggregates (granites) used to produce asphalt concrete were not that rich in quality minerals such as amphibole, mica, quartz, and field spar, which boost the interlocking properties for compatibility in crush aggregates (granites). The crushed aggregates used in this study are rich in quality minerals, which makes them suitable for the best production of quality asphalt for rigid pavement formation. Other aggregates (uncrushed edged), such as sharp sand, quarry dust, and soft sand, possess the same qualities for better asphalt production.

As well know, the method of carrying out a product's design and production depends on the product's quality level. As used in this experiment, the percentage of crushed aggregates used ranged from 11–27% for 3/8", 1/2", and ¾" grades, contributing majorly to their efficiency in making the rigid and flexible asphaltic pavement. As used in this study, the application of many quarry dust (31.1%) for the production of asphalt concrete highly contributed to the compatibility of the aggregates used. Likewise, applying a small percentage of sand and bitumen in the mix gives room for an increase in the quality of asphalt concrete produced compared to concrete with second and third-mix designs. Leveling is one of the best methods of determining the accurate cost of asphalt concrete laid on road pavement.

As observed from the investigation results, all the Marshall Test results agreed with the standard of quality of products obtained as specified by the Federal Ministry of Works and Housing. This proves that the values of passed aggregates obtained using the first mix design, that is, 35.6%, 26.2%, 18.2%, and 13%, are so satisfactory with the value of mineral properties (amphibole, mica, quartz, and field spar) possessed together with well proportioning of the aggregates for better asphalt production. Other aggregates from the second and third mix designs were not appropriately proportioned. Applying the first asphalt mix designs for binder and wearing pavements has dramatically influenced the quality of pavement rigidity in the global road construction industries.

Having predicted the amount of well-compacted asphalt concrete on road pavement at the initial project evaluation stage, the actual volume of asphalt laid was determined using the standard leveling method. The cost of materials and asphalt produced were evaluated with accurate calculations.

As observed from the findings of this study, the rigidity of road pavement depends solely on the sustainability capacity of its sub-base, base, sub-grade, binder, and wearing courses. The accurate and standard mix designs of the aggregate use for these layers were based on the basic principle of road pavement sustainability and durability. To conclude, the results of this study proved that a standard aggregate mix design of asphalt concrete is a crucial determinant of its durability, sustainability, rigidity, and stability. Therefore, it was suggested that the first asphalt concrete mix design used in this study with standard formulation, gradation, and proportion, which certified the specified boundary, is the best to be adopted to produce asphalt concrete for road binder course laying globally. Also, the formulation used in this study for the wearing course asphalt concrete production is recommended for asphalt concrete mixing for durable road pavement at the first wearing course. This will prevent frequent spending on road pavement maintenance.

The survey leveling method used in this experiment is one of the best methods for calculating the volume of asphalt concrete produced or laid without error. The outcome of this study proved that its application in construction industries would prevent unnecessary spending on road pavement resulting from poor cost estimation and inaccurate aggregate proportioning during asphaltic concrete production and laying. Therefore, it is recommended that the leveling method be adopted to estimate accurately the volume and thickness of asphalt concrete produced and laid in the global construction industries.

ETHICS

There are no ethical issues with the publication of this manuscript.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

FINANCIAL DISCLOSURE

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