STRENGTH CHARACTERISTICS OF RECLAIMED ASPHALT PAVEMENT-STONE DUST COMPOSITE BLENDED WITH FRESH BITUMEN

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MEng/SIPET/2018/8191

DEPARTMENT OF CIVIL ENGINEERING
FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

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THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA
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ABSTRACT

The recycling of asphalt has become a common practice in the transportation industry. Motivation for recycling typically includes the environmental, economic and social benefits. The use of RAP in the roadway construction fits with the global objectives of sustainable development by the prudent use of natural resources. This and other factor has attracted the attention of this research. Sieve analysis, specific gravity, bulk density were determined on both RAP and stone dust. The strength characteristics such as compaction and CBR were also carried out on the five different mixes A to E at varying percentage of bitumen content. The result shows that RAP has a uniform gradation while stone dust is medium coarse sand, the specific gravity of RAP and stone dust were found to 2.2 and 2.67 and their corresponding bulk densities were 1.19 and 1.78g/cm^3.The highest MDD for 0% bitumen was 2.56g/cm^3 with OMC of 8.2% and the least was 1.874g/cm3 MDD with 10.4% OMC. The highest MDD after the control was 2.53g/cm^3 at 2% bitumen with 9% OMC. The minimum MDD recorded after apart from that of control was 1.876g/cm^3 at 10.8% OMC also at 2% bitumen content. The maximum CBR value apart from that of control (0%) was at 1% bitumen for all different types of mixes.

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ABBREVIATIONS, GLOSSARIES AND SYMBOLS

FDR	Full Depth Reclamation
HMA	Hot Mix Asphalt
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
NCAT	National Center for Asphalt Technology
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
CBR	California Bearing Ratio
LBR	Lime Rock Bearing Ratio

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Road networks worldwide cost billions of dollars. Structural design of roads consists of asphalt layer, base layer; sub base layer on top of the sub grade layer. The constructions of roads have been increasing recently (Abdelzaher *et al.* 2022). A pavement is said to be relatively stable layer or crust constructed over a natural soil. It can also be defined as layers of process and unprocessed materials placed on the natural soil, configured to carry traffic of any kind. The main function of pavement is to support and distribute the heavy wheel loads of vehicles over a wide area of the underlying natural soil called sub grade and permitting the deformation within elastic or allowable range and to provide adequate surface (Ahmed *et al*, 2011).

Depending on the types of pavement, some materials differ. Virgin aggregate which can be substituted with Recycle asphalt pavement (RAP), stone dust and fresh bitumen make up a part of flexible pavement compositions. Reclaimed Asphalt Pavement is the most widely used recycle material. It is produced by removing and reprocessing existing asphalt pavement. Reclaimed Asphalt Pavement (RAP) is defined as pavement materials containing asphalt and aggregates which have been removed and reprocessed. These materials are generated when asphalt pavements are removed for reconstruction, resurfacing, or to obtain access to buried utilities. When properly crushed and screened, RAP consists of high-quality, well-graded aggregates coated by asphalt cement (Jirayut and Suksan, 2014).

Asphalt pavement is generally removed either by milling or full-depth removal; Milling entails removal of the pavement surface using a milling machine, which can remove up to 50mm (2) thickness in a single pass. Full-depth removal involves ripping and breaking the pavement using a Rhino horn on a bulldozer and/or pneumatic pavement breakers. In most cases, the broken material is picked up and loaded into haul trucks by a front-end loader and transported to a central facility for processing. At this facility, the RAP is processed using a series of operations, including crushing, screening, conveying, and stacking (Jirayut and Suksan, 2014).

Rehabilitation of asphalt pavement includes the milling of asphalt pavement layer, which produces a great amount of Reclaimed asphalt pavement. RAP from the rehabilitation of asphalt road are a major problem for many countries. Reclaimed asphalt pavement can be recycled by the following applications:

1. Cold in-place recycling
2. Cold planning
3. 3: Hot recycling
4. Hot in-place recycling
5. Full depth reclamation

Although RAP can be recycle directly as a recycled proportion of new hot mix asphalt concrete. This is generally limited to 25% (or less) of the new material according to the standard. An alternative method for disposal of RAP would need to be developed. When used as a total substitute for natural aggregates, most RAP materials do not often meet the minimum base material requirements set forth by the standard or local state guidelines (Jirayut and Suksan, 2014). The use of RAP as a granular base is one solution available for the disposal of RAP as solid waste and provides good application where no suitable materials are available. RAP can be used as aggregate in pavement base or sub base if mixed with other natural aggregates However, the natural soils mixed with RAP exhibit low strength and collapse (Jirayut and Suksan, 2014).

Reclaimed Asphalt Pavement (RAP) is a latest technology in the field of construction of bituminous pavements. RAP is being widely adopted all over the world as it has several benefits. By using RAP the cost of project is marginally reduced and it also has a favorable effect on environmental impact. RAP also leads to optimization of resources. Over a period of time the technological improvements have resulted in reclaiming the bituminous pavement in usable condition. Earlier the old pavements were excavated using excavators which resulted in availability of bituminous mix in form of chunks. In modern times, the scarifying process using diamond cutters result in removal of pavement in sizes nearly aggregate size. The results given by RAP mixes are either similar or better than virgin mixes. Hence the use of Reclaimed asphalt pavement is justified (Jashanjot and Duggal, 2015).

Bitumen can be defined as a mixture of organic liquid that are highly viscous, black, sticky, entirely soluble in carbon disulfide and composed primarily of highly condensed chemical compound or can be defined as an amorphous, black or dark color (solid, semi-solid, or viscous) cementations substance, composed principally of high molecular weight hydrocarbons, and soluble in carbon disulfide. Bitumen is the residual or by product obtained by fractional distillation of crude oil. It is the heaviest fraction and the one with highest boiling point (Herbert, 2007). Stone dust is another material to be used.

The performance of bituminous mix generally depends on the amount of filler in the mix. The workability of a mix depends, to some extent, on the amount and type of the filler present in the mix. The mixture performance also affected by the interactions between asphalt and filler because of the larger surface area, filler may absorb more asphalt and its interaction with asphalt may lead to different performance of asphalt-concrete mixture. The size distribution, particle shape, surface area, surface texture, voids content, mineral composition, and other physiochemical properties vary for several fillers.

Therefore, their effect on the properties of asphalt-concrete mixture also varies. Conventionally in Bangladesh, fine sand with stone dust is used as filler material in bituminous mix. In this study an attempt is made to find the effect of types of cheap & non-conventional filler on the behavior of bituminous mixes. For this purpose, stone dust fillers will be used Sutradhar, MintuMiah, *et al*. (2015). The use of RAP fully or partially, without and with the addition of industrial waste or fresh material as filler have been studied by researchers such as: NagaRajesh *et al*. (2018) and Jashanjot and Duggal (2015), but most of the studies were aimed at comparing the strength, marshall stability, flow value and density of the bituminous mixes against the conventional mixes.

1.2 Statement of the Research Problem

The recycling of asphalt has become a common practice in the transportation industry. Motivation for recycling typically includes the environmental, economic and social benefits. The use of RAP in the roadway construction fits with the global objectives of sustainable development by the prudent use of natural resources (Edward *et al.*, 2015).The current practice considers only one pavement property, which is the relative density, to accept or reject the as-built condition of the newly paved roads (MTO, 2004). The primary assumption of relaying on relative density as an indicator is that road sections with acceptable relative density are more durable and will have better long-term performance. In the as-built condition, acceptable levels of relative density may not be sufficient to represent other important physical properties related to moisture and water infiltration rates. In fact, various pavement failure modes including moisture-induced damage, thermal and fatigue cracking, and potholes were observed at road pavements that were considered accepted according to the current quality control specifications.

Consequently, it is not very rational to depend solely on one pavement property to evaluate the newly built HMA road pavements. Alternatively, considering other pavement characteristics could be beneficial in evaluating these new constructed roads and should provide Quality assurance/Quality control engineers with sound understanding of the expected pavement performance in short and long terms. There is a need to address the issue of using other pavement properties when assessing the as-built pavement condition in order to ensure and attain the highest possible quality especially when material like Reclaimed Asphalt Pavement (RAP) are considered.

1.3 Aim and Objectives of the Study

1.3.1 Aim

The aim of the study is to investigate the strength characteristics of reclaimed asphalt pavement stone dust composite blended with fresh bitumen.

1.3.2 Objectives of the study

To achieve this aim, the following objectives were set out:

i. Determine the physical properties of RAP, Stone dust and fresh Bitumen
ii. Determine the compaction characteristics of the mixes with varying percentage of fresh bitumen.
iii. Determine the CBR characteristics of the mixes with a varying percentage of fresh bitumen.

1.4 Justification for the Study

The use of Reclaimed Asphalt Pavement, stone dust mix will assist in the reduction of the cost of construction and protect the environment. Evaluating the strength characteristics of each component; RAP, stone dust and fresh bitumen will greatly assist in reducing the cost of construction. This will also reduce the waste from the RAP which causes environmental imbalances by modifying these RAP either increasing or decreasing the proportion of other components which make up a pavement. Knowing the Engineering properties of these materials, necessary recommendation can be made as whether to accept the materials for construction purposes or to recommend them for other engineering application.

1.4.1 Scope of the study

This study will be confined to the physical laboratory test such as particle size distribution, sieve analysis, specific gravity to determine the physical properties of the compositions; RAP, stone dust and bitumen. Strength characteristics such as compaction and CBR were conducted on the mixture for varying proportion and fresh bitumen content.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Bituminous Roads

Bituminous roads are defined as the roads in the construction of which bitumen is used as binder. It consists of an intimate mixture of aggregates, mineral filler and bitumen. The quality and durability of bituminous road is influenced by the type and amount of filler material is used. The filler tends to stiffen the asphaltic cement by getting finely dispersed in it. Various materials such as cement, lime, granite powder, stone dust and fine sand are normally used as filler in bituminous mixes. Cement, lime and granite powder are expensive and used for other purposes more effectively.

Fine sand, ash, waste concrete dust and brick dust finer than 0.075mm sieve size appear to be suitable as filler material. The use of waste powder as filler in asphalt mixture has been the focus of several research efforts over the past few years. Phosphate waste filler, Jordanian oil shale fly ash, bag house fines, recycled waste lime, municipal solid waste incineration ash and waste ceramic materials have been investigated as filler. It was proved that these types of recycled filler could be used in asphalt mixture and gave improved performance.

So the present study has been taken in order to investigate the behavior of bituminous mixes with different types of filler materials locally available. If filler is mixed with less bitumen than it is required to fill its voids, a stiff dry product is obtained which is practically not workable. Overfilling with bitumen, on the contrary, imparts a fluid character to the mixture. The filler has the ability to increase the resistance of particle to move within the mix matrix and/or works as an active material when it interacts with the asphalt cement to change the properties of the mastic.

Elastic modulus of asphalt concrete mixture can increase by the addition of mineral filler. But excessive amount of filler may weaken the mixture by increasing the amount of asphalt needed to cover the aggregates. The effects of these fillers are also dependent on gradations.

2.2 Reclaimed Asphalt Pavement

Reclaimed Asphalt Pavement (RAP) is defined as pavement materials Containing asphalt and aggregates which have been removed and reprocessed. These materials are generated when asphalt pavements are removed for Reconstruction, resurfacing, or to obtain access to buried utilities. When properly crushed and screened, RAP consists of high-quality, well-graded Aggregates coated by asphalt cement (Jirayut and suksan 2014).

RAP is gotten from Hot Mix Asphalt (HMA) layer of an existing road way; full Depth reclamation (FDR) refers to the removal and reuse of HMA and the entire Base course layer and part of the underlying sub grade implying a mixture of Pavement layer materials. Unless specified these three distinct recycled Asphalt materials will be collectively referred to as Reclaimed Asphalt Pavement. Reclaimed Asphalt Pavement is typically produced through milling operations which involves the grinding and collection of existing HMA, FDR and RPM are typically excavated using full-size Reclaimers or portable asphalt recycling machines. RAP can be stockpiled, but is most frequently reused immediately after processing at the site (Gregory and Tuncer, 2009).

RAP (waste asphalt removed from a failed pavement surface) is a mixture of Aggregate coated by bitumen and is collected from failed asphalt pavement surfaces. RAP has been in use in most developed countries for more than 30 years. It has been used as aggregate in the cold recycling of asphalt paving mixtures either by the method of cold mix plant recycling or cold in place recycling process. Some of the engineering properties of RAP that are of important when used in applications include its gradation, asphalt content, and the penetration and viscosity of the asphalt binder.

The aggregate gradation of RAP is somewhat finer than that of the virgin aggregate. This is due to mechanical degradation during asphalt pavement removal and processing. RAP aggregates usually can satisfy their requirements of ASTM D692 for coarse aggregate and ASTM D1073 for fine aggregates. According to Epps *et al*. (2014); the asphalt content of oldest pavements will comprise approximately 3 to 7% by weight of the pavement.

2.3 Stone Dust

Quarry dust as otherwise known is a byproduct of the crushing process which is a concentrated material to use as aggregates for construction purpose, especially as fine aggregates. In quarrying activities, the rock has been crushed into various sizes; during the process the dust generated is called quarry dust and it is formed as waste. Quarry dust has been used for different activities in the construction industry, such as building materials, road development materials, aggregates, bricks, and tiles.

A large amount of quarry dust waste is dispose into landfills every year. This waste is obtained as a byproduct during the production of aggregates through the crushing process of rocks in rubble crusher units. The increasing volume of waste will have significant impact towards health and environment. Recycling such wastes by incorporating them into construction materials is a practical solution for pollution problem. Kadir *et al*. (2017)

2.4 Bitumen

Bitumen is obtained by the partial distillation of crude petroleum. It is also called as mineral tar and is present in asphalt also. It contains 87% carbon, 11% hydrogen and 2% oxygen. Bitumen is defined by the U.S. Geological Survey as extra-heavy oil with API gravity less than 10° and a viscosity greater than 10,000 centipoises. At the temperatures normally encountered in natural deposits, bitumen will not flow; in order to be moved through a pipe, it must be heated and, in some cases, diluted with lighter oil. It owes its density and viscosity to its chemical composition mainly large hydrocarbon molecules known as asphaltenes and resins, which are present in lighter oils but are highly concentrated in bitumen. In addition, bitumen frequently has a high content of metals, such as nickel and vanadium, and nonmetallic inorganic elements, such as nitrogen, oxygen, and sulfur. Depending on the use to which bitumen is put, these elements may be contaminants that have to be removed from the finished product. By far most refined bitumen is used in paving asphalt and roofing tiles, as is a large amount of natural bitumen. However, most of the bitumen extracted from Canada's oil sands is upgraded into synthetic crude oil and sent to refineries for conversion into a full range of petroleum products, including gasoline.

2.4.1 Nominal maximum aggregate size and lift thickness

Several attempts were carried out to relate the permeability to both the nominal maximum aggregate size (NMAS) and the lift thickness. In a study conducted by Cooley *et al*. (2002) on two coarse-graded mixtures with different NMAS and possessing the same air void percentage had different permeability values. Similar conclusion was reported by the National Center for Asphalt Technology (NCAT), (Mallick *et al*., 2003). The ratio between the lift thickness and the NMAS influences particular mixes; however, this ratio does not correlate with permeability values (Vardanega, 2014).

Mohammad *et al.* (2003) observed a trend where permeability decreases with the increase of lift thickness for lifts greater than 60 mm concluded that low air voids content in the pavement structure can be achieved when the ratio between lift thickness to the NMAS (t/NMAS) is high (Brown *et al*., 2004).

2.4.2 Surface texture

Few researchers have studied the relationship between air voids, permeability and surface texture on Portland cement concrete pavement, however; there is lack of research concerning the relationship between the permeability and its surface texture in asphalt pavement area. The conclusions of previous studies suggest that low air voids content can be correlated to a smoother surface and thus less permeable pavement structure (Vardanega, 2014). However, due to the fact that the texture of different asphalt roads is currently achieved using the same compaction technology, a scientific assessment of this factor is not currently possible.

2.5 Field Compaction Methods

In the literature, compaction is defined as the process by which the volume of air in an HMA mixture is reduced by using external forces to reorient the constituent aggregate particles into a more closely spaced arrangement (Roberts *et al*., 1996). Reducing the air voids will in turn result in increasing the HMA density level. This dissertation studied two fields compaction equipment that are designed and operated based on different principles. In this research, the term “conventional” refers to the current compaction methods, while the term “advanced” refers to a recent developed compaction technology.

2.5.1 Conventional compaction methods

The currently common practice followed by HMA community to compact new roadways is carried out using three basic pieces of self-propelled equipment of different functions. This equipment is the steel static wheeled roller, pneumatic tire roller, and vibratory static wheeled roller. First, a paver screed places the HMA over the road base course. Then, the steel wheeled roller passes over the placed mix to apply the required compressive forces and achieve the desired relative density. In general, the steel roller (static or vibratory) has a roller diameter that ranges between 20 and 60 inches, while the roller width ranges from 35 to 85 inches (Pavement Interactive, 2009; Abd El Halim *et al.*, 2013). Therefore, the static, vibratory and pneumatic rollers in use are described in the following sub sections:

2.5.1.1 Static steel wheel roller

The static roller is either two or three-wheel of variety of shapes and weights. The three-wheel roller weighs 13600 kg and has two rear wheels of the same diameter and width, while the front wheels have different diameter and width compared to the two rear wheels (Geller, 1984). These types of rollers have the potential to apply high pressure because of the large rear wheels. Since there is a difference in both the diameter and width between the front and wheels, this will possibly cause inconsistency and variability in compaction progression (Huerne, 2004). On the other hand, the two-wheel roller has similar width and diameter in the front and rear wheels. It had been suggested that the actual compactive effort is dependent upon the contact pressure between the roller and the compacted asphalt layer (Roberts *et.al.*, 1996). Also, the contact pressure depends upon the penetration depth in a way that as the penetration depth increases, the contact area increases, and in turns the contact pressure decreases.

2.5.1.2 Vibratory steel wheel roller

Unlike the static rollers, the vibratory rollers are produced in two-wheel design and can be used in static or vibratory mode depending on the need. The roller vibrating frequency ranges between 15 and 20 Hz. Compared to the static rollers, the vibratory ones are much more effective since it requires less number of passes to achieve the desired relative density. It is believed that the relative density increases as the vibration reduces the internal and mechanical friction in the mineral mix (BOMAG Fayat Group, 2009). This reduction yields to an increase in the mechanical interlock later on (Roberts *et al*., 1996).

However, the vibratory rollers require high skilled operator to avoid poor compaction. In particular, improper selection of the dynamic force level (represented by the amplitude and frequency), compaction speed, number of passes, or combination of them can considerably affect the end-results of the paved section. This attributed to the fact that applying heavy and dynamic load on a soft material (asphalt mix) will likely cause shearing of the material if improper compaction efforts is achieved (Huerne, 2004).

2.5.1.3 Pneumatic-tired rollers

The pneumatic tires roller is used in the intermediate phase between the vibratory/static roller and the static finish roller. These rollers are designed in such a way that the steering/oscillating axle is located at the front and while a rigid drive axle is located at the rear (BOMAG Fayat Group, 2009). Typically, the roller can have 4, 5, 6, or 7 tires in front while having 3, 4, 5, or 6 at the rear. In general, pneumatic roller is intended to increase the relative density which cannot be achieved in many situations by the steel roller alone, remove the possible checking caused by the steel roller, and provide higher degree of uniformity in terms of compaction (Huerne, 2004).

2.5.2 Advanced compaction technology/asphalt multi-integrated roller II (AMIR-II):

The mismatching in rigidities between the compacted structural systems (soft asphalt mistrial) and the compacting equipment of high stiffness (steel roller) during field compaction were suggested by Abd El Halim *et al*., 2013 to be the main deficiency in the current compaction methods. This deficiency has contributed to produce what is known as the construction induced cracks or hairline cracks. These are surface cracks that are perpendicular to the rolling direction. In an attempt to minimize the mismatch in rigidities, the Asphalt Multi-Integrated Roller II (AMIR-II) prototype was introduced and designed by Carleton University and the National Research Council of Canada in 1989 (Abd El Halim *et al*., 2013). AMIR is a self-propelled roller that has two drums connected with a multilayered belt made of specialized rubber to create one flat surface of approximate.

This large contact area as well as the flexibility of the rubber belt minimizes the mismatch in rigidity to the asphalt surface. Although the large contact area yields less applied pressure at 41.6 KPa compared to the conventional compaction methods of 1.38 MPa, the load duration for AMIR roller is 30 longer than steel roller at the same rolling speed. The longer contact duration in addition to the larger contact area provides uniformity in terms of load distribution over the asphalt mat. This in turns minimize the horizontal forces while increasing the degree of confinement during field compaction.

In addition, the uniform load distribution allows visco-plastic flow of asphalt which ensures proper expulsion of the possible entrained air. These aforementioned mechanisms have eliminated the hairline cracks, achieved tighter asphalt surface of low permeability, and increases pavement strength and resistance to fatigue damage (Abd El

Halim, *et al*., 2013). Figure 2.2and Figure 2.3.illustrate the two compaction methods; the conventional and advanced respectively.

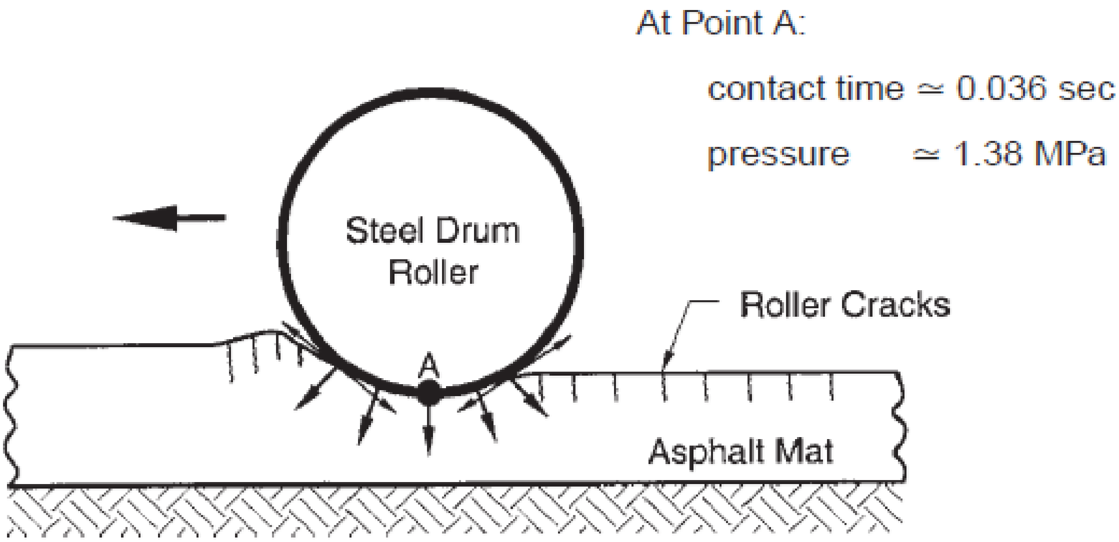

Figure 2.2: Schematic of the Conventional Steel Drum Rolling
Source: Abd El Halim and Mostafa, 2006

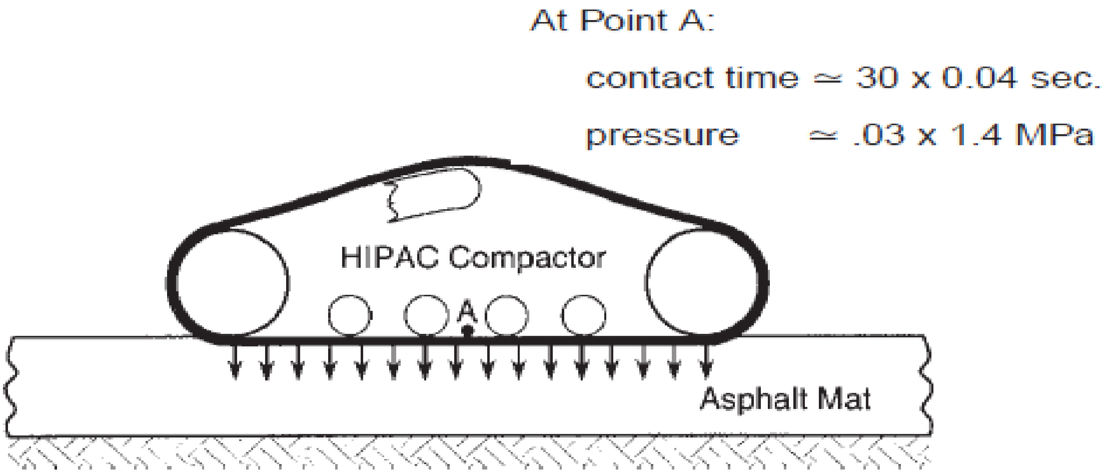

Figure 2.3: Schematic of the Advanced Rolling
Source: Abd El Halim and Mostafa, 2006

2.6 Use of Reclaimed Asphalt Pavement in Road Surface

In Nigeria and some other West African countries RAP usually constitute a waste due to limited technology of recycling asphalt. The use of RAP mixed with little amount of bitumen and other related admixtures to reconstitute fresh Asphalt for road surfacing were studied by some researchers: Al-Rousan *et al.* (2008); Al-Qadi *et al.* (2014); Pradyumna *et al.* (2013); Varamini *et al.* (2014); Akbulut and Gurer, (2007). Many studies have been published on laboratory performance, field performance, and pavement design with virgin asphalt mixes. Some research studies conducted in the past indicated that the structure performance of asphalt mixture containing RAP could perform equally as well or better than the virgin asphalt concrete with a proper recycled asphalt concrete design and suitable the percentage of RAP. There are some published studies on engineering characterization of asphalt surface course containing RAP. TxDOT had reported that 30% RAP of mixtures have an excellent performance on the SPS-5 overlay (50mm) sections studied under LTPP. Regis L. Carvalho *et al.* studied the short and long-term field performance of RAP mixes when compared to virgin HMA overlays used in flexible pavements. This research indicated that RAP overlays can provide structural improvement equivalent to virgin HMA overlays on low-volume roads. Some studies on the influence of reclaimed asphalt pavement on surface friction suggest that the threshold level of RAP that can be used in surface mixes without detrimental effect on their frictional properties was about 30%.

Several research projects evaluated the possibility of using RAP as a surface course in airport pavement and the results showed that recycled asphalt concrete can achieve the similar properties against long-term aging as virgin asphalt and recommended that high percentages of RAP should not be used. The bituminous pavement rehabilitation alternatives are mainly overlying, recycling and reconstruction. In recycling process, the material from deteriorated pavement (RAP), is partially or fully reused in fresh construction. In advanced countries bituminous material is the most recycled material in the construction industry.

RAP is a deteriorated bituminous mix that contains aged bitumen and aggregates. Hence its performance is poorer when compared to fresh mix. The purpose of bituminous recycling is to regain the property of the RAP, such that it tends to perform as good as the fresh mix. Thus, the process of bituminous recycling involves mixing of the RAP, fresh bitumen, rejuvenators and new aggregates in suitable proportions (Aravind and Animesh, 2007).

2.7 The Use of Stone Dust as Filler in Asphalt Pavement

The properties of fillers have noticeable effect on the durability of bituminous mix; it was also confirmed by the Craus *et al*. (1981), study on mixes consisting of one type of aggregate, one gradation and six types of filler. Among the fillers Lime and Stone dust/Quarry Dust are predominantly used in the mix. Their influence on fatigue performance was studied by Chari and Jacob (1984) and they found lime to have some effect on the fatigue properties, although static strength remained unaltered for the both. Many waste materials can be used in bituminous mix as filler material which would reduce the problem of disposal.

The lab and field evaluation of such materials was discussed by Kandhal (1995). Fwa and Aziz (1995) partial replaced aggregates used in bituminous mix with incinerator residue. Baig and Wahhab (1998) compared rock wool natural fibers – hematite, as filler material and compared with conventional crushed stone filler. Katamine (2000) studied the strength of bituminous mix with oil shale fillers. From the results of Marshal

Stability tests, it was found that Optimum Binder content was not altered, also stability was more. Taha *et al*. (2002) studied cement Bypass Dust (CBPD) and Karasahin and Terzi (2007) studied marble dust as filler. Both filler material gave required strength to bituminous mix. Sharma *et al*. (2010) showed that use of fly ash in bituminous mix would increase the strength of mix as it contains high calcium oxide which is important strength governing parameter.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Preamble

The undertaking of this project was to determine the strength characteristics of reclaimed asphalt pavement– stone dust composite blended with fresh bitumen.

3.2 Materials for the Investigation

The materials to be use for the study will include;

(i) Reclaimed Asphalt Pavement

The sample source for the RAP was obtained from the ongoing rehabilitation of Suleja-Minna road.

Plate I: Reclaimed Asphalt Pavement

(ii) Stone Dust

The stone dust from a quary along Abuja – Kaduna express way behind Zuma Rock Niger State, Nigeria.

Plate II: Stone dust

(iii) Fresh Bitumen

Bitumen was obtained from a market within Minna.

Plate III: Bitumen

All these materials were transported down to the Civil Engineering Laboratory, Federal University of Technology, Minna.

3.3 Methods

RAP was broken and passed through 5mm sieve while the stone dust was sieved through 2mm sieve aperture, laboratory tests were carried out on the physical properties of RAP, Stone dust and the fresh bitumen. Strength test were carried out on sample mix of RAP, stone dust at different proportion blended with varying percentage of fresh bitumen. The RAP and stone dust was blended in various proportions as seen in the Table 3.1 with bitumen 0 – 3%.

Table 3.1: Various Mix Proportion

Mix type	RAP%	Stone Dust%
A	10	90
B	25	75
C	50	50
D	75	25
E	90	10

3.3.1 Grain size analysis (sieve analysis) procedure

The procedure adopted was as outlined in BS 1377 (1990) which involved soaking 300g of RAP for 24hr and then washing, oven drying and making it ready for the grain size test. The retained samples during washing on sieve size 2.0mm and 0.075mm was carefully removed and placed in a pan, which was in turn placed in oven at 105^{o}C to 110^{o}C for 24 hours. Set of sieves were measured empty and arranged sequentially with the largest on top and the lowest size below as follows; 5.0, 3.35, 2.0, 1.18, 0.85, 0.60, 0.425, 0.300, 0.150, and 0.075mm, and base pan. The oven dried samples was poured into the uppermost sieve and the sieves were placed on mechanical sieve shaker and allowed to shake for 10 minutes. The weight of each sieves were taken and recorded. The weights of empty sieves were subtracted to give the weight of the retained RAP sample on each sieve. The percentage of total sample, passing each of the sieves was then calculated. The same procedure was repeated for stone dust with different sieve sizes. Plate IV shows the Set of Sieves.

Plate IV: Set of Sieves

3.3.2 Specific gravity test procedure

The procedure adopted was as outlined in BS 1377(1990). The density bottles with stoppers were washed dried and weighed empty with the stopper as M_1. About 50g of soil sample which passed through sieve size 5mm were poured into the density bottles. The density bottles and content together with the stoppers was weighed as M_2. Distilled water was added, covered and allowed to fully soak. After this, the stopper was inserted, the bottle together with the content was shaken, and the stoppers were then removed and water added to reach 250ml capacities. The bottles with the content and stoppers were weighed as M_3. The density bottle was emptied and thoroughly cleaned and oven dried at 105°C. The clean oven dried density bottles was filled with distilled water to 250ml capacities and stoppers were inserted and then weighed as M_4. The specific gravity of the sample was calculated in Equation (3.1):

$$G_{bcm} = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \tag{3.1}$$

Where;

$M1$ = Weight of bottle

$M2$ = Weight of bottle +dry RAP

$M3$ = Weight of bottle + RAP + water

$M4$ = Weight of bottle + water

3.3.3 Bulk density of the compacted specimen

The bulk density of the sample is usually determined by weighting the sample in air and in water. It may be necessary to coat samples with paraffin before determining density. The specific gravity $Gbcm$ of the specimen is given by Equation (3.2):

$$G_{bcm} = \frac{W_a}{W_a - W_w} \tag{3.2}$$

Where;

Wa = weight of sample in air (g)

Ww = weight of sample in water (g)

3.3.4 Bulk density of the compacted specimen

The sample divider was weighed and recorded. It was then filled up to one-quarter of its volume with RAP and tamped 25 times using a tamping rod in three layers. This procedure was repeated for another two layers with the third layer filled to the brim. The excess RAP was removed and the top was carefully trimmed. The weight of the divider with sample was weighed and the bulk density calculated in Equation 3.3. The same test was also carried out on Stone dust.

$$\text{Bulk density, } \rho = \frac{M}{V} \tag{3.3}$$

Where;

M = Mass

V = Volume

3.3.5 Compaction characteristics procedure

The procedure adopted was as outlined in BS1377 (1990). The mass of an empty mould was weighed, noted and recorded as M_1. Then, a 3kg of air dried mix sample was thoroughly mixed with small amount of water. The mixed samples (RAP-Stone dust-Bitumen) was compacted into a 940cm^3 cylindrical mould in three layers of approximately equal mass, with each layer receiving 25 blows of a 2.5kg rammer falling freely through a height of 300mm. After compacting the last (fifth layer), the collar was removed and the surface of the mix was trimmed to level with the mould and then weighed as M_2. Specimen from top and bottom of the mould were taken for moisture content determination. The mix were demolded and mixed together with the remaining sample on the tray. The above procedure was repeated at varying moisture content, until the mass decreased. The dry density, in each case was calculated and plotted against its corresponding moisture content. The bulk density and the dry density were calculated using Equation 3.4 and 3.5. The same procedure was repeated for all other mixes B, C, D and E with varying percentage of bitumen content.

$$\rho_b = \frac{M_2 - M_1}{V} \qquad (3.4)$$

$M1$ = mass of empty mould

$M2$ = mass of mould + soil

V = Volume of mould

Also, dry density,

$$\rho_d = \frac{\rho_b}{1+w} \qquad (3.5)$$

Where w = Moisture content of the soil

Plate V: Weighting the Compaction Mould

3.3.6 CBRcharacteristics procedure

An empty compaction mould with base plate, with extension collar removed was weighed. The soil sample was thoroughly mixed at OMC. A spacer disk was inserted over the base plate and a coarse filter paper was placed on top of the spacer disc. The mould was placed on a solid base (concrete floor) and the wet mixture with varying bitumen content of 0, 1, 2 and 3% into the mould was compacted in five layers of approximately equal mass, each layer was given 62 blows with 4.90kg hammer equally distributed and dropped from a height of 450mm above the soil. The extension was removed and carefully the compacted mixture was leveled.

CBR is computed from the relation the Equation (3.6):

$$\text{CBR in } \% = \frac{\text{Load at 2.5 or 5.0mm penetration}}{\text{Statndard Load factor}} \text{ x } 100\% \qquad 3.6$$

Plate VI: California Bearing Ratio Set - Up

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Result on Physical Characteristics of RAP and Stone dust

4.1.1 Sieve Analysis Results

The Sieve analysis carried out was on two materials; RAP and rock fill flour (Stone dust). RAP was broken and passed through 5mm sieve while the stone dust was sieve through 2mm sieve aperture. The results are presented in appendix A for Stone dust and RAP.

Figure 4.1 presents the result for the sieve analysis of stone dust. The result shows that a large portion of the sample was retained on sieve 3.35mm and almost all the sample passes 95.77% with 4.23% retained on 5mm. The result also shows a uniform graded curve ranging from fine to coarse sand.

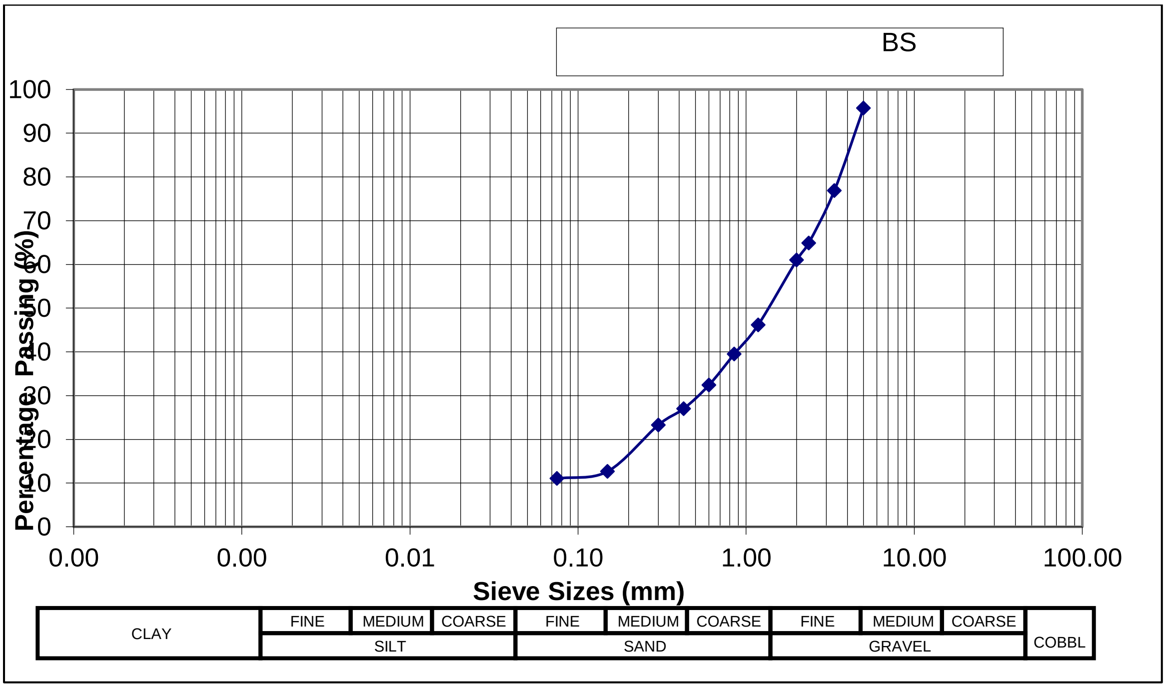

Figure 4.1: Stone dust Sieve Analysis Graph

Figure 4.2 presents the sieve analysis result for RAP; it was observed that 100% of the material passes through the maximum sieve aperture. The distribution was well graded ranging from fine to coarse sand material.

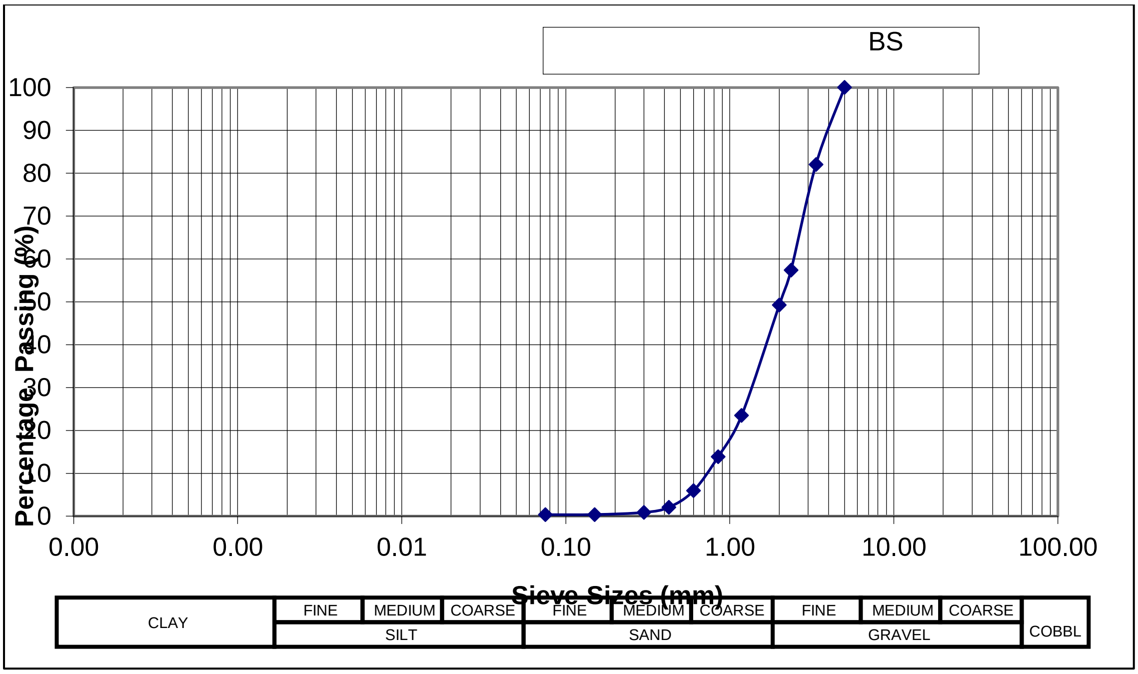

Figure 4.2: RAP Sieve Analysis Result

4.1.2 Specific Gravity Results

The average specific gravity of Stone dust was found to be 2.67 as presented in Table 4.1, this shows that the material is 2.67 times heavier than it equal volume of water. While Table 4.2 shows the average specific gravity of RAP with 2.20 less than that of the stone dust. The specific gravity for stone dust falls within the standard range of 2.6 to 2.7 for conventional aggregate. While, that of RAP fall outside and below the standard range. Hence it is not a conventional aggregate.

Table 4.1: Stone Dust Specific Gravity Result

Trial no.	1	2	3
Wt. of empty bottle (m_1)	46.1	43.6	69
Bottle Wt. + Sample (m_2)	86.4	83.7	104.9
Wt. of bottle + Sam + Water (m_3)	170.1	167.5	190.9
Wt. of Bottle + Water (m_4)	145	142.4	168.3
Specific gravity $S.G = \frac{m_2-m_1}{(m_4-m_1)-(m_3-m_2)}$	2.65	2.67	2.70
Average specific gravity, Gs		**2.67**	

Table 4.2: RAP Specific Gravity Result

Trial no.	1	2	3
Wt. of empty bottle (m_1)	69	43.6	46.1
Bottle Wt. + Sample (m_2)	111.2	76.2	87.9
Wt. of bottle + Sam + Water (m_3)	191.3	160.3	167.5
Wt. of Bottle + Water (m_4)	168.3	142.3	144.9
Specific gravity $S.G = \frac{m_2-m_1}{(m_4-m_1)-(m_3-m_2)}$	2.20	2.23	2.18
Average specific gravity, Gs		**2.20**	

4.1.3 Bulk Density Result

The bulk density of stone dust and RAP are presented in Table 4.3 and 4.4. The density depends on how densely the aggregate particles are parked and it is influenced by the nature of compaction. The density of stoned dust was 1.78g/cm^3 which is above the range of 1.52-1.68g/cm^3 for normal weight aggregate; hence it is not a normal weight aggregate but heavy weight. In the same vein, the bulk density for RAP was 1.15g/cm^3 which also fall out and below the range of standard normal weight. Hence it is a light weight aggregate and can only be used for light weight concrete production. However, it can be used for road construction material when modify and its other properties such aggregate impact value (AIV) and aggregate crushing values (ACV) were checked.

Table 4.3: Stone Dust Bulk Density Result

Trial no.	**1**	**2**	**3**
Wt. of mould (m_1)	268.8	268.7	270.9
Wt. of mould + Sample (m_2)	741.8	744.8	732.1
Weight of Sample (m_3) = (m_2 - m_1)	473	476.1	461.1
Vol. of Mould (cm^3)	264.96	264.96	264.96
Density $(\rho) = \frac{\text{mass(m3)}}{\text{volume}}$	1.79	1.80	1.74
Average Density (g/cm^3)		**1.78**	

Table 4.4: RAP Bulk Density Result

Trial no.	**1**	**2**	**3**
Wt. of mould (m_1)	268.7	270.9	268.8
Wt. of mould + Sample (m_2)	584.5	583.4	587.6
Weight of Sample (m_3) = (m_2 - m_1)	315.8	312.5	318.8
Vol. of Mould (cm^3)	264.96	264.96	264.96
Density $(\rho) = \frac{\text{mass(m3)}}{\text{volume}}$	1.19	1.18	1.20
Average Density (g/cm^3)		**1.19**	

4.2 Compaction Result

The compaction test was carried out on 5 different mixes (A to E) at varying bitumen content (percentage) (0, 1, 2 and 3%). The various tables for each of the mix at every bitumen contents were presented in appendices B. The graphs are shown in Figure 4.1 through 4.20.

4.2.1 Compaction at 0% Bitumen

At no bitumen content, Mix A has the maximum MDD value of 2.56g/cm^3 with a corresponding OMC of 8.2%, while mix C has the least MDD 1.872g/cm^3 and OMC of 10.4%. Hence a mixture of RAP/Stone dust with a proportion of 0%-90% gives the highest MDD.

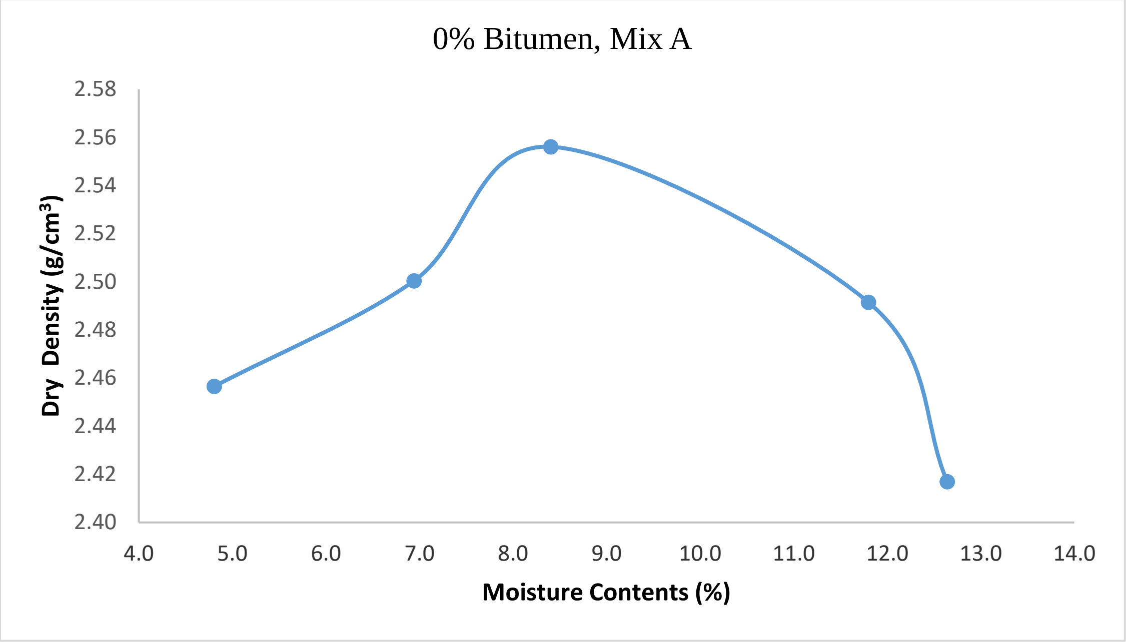

Figure 4.1: Compaction curve for Mix A at 0% Bitumen

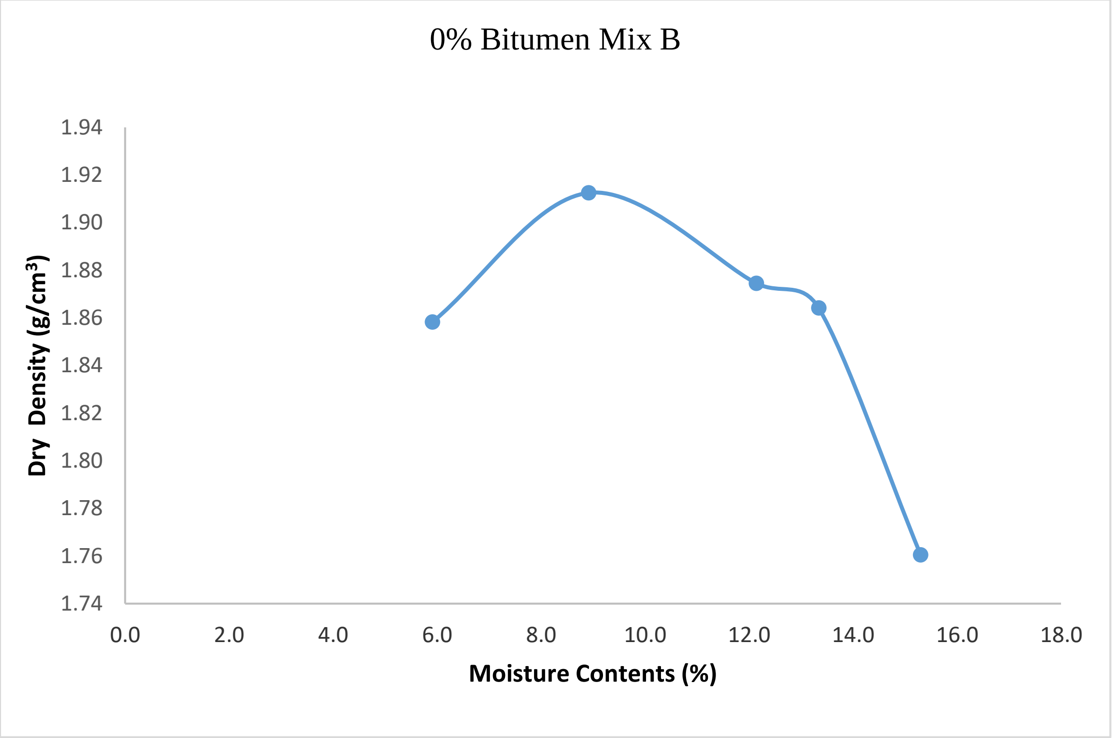

Figure 4.2: Compaction curve for Mix B at 0% Bitumen

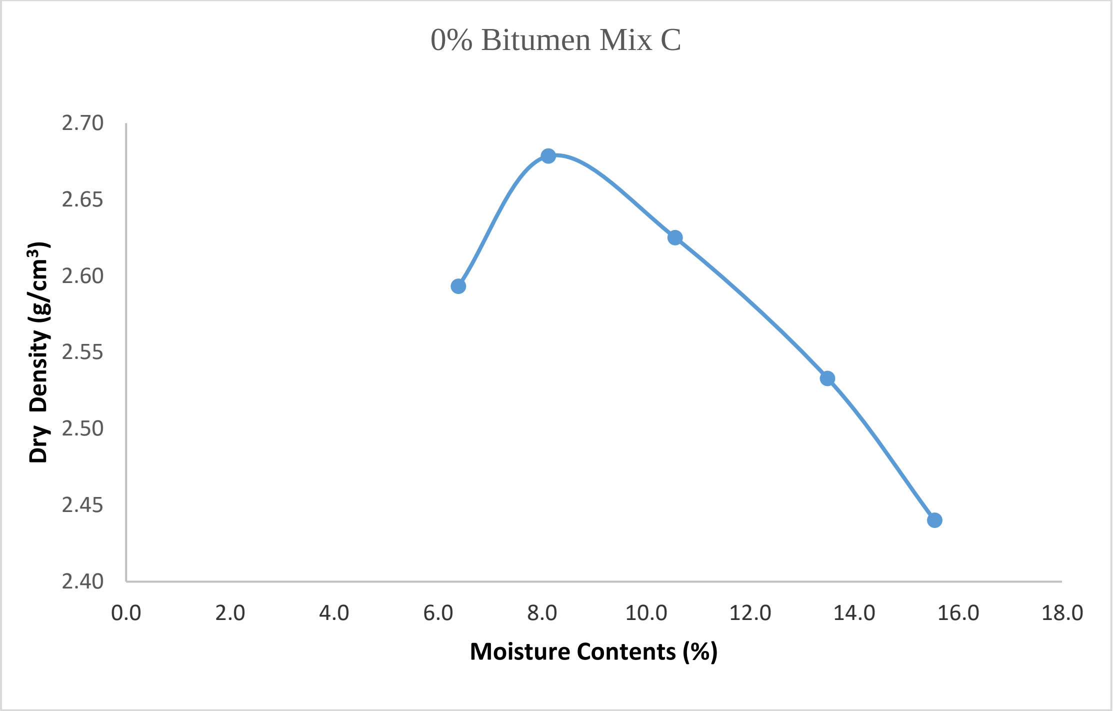

Figure 4.3: Compaction curve for Mix C at 0% Bitumen

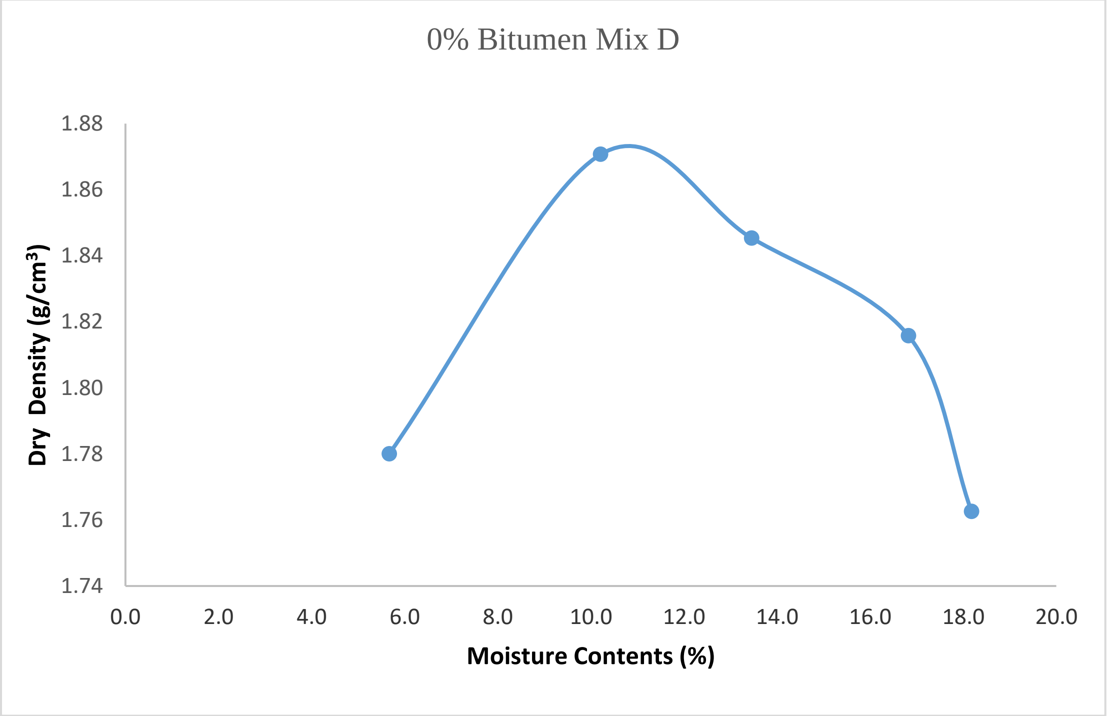

Figure 4.4: Compaction curve for Mix D at 0% Bitumen

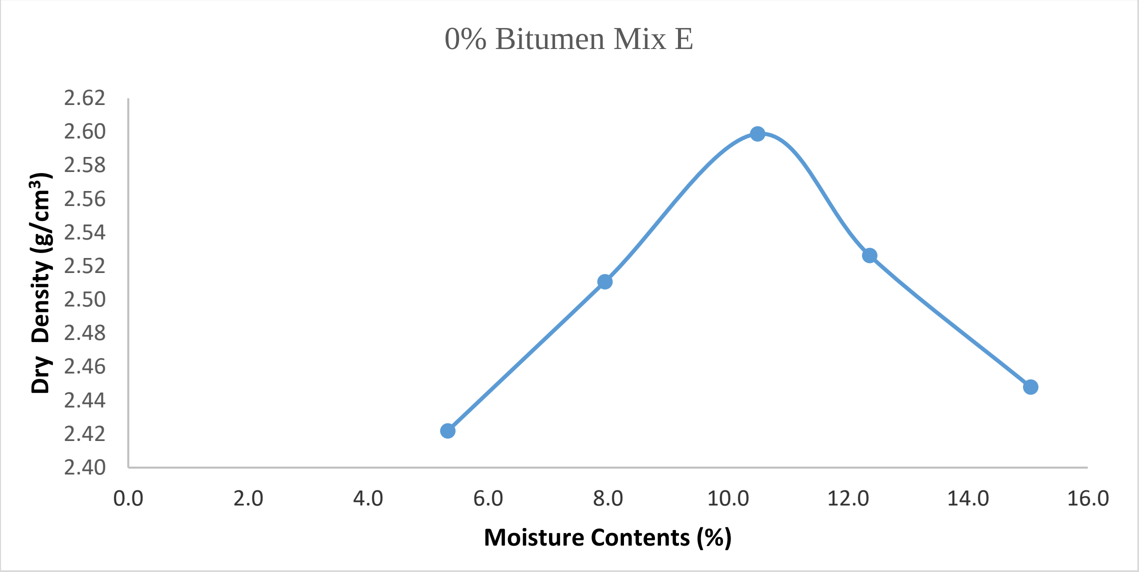

Figure 4.5: Compaction curve for Mix E at 0% Bitumen

4.4.2 Compaction at 1% Bitumen

When bitumen was added by 1%, Mix A was still found to have the maximum MDD of 2.19 less than the maximum value for no bitumen content (2.56) and corresponding OMC of 7.6%, while Mix D has the minimum MDD of 1.895 slightly greater that of case with 0% bitumen content and corresponding OMC of 10.4%

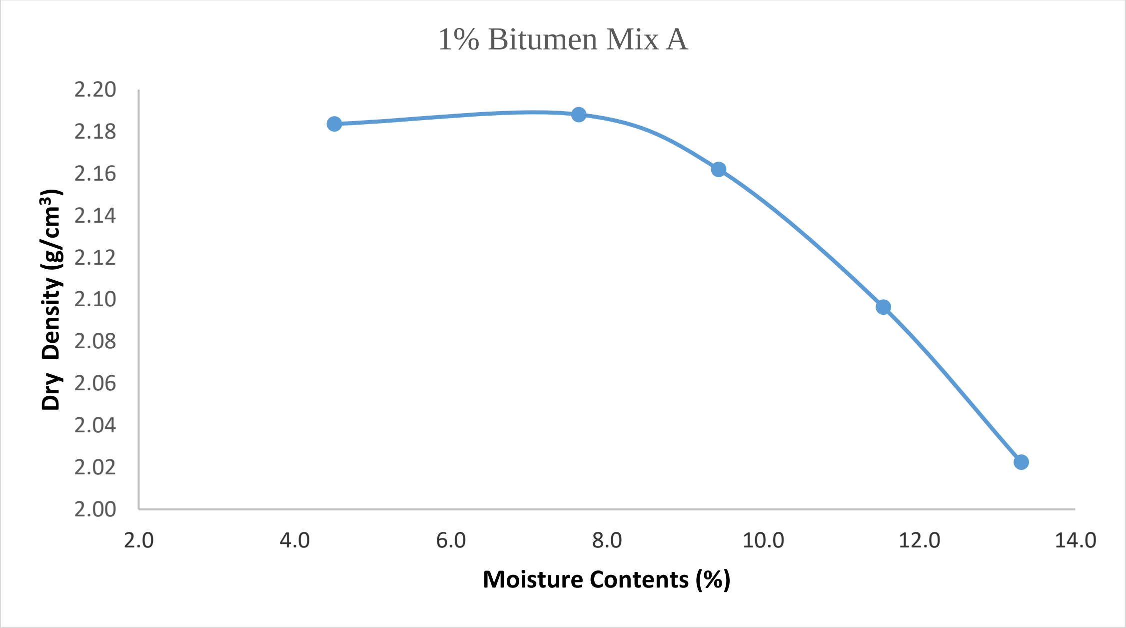

Figure 4.6: Compaction curve for Mix A at 1% Bitumen

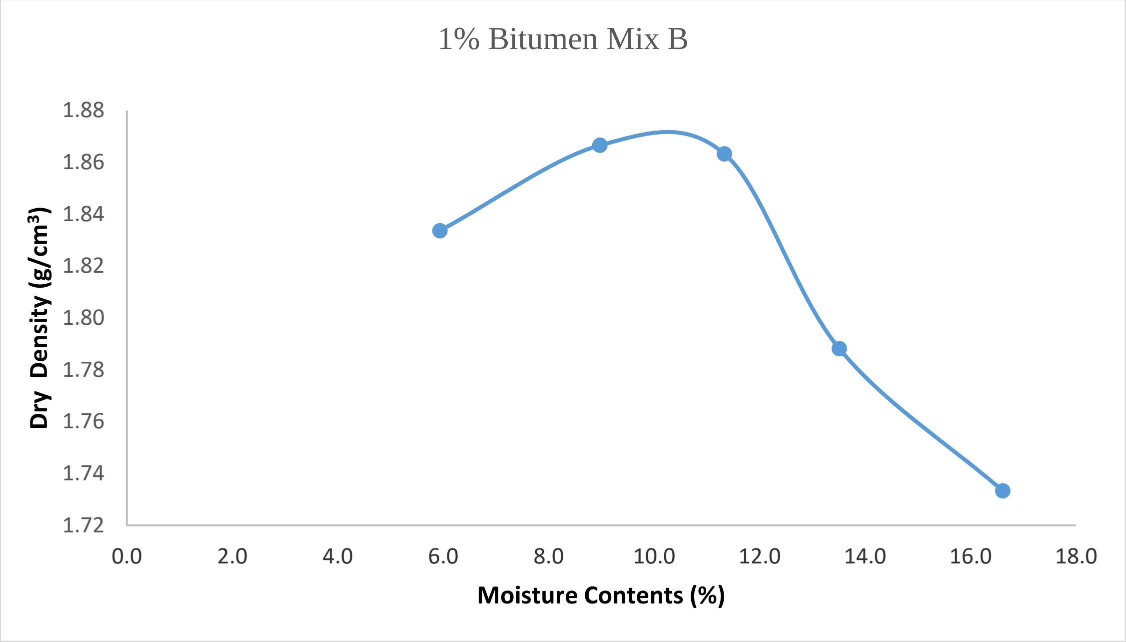

Figure 4.7: Compaction curve for Mix B at 1% Bitumen

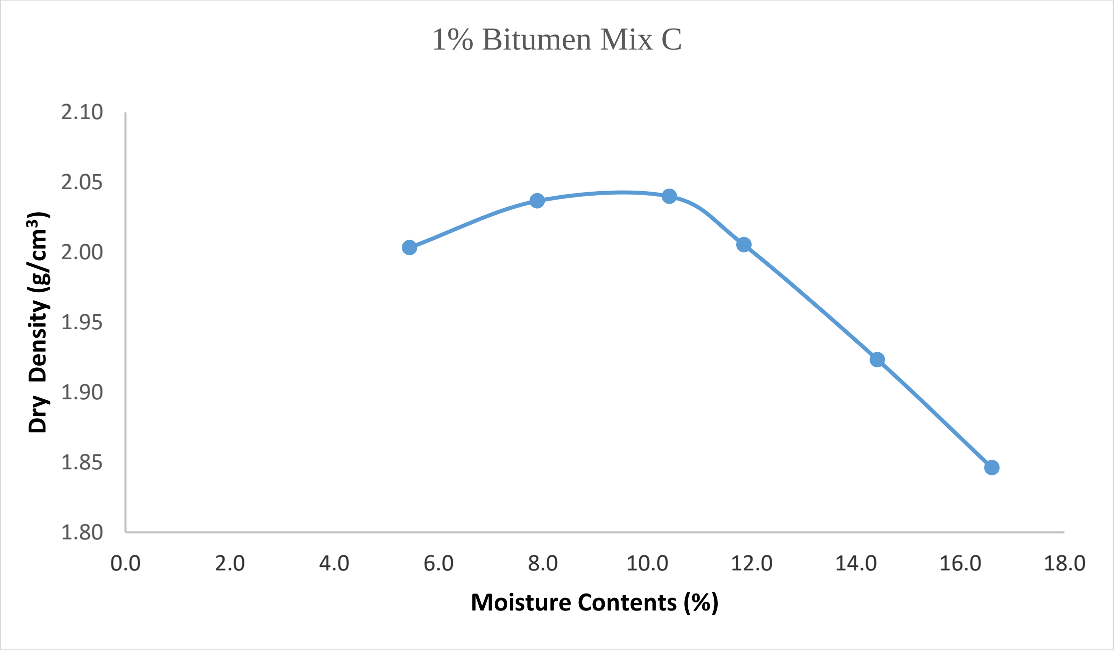

Figure 4.8: Compaction curve for Mix Cat 1% Bitumen

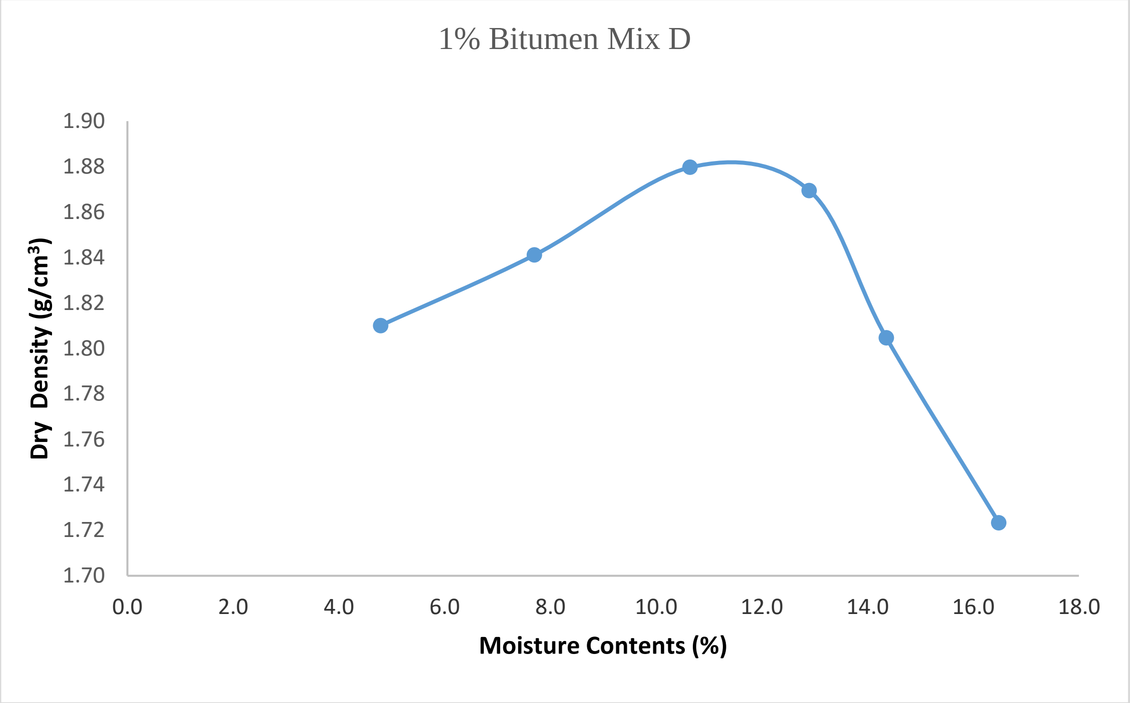

Figure 4.9: Compaction curve for Mix D at 1% Bitumen

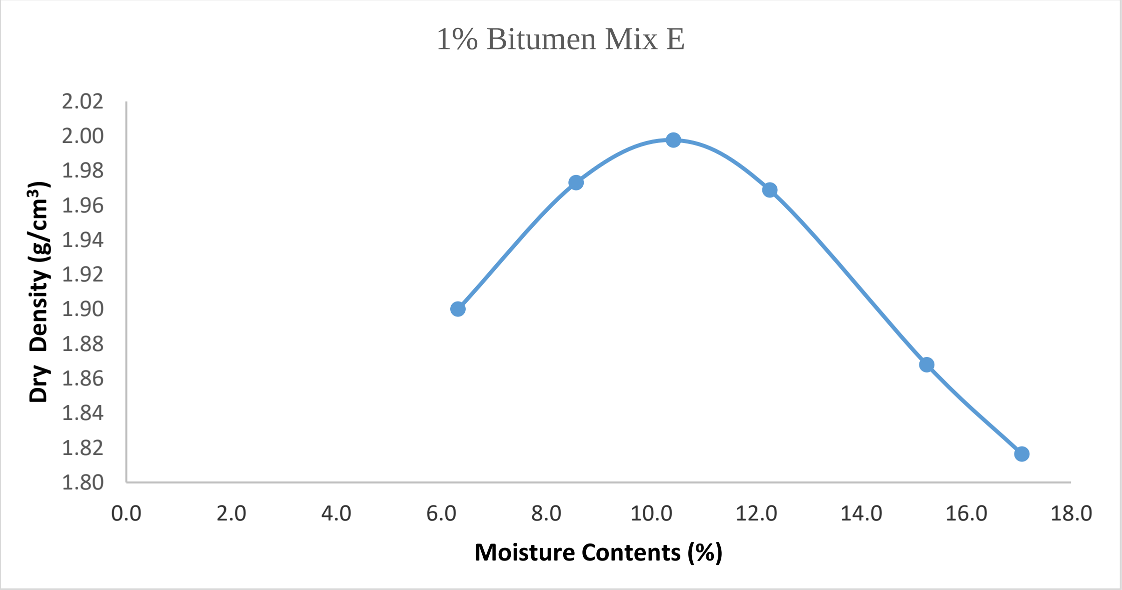

Figure 4.10: Compaction curve for Mix E at 1% Bitumen

4.4.3 Compaction at 2% Bitumen

As the bitumen content increases to 2%, Mix A still have the highest MDD value of 2.53g/cm^3 greater that of 2% and less than that of 0%, it has a corresponding OMC of 8.6%. While Mix B has the lowest MDD value of 1.876g/cm^3 slightly greater than that of 0% but less than that of 1%, it also has the corresponding OMC of 10.8%.

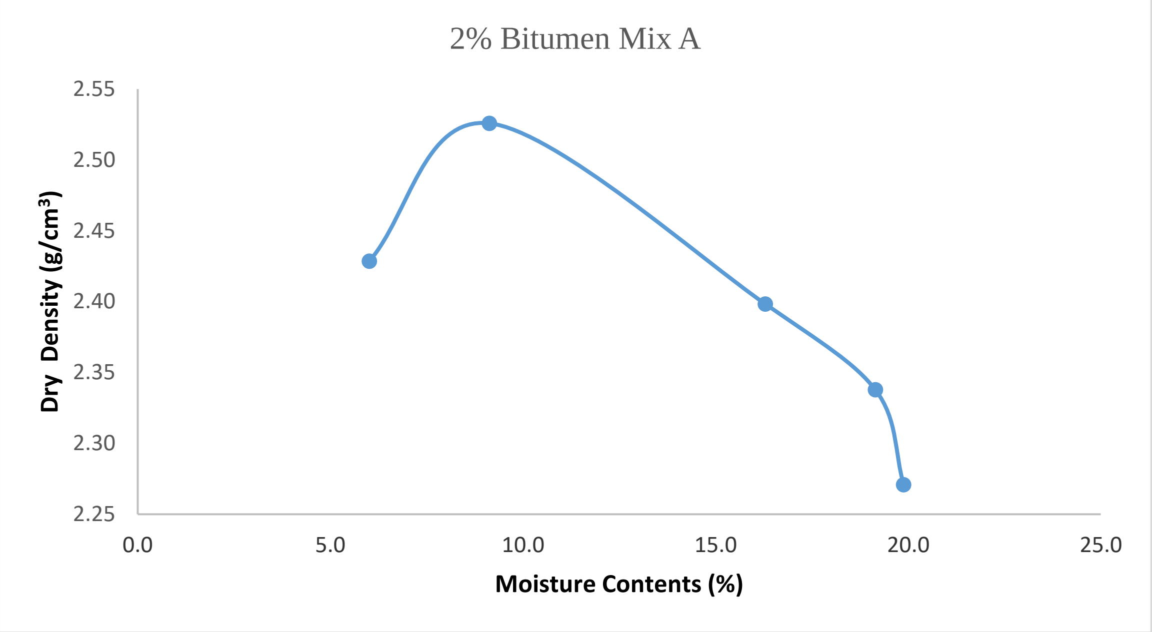

Figure 4.11: Compaction curve for Mix A at 2% Bitumen

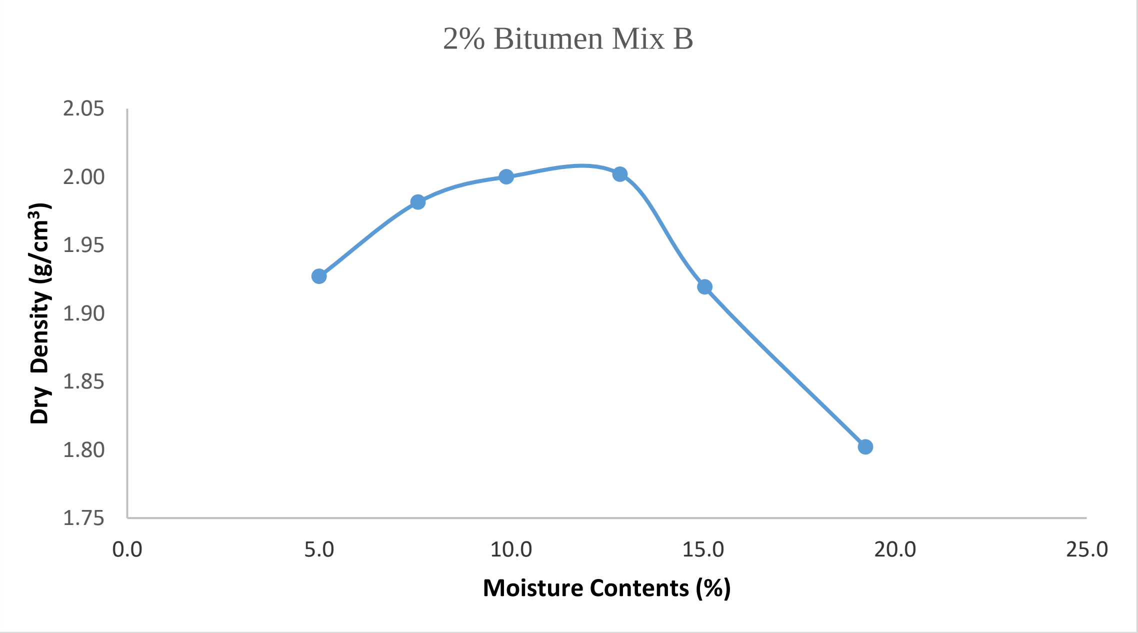

Figure 4.12: Compaction curve for Mix B at 2% Bitumen

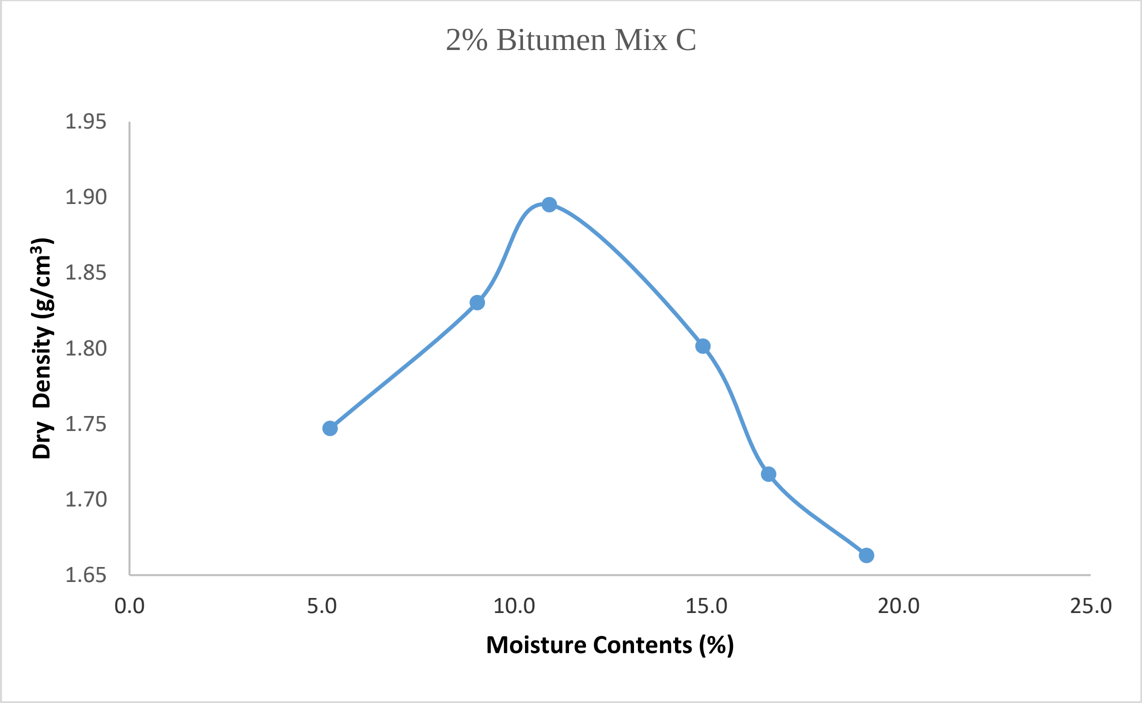

Figure 4.13: Compaction curve for Mix C at 2% Bitumen

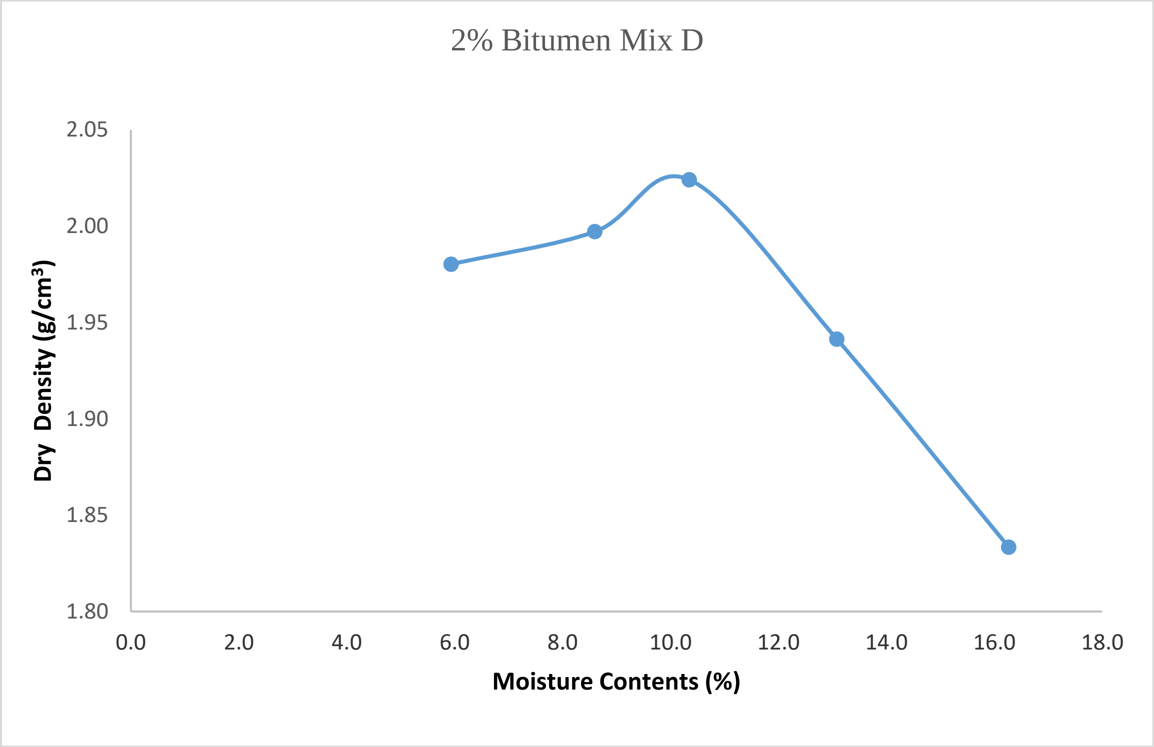

Figure 4.14: Compaction curve for Mix D at 2% Bitumen

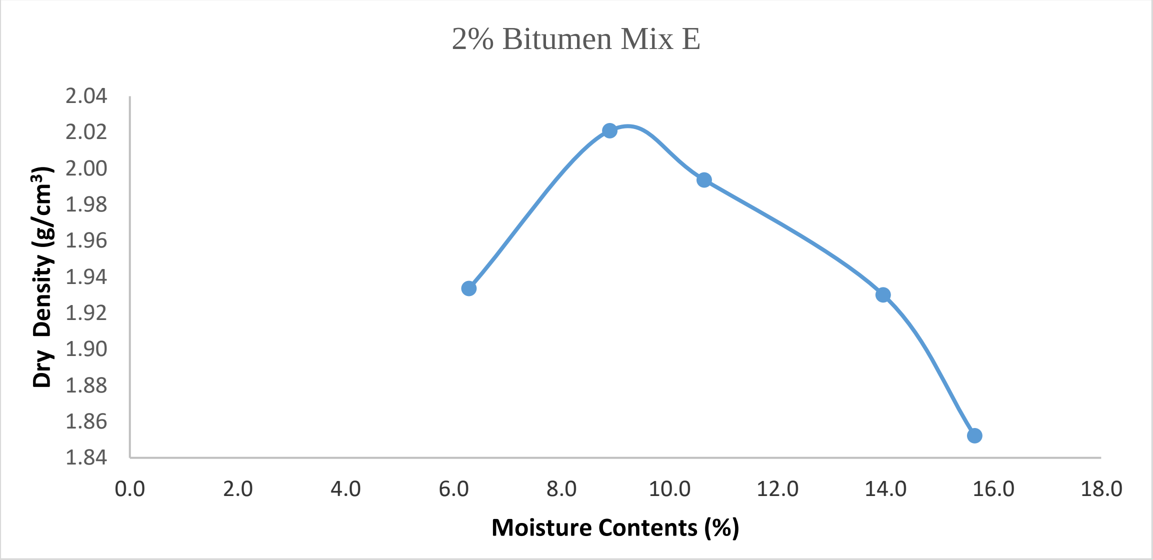

Figure 4.15: Compaction curve for Mix E at 2% Bitumen

4.4.4 Compaction at 3% Bitumen

At 3% bitumen content, Mix A still shows the highest MDD value of 2.21 which is greater than that of 1% but less than that of 0 and 2% bitumen, it has the corresponding OMC of 8.6%. While Mix E has the minimum MDD value of 1.985 which is greater than the minimum value for all other mixes.

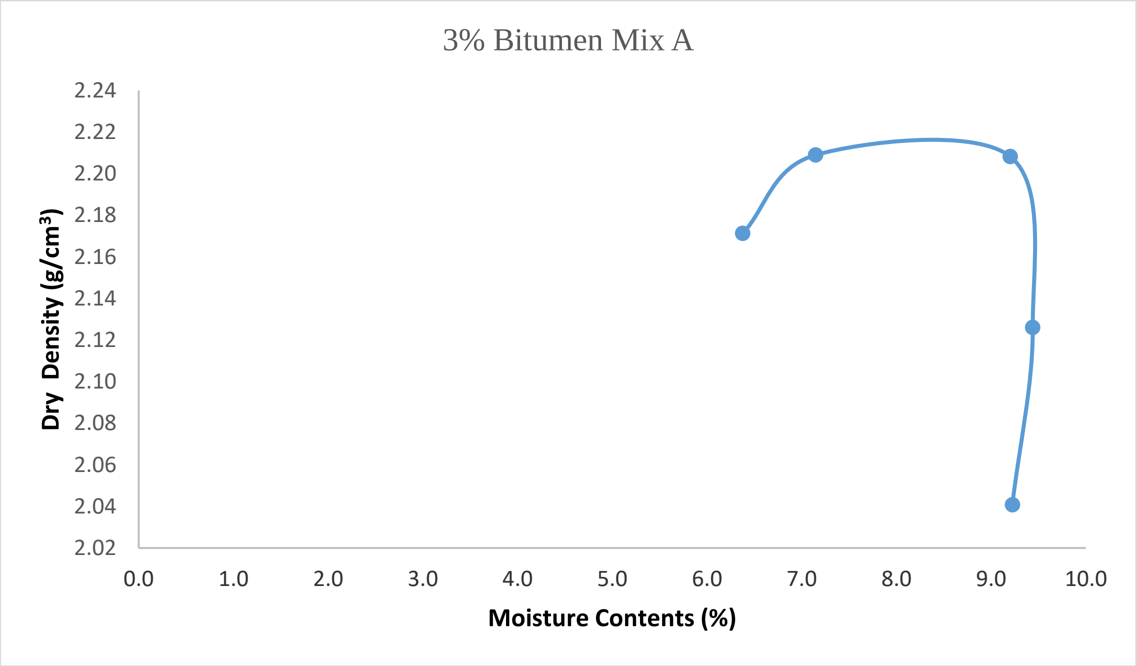

Figure 4.16: Compaction curve for Mix A at 3% Bitumen

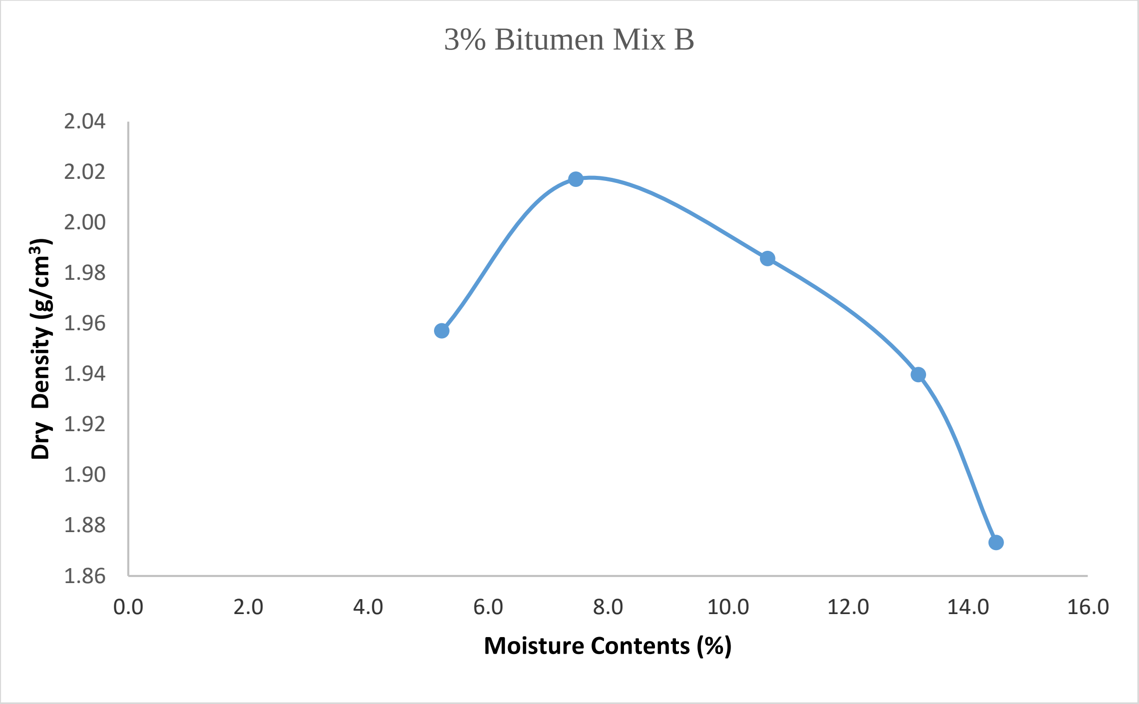

Figure 4.17: Compaction curve for Mix B at 3% Bitumen

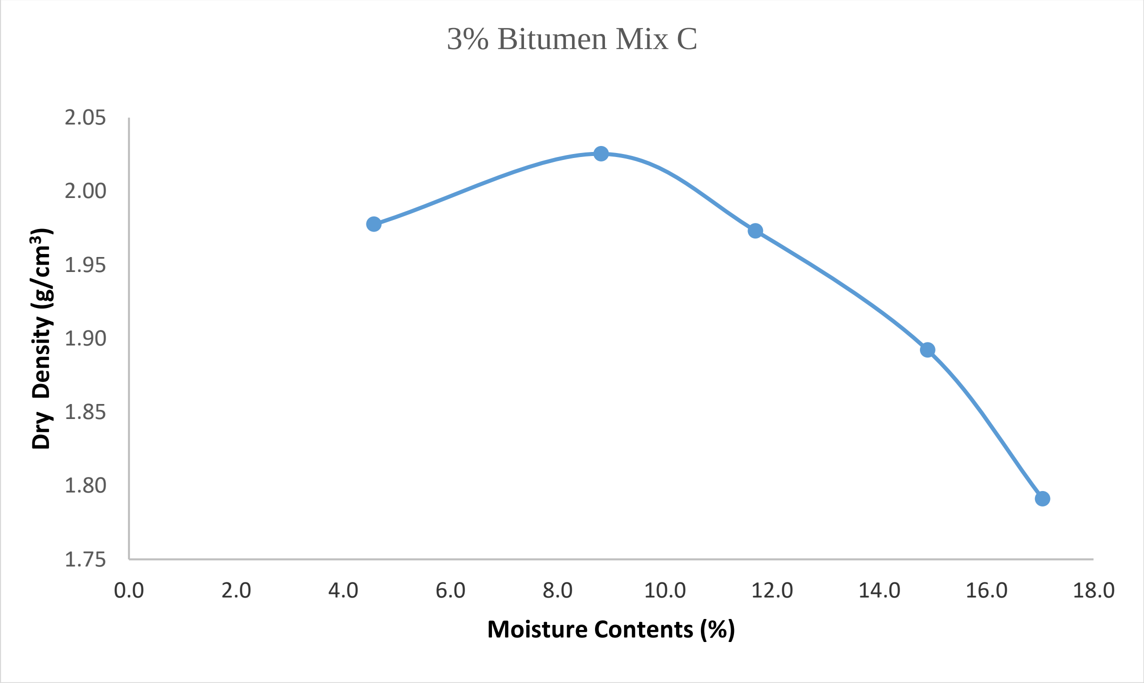

Figure 4.18: Compactioncurve for Mix C at 3% Bitumen

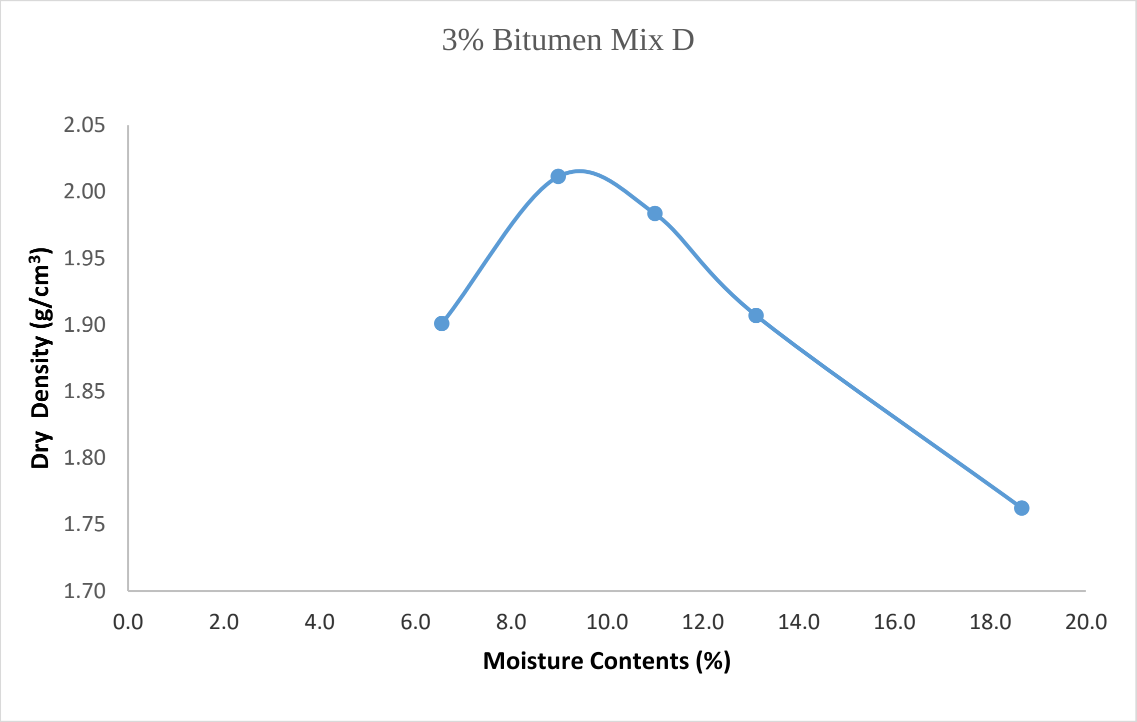

Figure 4.19: Compaction curve for Mix D at 3% Bitumen

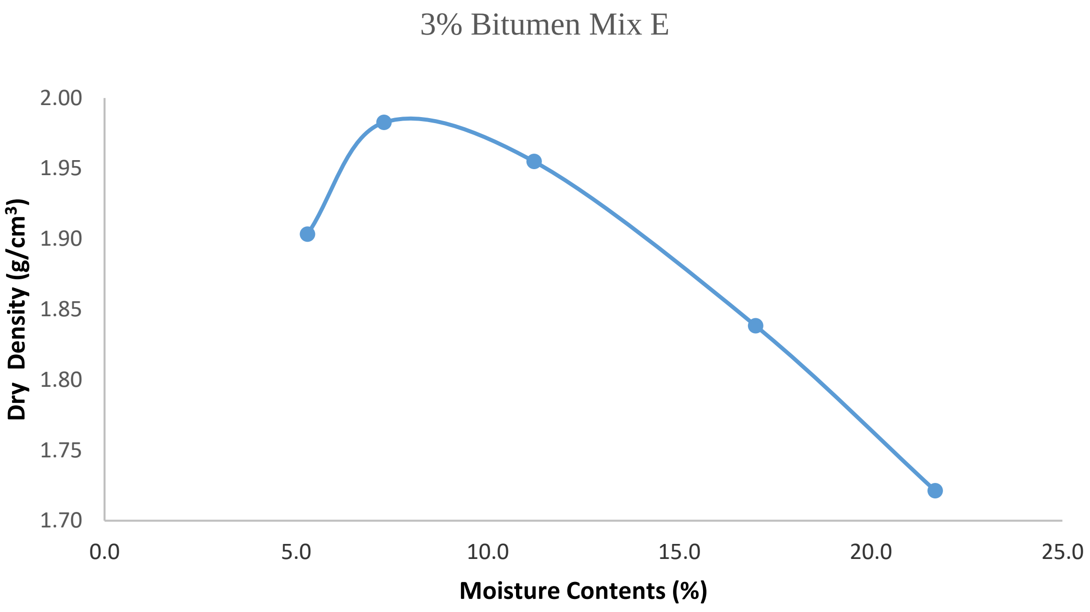

Figure 4.20: Compaction curve for Mix E at 3% Bitumen

4.4.5 Summary of Compaction Results

Table 4.8 presents summarily the compaction result for all mixes with varying bitumen content. It was observed that, Mix A with 10% to 90% representing RAP – Stone dust shows the maximum values of MDD with the highest of them being at 2% bitumen less than the control value of 2.56.

Table 4.5: Summary of Compaction Result

Bitumen Content	Mixes	A	B	C	D	E
0%	OMC	8.2	8.8	10.4	11.2	7.6
	MDD	2.56	1.912	1.872	2.01	2.018
1%	OMC	7.6	8.4	9.6	10.4	8.4
	MDD	2.19	2.68	2.04	1.895	2.025
2%	OMC	9	10.8	11.6	10	9.6
	MDD	2.53	1.876	1.884	2.025	2.015
3%	OMC	8.6	10.8	10.4	9.6	8
	MDD	2.21	2.6	1.998	2.04	1.985

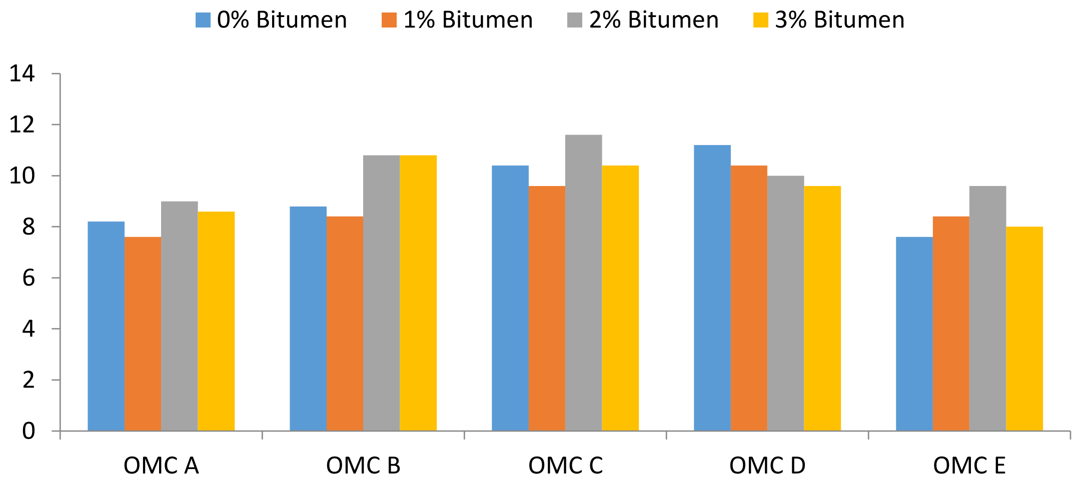

Figure 4.21: Summary of OMC Variation with Mixes

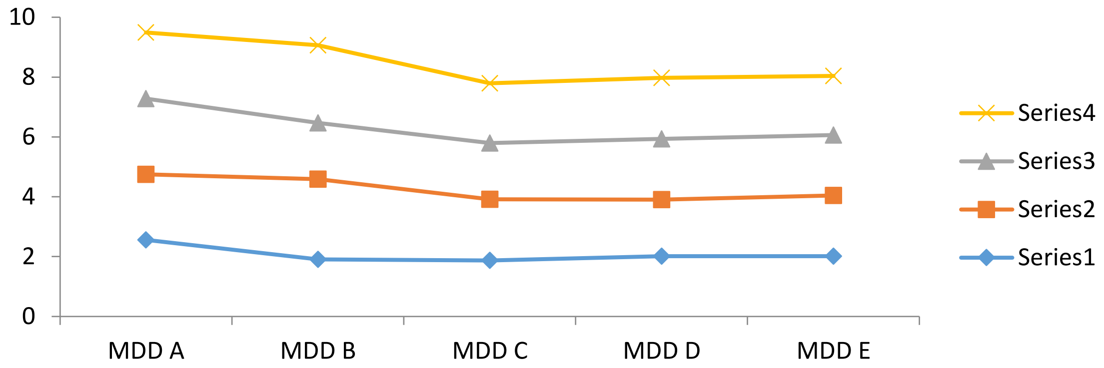

Figure 4.22: Summary of MDD Variations with Mixes

4.5 CBR Result

At 0% bitumen content, the CBR results for different mixes were presented in Figure 4.23. It was observed that the trend follows a parabolic curve as the strength increases from mix A through B with maximum value of 65.67% down to mix E with least CBR value of 14.29%

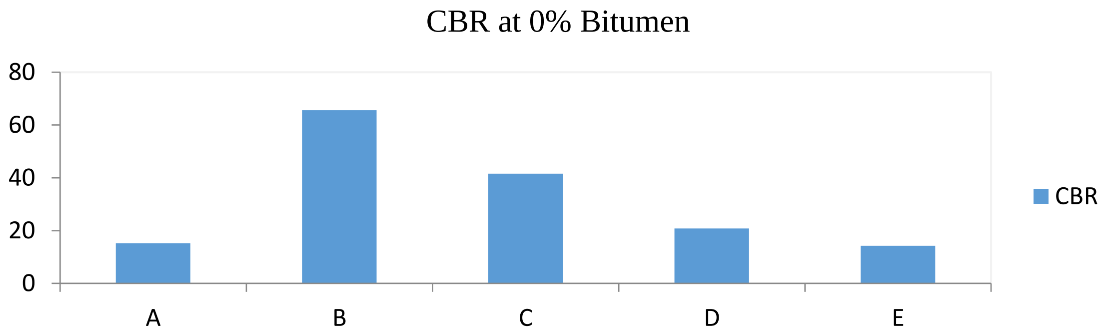

Figure 4.23: CBR at 0% Bitumen Content

As bitumen was added by 1%, the trend behavior changes from parabola to sinusoidal as in the case of 0%. The maximum CBR was still at mix B which is less than that of 0% bitumen content and the minimum was at mix C but less than that of 0% bitumen.

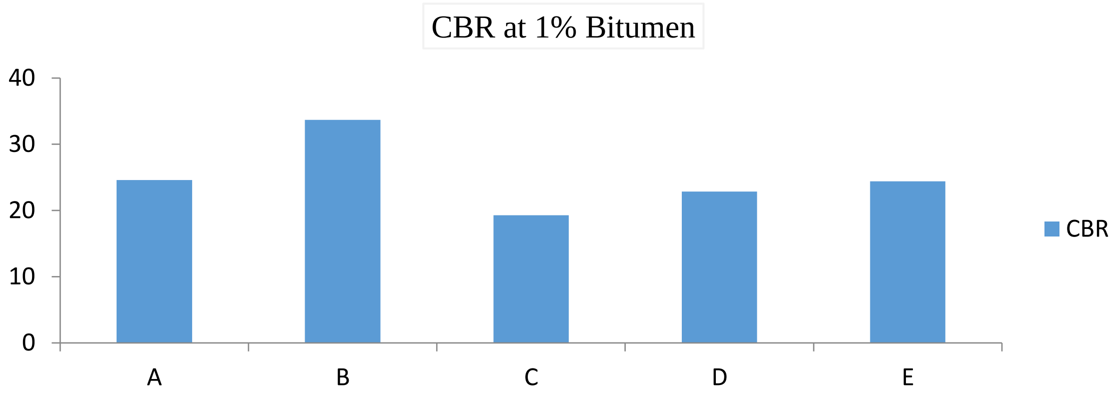

Figure 4.24: CBR at 1% Bitumen Content

As more bitumen was added in 2%, mix A has the highest CBR but less than that of 0% bitumen content, while mix B have the least CBR which is also below that of 0 and 1% bitumen content.

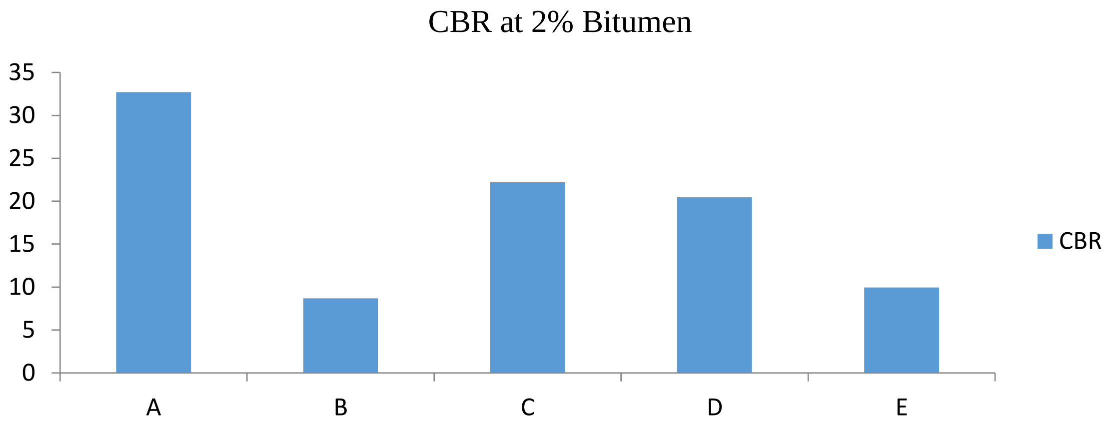

Figure 4.25: CBR at 2% Bitumen Content

When the percentage of bitumen content was increased to 3%, the CBR values for all mixes slightly vary from one another. However, mix B shows the highest CBR while mix A and E are the lowest as presented in Figure 4.26.

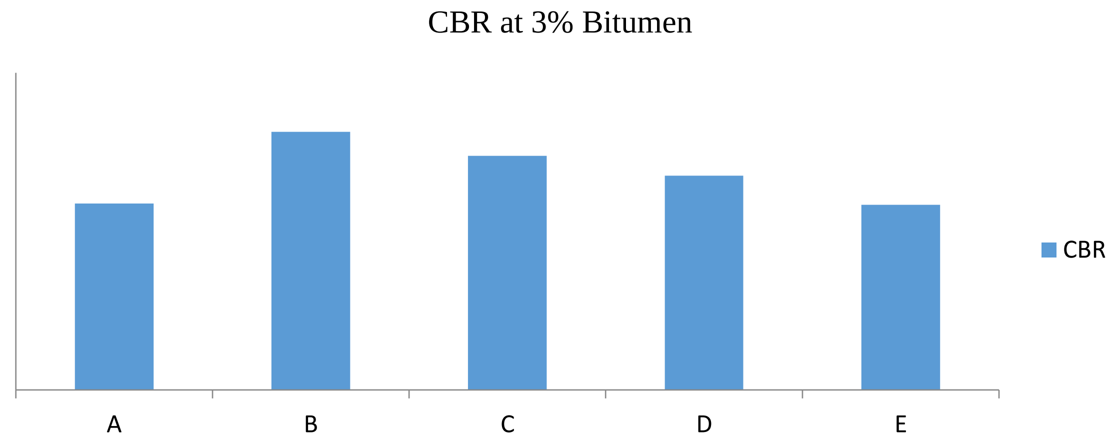

Figure 4.26: CBR at 3% Bitumen Content

Apart from the 0% bitumen content, 1% bitumen addition averagely yields better result in-terms of the maximum CBR value in comparison to other bitumen content. In fact, adding more bitumen to the mixes reduces the CBR strength characteristics as shown in Figure 4.27.

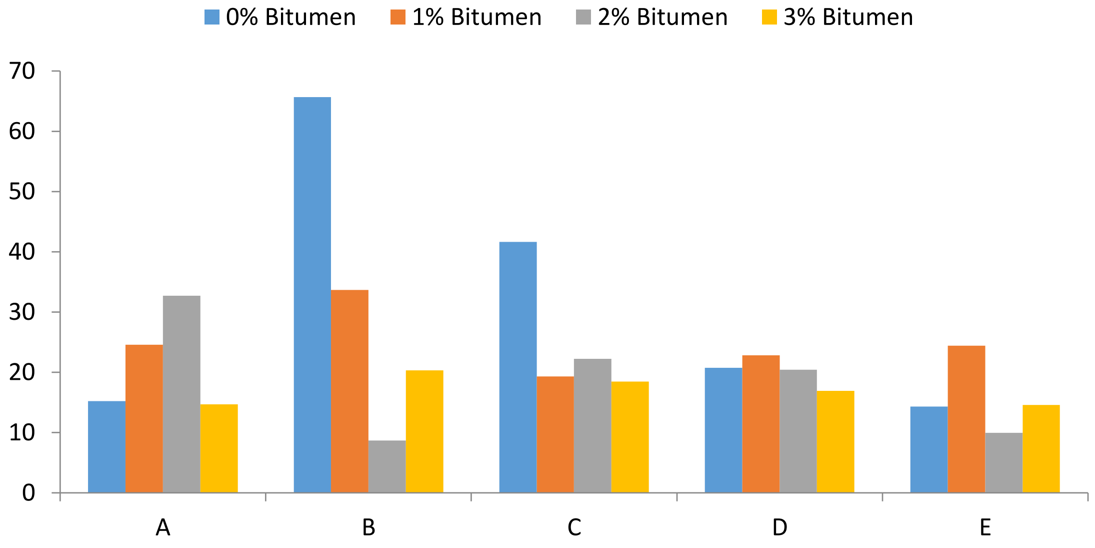

Figure 4.27: Combined CBR for all Bitumen Content

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

At the end of the research and result analysis, the following conclusions were drawn: The specific gravity test was conducted on both the RAP and stone dust. The Specific gravity for both RAP and stone dust were respectively 2.20 and 2.67. The bulk density of RAP and stone dust are respectively 1.19g/cm^3 and 1.78g/cm^3. The highest MDD for 0% bitumen was 2.56g/cm^3 with OMC of 8.2% and the least was 1.874g/cm^3 MDD with 10.4% OMC. The highest MDD after the control was 2.53g/cm^3 at 2% bitumen with 9% OMC. The minimum MDD recorded was 1.876g/cm^3 at 10.8% OMC and at 2% bitumen content. The optimum CBR value was at 1% bitumen for all different types of mixes.

5.2 Recommendation

1. A composite of RAP and stone dust blended with 1% fresh bitumen content can be used for base/sub base layer of road construction.
2. Further addition of bitumen content to the composite does not yield positive result, hence it should not be encouraged for used in road construction.
3. Further research should be carried out the composite by varying the bitumen content below 1%.

The maximum CBR value apart from that of control (0%) was at 1% bitumen for all different types of mixes.

5.3 Contribution to knowledge

The bitumen content at 1% yields the optimum strength characteristics across all the mix proportion. RAP and stone dust composite blended with bitumen was found to be useful as a base material for road construction.

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APPENDICES

Appendix A: Sieve Analysis Result

Table A1: Stone dust Sieve Analysis Result

Sieve Designation	Mass. Retained	% Retained	% PASSING
5.00	12.7	4.23	95.77
3.35	56.7	18.90	76.87
2.36	35.9	11.97	64.90
2.00	11.8	3.93	60.97
1.180	44.4	14.80	46.17
0.850	20	6.67	39.50
0.600	21.4	7.13	32.37
0.425	16.1	5.37	27.00
0.300	11.2	3.73	23.27
0.150	31.8	10.60	12.67
0.075	4.9	1.63	11.03

Table A2: RAP Sieve Analysis Result

Sieve Designation	Mass. Retained	% Retained	% PASSING
5.00	0.00	0.00	100.00
3.35	53.80	17.93	82.07
2.36	74.10	24.70	57.37
2.00	24.40	8.13	49.23
1.180	77.30	25.77	23.47
0.850	28.80	9.60	13.87
0.600	23.90	7.97	5.90
0.425	11.50	3.83	2.07
0.300	3.60	1.20	0.87
0.150	1.50	0.50	0.37
0.075	0.10	0.03	0.33

Appendix B: Result for 0% Bitumen Content

Appendix B1: Result for 0% Bitumen for Mix A

					TEST DATA					
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5528		5610		5690		5702		5650	
Wt. of Mold	3404		3404		3404		3404		3404	
Wt. of wet Sample	2124		2206		2286		2298		2246	
Volume of sample	825		825		825		825		825	
Wet Density	2.57		2.67		2.77		2.79		2.72	
Cont.No.	TA	B2	3H	SA	L2	RM11	RM16	RM18	V1	A1
Wt. Wet Sample + Cont	38.5	39.7	37.7	35.6	B	38.8	39.7	37.8	52.9	56
Wt. Dry Sample + Cont.	37.9	38.9	36.7	34.9	39.2	37.7	38.3	36.1	49.6	52.4
Wt. Water	0.60	0.80	1.00	0.70	1.20	1.10	1.40	1.70	3.30	3.60
Wt. Cont.	24.80	23.00	23.60	23.70	23.80	25.50	24.60	23.40	24.30	23.00
Wt, Dry Sample	13.1	15.9	13.1	11.2	15.4	12.2	13.7	12.7	25.3	29.4
Moisture Content %	4.58	5.03	7.63	6.25	7.79	9.02	10.22	13.39	13.04	12.24
Average moisture content %	4.81		6.94		8.40		11.80		12.64	
Dry Density	2.46		2.50		2.56		2.49		2.42	

Appendix B2: Result for 0% Bitumen for Mix B

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	4662		4770		4788		4798		4720	
Wt. of Mold	2812		2812		2812		2812		2812	
Wt. of wet Sample	1850		1958		1976		1986		1908	
Volume of sample	940		940		940		940		940	
Wet Density	1.97		2.08		2.10		2.11		2.03	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	36.3	44.5	42	48	44.8	39.8	60.4	54.8	45.3	45
Wt. Dry Sample + Cont.	35.5	43.4	40.3	46.6	42.9	37.7	55.1	51.5	41.5	42.5
Wt. Water	0.8	1.1	1.7	1.4	1.9	2.1	5.3	3.3	3.8	2.5
Wt. Cont.	22.9	23.3	22.3	29.9	26.0	21.6	21.3	21.5	21.3	21.3
Wt, Dry Sample	12.6	20.1	1.8	16.7	16.9	16.1	33.8	30	20.2	21.2
Moisture Content %	6.3	5.5	9.4	8.4	11.2	13.0	15.7	11.0	18.8	11.8
Average moisture content %	5.9		8.9		12.1		13.3		15.3	
Dry Density	1.86		1.91		1.87		1.86		1.76	

Appendix B3: Result for 0% Bitumen for Mix C

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5411		5540		5546		5520		5468	
Wt. of Mold	2812		2812		2812		2812		2812	
Wt. of wet Sample	2599		2728		2734		2708		2656	
Volume of sample	942		942		942		942		942	
Wet Density	2.76		2.90		2.90		2.87		2.82	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	44.7	48.9	48.5	42.4	50.5	53.6	51.3	56.1	56.5	48.7
Wt. Dry Sample + Cont.	43.4	47.7	46.8	40.7	47.8	51	48.1	53	52.8	44.8
Wt. Water	1.3	1.2	1.7	1.7	2.7	2.6	3.2	3.1	3.7	3.9
Wt. Cont.	24.4	27.5	25.3	20.3	22.6	26.0	24.2	30.2	25.3	22.7
Wt, Dry Sample	19	20.2	21.5	20.4	25.2	25	23.9	22.8	27.5	22.1
Moisture Content %	6.8	5.9	7.9	8.3	10.7	10.4	13.4	13.6	13.5	17.6
Average moisture content %	6.4		8.1		10.6		13.5		15.6	
Dry Density	2.59		2.68		2.63		2.53		2.44	

Appendix B4: Result for 0% Bitumen for Mix D

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	4580		4750		4780		4806		4770	
Wt. of Mold	2812		2812		2812		2812		2812	
Wt. of wet Sample	1768		1938		1968		1994		1958	
Volume of sample	940		940		940		940		940	
Wet Density	1.88		2.06		2.09		2.12		2.08	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	33.6	36.7	36.9	37.9	38.6	49.8	45.8	44.3	48.9	47.3
Wt. Dry Sample + Cont.	32.9	35.9	35.6	36.2	36	47.1	43	41.6	45.4	43.3
Wt. Water	0.7	0.8	1.3	1.7	2.6	2.7	2.8	2.7	3.5	4.0
Wt. Cont.	21.9	19.8	19.9	22.2	19.9	22.0	26.2	25.7	24.0	23.3
Wt, Dry Sample	11	16.1	15.7	14	16.1	25.1	16.8	15.9	21.4	20
Moisture Content %	6.4	5.0	8.3	12.1	16.1	10.8	16.7	17.0	16.4	20.0
Average moisture content %	5.7		10.2		13.5		16.8		18.2	
Dry Density	1.78		1.87		1.85		1.82		1.76	

Appendix B5: Result for 0% Bitumen for Mix E

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5215		5365		5517		5486		5465	
Wt. of Mold	2812		2812		2812		2812		2812	
Wt. of wet Sample	2403		2553		2705		2674		2653	
Volume of sample	942		942		942		942		942	
Wet Density	2.55		2.71		2.87		2.84		2.82	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	35.6	40.4	40.9	38.8	40.1	38.0	47.3	42.3	45	38.3
Wt. Dry Sample + Cont.	34.8	39.4	39.5	37.3	38.1	36.2	44.5	40.3	41.9	35.9
Wt. Water	0.8	1.0	1.4	1.5	2.0	1.8	2.8	2.0	3.1	2.4
Wt. Cont.	18.5	22.0	22.0	18.3	21.6	15.9	24.3	21.9	22.4	19.0
Wt, Dry Sample	16.3	17.4	17.5	19	16.5	20.3	20.2	18.4	19.5	16.9
Moisture Content %	4.9	5.7	8.0	7.9	12.1	8.9	13.9	10.9	15.9	14.2
Average moisture content %	5.3		7.9		10.5		12.4		15.0	
Dry Density	2.42		2.51		2.60		2.53		2.45	

Appendix C: Result for 1% Bitumen Content

Appendix C1: Result for 0% Bitumen for Mix A

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5556		5625		5635		5609		5565	
Wt. of Mold	3404		3404		3404		3404		3404	
Wt. of wet Sample	2152		2221		2231		2205		2161	
Volume of sample	943		943		943		943		943	
Wet Density	2.28		2.36		2.37		2.34		2.29	
Cont.No.	D2	S4	S6	S9	S1	S10	A41	B+	3T	G3
Wt. Wet Sample + Cont	42.5	37.2	41.1	38.4	40.2	42.6	44.1	48.0	49.1	47.3
Wt. Dry Sample + Cont.	41.7	36.6	39.7	37.4	39	40.8	42.1	45.3	46.3	44.3
Wt. Water	0.80	0.60	1.40	1.00	1.20	1.80	2.00	2.70	2.80	3.00
Wt. Cont.	24.90	22.50	22.90	23.00	25.20	23.10	23.20	23.70	24.30	22.70
Wt, Dry Sample	16.8	14.1	16.8	14.4	13.8	17.7	18.9	21.6	22	21.6
Moisture Content %	4.76	4.26	8.33	6.94	8.70	10.17	10.58	12.50	12.73	13.89
Average moisture content %	4.5		7.6		9.4		11.5		13.3	
Dry Density	2.18		2.19		2.16		2.10		2.02	

Appendix C2: Result for 1% Bitumen for Mix B

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	4638		4724		4762		4720		4712	
Wt. of Mold	2812		2812		2812		2812		2812	
Wt. of wet Sample	1826		1912		1950		1908		1900	
Volume of sample	940		940		940		940		940	
Wet Density	1.94		2.03		2.07		2.03		2.02	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	49	40.6	44.4	47	41	48.2	50.6	47.6	45	52.9
Wt. Dry Sample + Cont.	47.9	39.7	42.6	45.3	39.2	45.2	46.7	44.9	42.4	47.8
Wt. Water	1.1	0.9	1.8	1.7	1.8	3.0	3.9	2.7	2.6	5.1
Wt. Cont.	30.0	24.0	22.7	26.2	21.4	21.3	21.6	21.4	21.6	23.2
Wt, Dry Sample	17.9	15.7	19.9	19.1	17.8	23.9	25.1	23.5	20.8	24.6
Moisture Content %	6.1	5.7	9.0	8.9	10.1	12.6	15.5	11.5	12.5	20.7
Average moisture content %	5.9		9.0		11.3		13.5		16.6	
Dry Density	1.83		1.87		1.86		1.79		1.73	

Appendix C3: Result for 1% Bitumen for Mix C

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5402		5482		5534		5525		5485	
Wt. of Mold	3412		3412		3412		3412		3412	
Wt. of wet Sample	1990		2070		2122		2113		2073	
Volume of sample	942		942		942		942		942	
Wet Density	2.11		2.20		2.25		2.24		2.20	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	35.6	29.4	39.3	34.3	38.5	39.6	46.1	42.9	47.1	55.1
Wt. Dry Sample + Cont.	34.9	28.7	37.9	33.1	36.6	38	43	40.6	43.7	51.5
Wt. Water	0.7	0.7	1.4	1.2	1.9	1.6	3.1	2.3	3.4	3.6
Wt. Cont.	22.0	15.9	19.8	18.2	19.1	22.0	18.5	19.8	21.9	24.3
Wt, Dry Sample	12.9	12.8	18.1	14.9	17.5	16	24.5	20.8	21.8	27.2
Moisture Content %	5.4	5.5	7.7	8.1	10.9	10.0	12.7	11.1	15.6	13.2
Average moisture content %	5.4		7.9		10.4		11.9		14.4	
Dry Density	2.00		2.04		2.04		2.01		1.92	

Appendix C4: Result for 1% Bitumen for Mix D

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	4595		4676		4767		4796		4752	
Wt. of Mold	2812		2812		2812		2812		2812	
Wt. of wet Sample	1783		1864		1955		1984		1940	
Volume of sample	940		940		940		940		940	
Wet Density	1.90		1.98		2.08		2.11		2.06	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	41.3	35.8	36	39.4	53.2	45.3	48.1	53.8	55.5	70.3
Wt. Dry Sample + Cont.	40.4	35.1	35.0	38.2	50.6	43.3	45.3	50.4	52.2	63.5
Wt. Water	0.9	0.7	1.0	1.2	2.6	2.0	2.8	3.4	3.3	6.8
Wt. Cont.	22.2	20.0	22.5	22.0	29.9	20.4	21.7	26.0	24.9	22.6
Wt, Dry Sample	18.2	15.1	12.5	16.2	20.7	22.9	23.6	24.4	27.3	40.9
Moisture Content %	4.9	4.6	8.0	7.4	12.6	8.7	11.9	13.9	12.1	16.6
Average moisture content %	4.8		7.7		10.6		12.9		14.4	
Dry Density	1.81		1.84		1.88		1.87		1.80	

Appendix C5: Result for 1% Bitumen for Mix E

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5315		5430		5490		5494		5440	
Wt. of Mold	3412		3412		3412		3412		3412	
Wt. of wet Sample	1903		2018		2078		2082		2028	
Volume of sample	942		942		942		942		942	
Wet Density	2.02		2.14		2.21		2.21		2.15	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	41.1	43.4	46.2	51.7	49.1	47.8	58.1	52.5	60.2	52
Wt. Dry Sample + Cont.	39.9	42.3	44.5	49.7	46.5	45.9	54.2	49.7	55.3	48.4
Wt. Water	1.2	1.1	1.7	2.0	2.6	1.9	3.9	2.8	4.9	3.6
Wt. Cont.	23.1	22.3	23.5	27.6	23.4	26.1	24.3	25.3	25.4	22.9
Wt, Dry Sample	16.8	20	21	22.1	23.1	19.8	29.9	24.4	29.9	25.5
Moisture Content %	7.1	5.5	8.1	9.0	11.3	9.6	13.0	11.5	16.4	14.1
Average moisture content %	6.3		8.6		10.4		12.3		15.3	
Dry Density	1.90		1.97		2.00		1.97		1.87	

Appendix D: Result for 1% Bitumen Content

Appendix D1: Result for 2% Bitumen for Mix A

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5528		5678		5705		5702		5650	
Wt. of Mold	3404		3404		3404		3404		3404	
Wt. of wet Sample	2124		2274		2301		2298		2246	
Volume of sample	825		825		825		825		825	
Wet Density	2.57		2.76		2.79		2.79		2.72	
Cont.No.	A6	A5	A10	A9	A1	A4	A8	A2	A7	A3
Wt. Wet Sample + Cont	37.2	37.6	42.5	43.5	39.8	37.7	41	44.0	46.5	49
Wt. Dry Sample + Cont.	36.4	36.80	40.9	41.9	37.7	35.6	36.9	42.5	42.8	45.5
Wt. Water	0.80	0.80	1.60	1.60	2.10	2.10	4.10	1.50	3.70	3.50
Wt. Cont.	23.80	22.70	24.40	23.20	24.40	23.10	23.30	24.10	24.40	27.70
Wt, Dry Sample	12.6	14.1	16.5	18.7	13.3	12.5	13.6	18.4	18.4	17.8
Moisture Content %	6.35	5.67	9.70	8.56	15.79	16.80	30.15	8.15	20.11	19.66
Average moisture content %	6.0		9.1		16.3		19.1		19.9	
Dry Density	2.43		2.53		2.40		2.34		2.27	

Appendix D2: Result for 2% Bitumen for Mix B

TEST DATA										
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5318		5420		5482		5540		5492	
Wt. of Mold	3412		3412		3412		3412		3412	
Wt. of wet Sample	1906		2008		2070		2128		2080	
Volume of sample	942		942		942		942		942	
Wet Density	2.02		2.13		2.20		2.26		2.21	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	34.3	36	42.7	44.2	55.7	52.0	48.1	50.4	47.2	46.2
Wt. Dry Sample + Cont.	33.8	35.4	41.4	42.7	52.9	49.4	44.9	47.7	44.8	42.9
Wt. Water	0.5	0.6	1.3	1.5	2.8	2.6	3.2	2.7	2.4	3.3
Wt. Cont.	22.8	24.4	24.5	22.6	23.1	24.3	23.2	23.0	25.8	24.0
Wt, Dry Sample	11	11	16.9	20.1	29.8	25.1	21.7	24.7	19	18.9
Moisture Content %	4.5	5.5	7.7	7.5	9.4	10.4	14.7	10.9	12.6	17.5
Average moisture content %	5.0		7.6		9.9		12.8		15.0	
Dry Density	1.93		1.98		2.00		2.00		1.92	

Appendix D3: Result for 2% Bitumen for Mix C

TEST DATA

Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	4540		4688		4788		4758		4694	
Wt. of Mold	2812		2812		2812		2812		2812	
Wt. of wet Sample	1728		1876		1976		1946		1882	
Volume of sample	940		940		940		940		940	
Wet Density	1.84		2.00		2.10		2.07		2.00	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	60.6	45.8	67.3	59.1	63.9	72.1	70	67.8	72.3	68.1
Wt. Dry Sample + Cont.	58.8	44.7	64.0	56.3	60.2	66.9	66.7	60	65.4	61.7
Wt. Water	1.8	1.1	3.3	2.8	3.7	5.2	3.3	7.8	6.9	6.4
Wt. Cont.	24.2	23.7	27.9	25.0	23.2	23.0	25.7	24.2	23.1	23.9
Wt, Dry Sample	34.6	21	36.1	31.3	37	43.9	41	35.8	42.3	37.8
Moisture Content %	5.2	5.2	9.1	8.9	10.0	11.8	8.0	21.8	16.3	16.9
Average moisture content %	5.2		9.0		10.9		14.9		16.6	
Dry Density	1.75		1.83		1.90		1.80		1.72	

Appendix D4: Result for 2% Bitumen for Mix D

TEST DATA

Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5388		5455		5516		5480		5420	
Wt. of Mold	3412		3412		3412		3412		3412	
Wt. of wet Sample	1976		2043		2104		2068		2008	
Volume of sample	942		942		942		942		942	
Wet Density	2.10		2.17		2.23		2.20		2.13	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	42	39.3	42.4	37.3	49.6	47.3	52.9	51.3	56.3	46.8
Wt. Dry Sample + Cont.	40.9	38.3	40.8	36.1	46.6	44.8	49.8	47.2	50.7	43.7
Wt. Water	1.1	1.0	1.6	1.2	3.0	2.5	3.1	4.1	5.6	3.1
Wt. Cont.	21.7	22.0	22.5	21.9	19.8	18.5	22.0	19.9	19.8	22.2
Wt, Dry Sample	19.2	16.3	18.3	14.2	26.8	26.3	27.8	27.3	30.9	21.5
Moisture Content %	5.7	6.1	8.7	8.5	11.2	9.5	11.2	15.0	18.1	14.4
Average moisture content %	5.9		8.6		10.3		13.1		16.3	
Dry Density	1.98		2.00		2.02		1.94		1.83	

Appendix D5: Result for 2% Bitumen for Mix E

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5348		5485		5490		5484		5430	
Wt. of Mold	3412		3412		3412		3412		3412	
Wt. of wet Sample	1936		2073		2078		2072		2018	
Volume of sample	942		942		942		942		942	
Wet Density	2.06		2.20		2.21		2.20		2.14	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	42.6	35.5	33.4	57.4	47.1	49.5	53.1	43.1	59.7	59.7
Wt. Dry Sample + Cont.	41.6	34.4	32.0	55.1	44.6	47.2	49.1	40.5	54.7	55.8
Wt. Water	1.0	1.1	1.4	2.3	2.5	2.3	4.0	2.6	5.0	3.9
Wt. Cont.	24.3	18.2	15.9	29.8	23.1	23.4	22.3	20.5	26.1	27.6
Wt, Dry Sample	17.3	16.2	16.1	25.3	21.5	23.8	26.8	20	28.6	28.2
Moisture Content %	5.8	6.8	8.7	9.1	11.6	9.7	14.9	13.0	17.5	13.8
Average moisture content %	6.3		8.9		10.6		14.0		15.7	
Dry Density	1.93		2.02		1.99		1.93		1.85	

Appendix E: Result for 3% Bitumen Content

Appendix E1: Result for 3% Bitumen for Mix A

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5582		5636		5678		5598		5506	
Wt. of Mold	3404		3404		3404		3404		3404	
Wt. of wet Sample	2178		2232		2274		2194		2102	
Volume of sample	943		943		943		943		943	
Wet Density	2.31		2.37		2.41		2.33		2.23	
Cont.No.	B2	B6	B4	B1	B3	C3	C5	C4	C9	C2
Wt. Wet Sample + Cont	42.7	42	47	48.4	41.3	40.8	47.3	42.8	48	49.6
Wt. Dry Sample + Cont.	41.6	40.9	45.6	46.6	39.4	39.7	45.2	41.3	46.4	46.9
Wt. Water	1.1	1.1	1.4	1.8	1.9	1.1	2.1	1.5	1.6	2.7
Wt. Cont.	24.3	23.7	24.3	23.3	23.1	23.4	24.1	24.5	24.6	22.6
Wt, Dry Sample	17.3	17.2	21.3	23.3	16.3	16.3	21.1	16.8	21.8	24.3
Moisture Content %	6.4	6.4	6.6	7.7	11.7	6.7	10.0	8.9	7.3	11.1
Average moisture content %	6.4		7.1		9.2		9.4		9.2	
Dry Density	2.17		2.21		2.21		2.13		2.04	

Appendix E2: Result for 3% Bitumen for Mix B

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5352		5454		5482		5480		5432	
Wt. of Mold	3412		3412		3412		3412		3412	
Wt. of wet Sample	1940		2042		2070		2068		2020	
Volume of sample	942		942		942		942		942	
Wet Density	2.06		2.17		2.20		2.20		2.14	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	46	45.5	50.2	46.1	50.1	42.9	49.2	58.6	49.4	50.7
Wt. Dry Sample + Cont.	44.8	44.6	48.2	44.5	47.4	40.8	46.2	54	45.9	47.4
Wt. Water	1.2	0.9	2.0	1.6	2.7	2.1	3.0	4.6	3.5	3.3
Wt. Cont.	24.1	25.3	21.1	23.3	21.4	21.6	21.7	24.4	21.5	24.8
Wt, Dry Sample	20.7	19.3	27.1	21.2	26	19.2	24.5	32.6	24.4	22.6
Moisture Content %	5.8	4.7	7.4	7.5	10.4	10.9	12.2	14.1	14.3	14.6
Average moisture content %	5.2		7.5		10.7		13.2		14.5	
Dry Density	1.96		2.02		1.99		1.94		1.87	

Appendix E3: Result for 3% Bitumen for Mix C

TEST DATA

Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5360		5488		5488		5460		5387	
Wt. of Mold	3412		3412		3412		3412		3412	
Wt. of wet Sample	1948		2076		2076		2048		1975	
Volume of sample	942		942		942		942		942	
Wet Density	2.07		2.20		2.20		2.17		2.10	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	39.9	52.5	40.7	41.2	45.6	46.4	56.2	56.7	58.6	60.7
Wt. Dry Sample + Cont.	38.9	51.3	39.4	39.9	43.1	44.1	51.4	53.2	53.7	56.4
Wt. Water	1.0	1.2	1.3	1.3	2.5	2.3	4.8	3.5	4.9	4.3
Wt. Cont.	19.1	22.0	25.4	24.3	23.4	22.6	22.9	26.2	26.1	30.1
Wt, Dry Sample	19.8	29.3	14	15.6	19.7	21.5	28.5	27	27.6	26.3
Moisture Content %	5.1	4.1	9.3	8.3	12.7	10.7	16.8	13.0	17.8	16.3
Average moisture content %	4.6		8.8		11.7		14.9		17.1	
Dry Density	1.98		2.03		1.97		1.89		1.79	

Appendix E4: Result for 3% Bitumen for Mix D

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5320		5477		5486		5444		5382	
Wt. of Mold	3412		3412		3412		3412		3412	
Wt. of wet Sample	1908		2065		2074		2032		1970	
Volume of sample	942		942		942		942		942	
Wet Density	2.03		2.19		2.20		2.16		2.09	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	44.9	45.8	56.3	43.6	54.8	53.5	63.8	57	50.5	53
Wt. Dry Sample + Cont.	43.6	44.5	54.0	41.8	51.4	50.4	59.4	54	46.3	48.1
Wt. Water	1.3	1.3	2.3	1.8	3.4	3.1	4.4	3.0	4.2	4.9
Wt. Cont.	22.6	25.7	26.1	23.3	20.4	22.3	29.8	27.6	23.1	22.6
Wt, Dry Sample	21	18.8	27.9	18.5	31	28.1	29.6	26.4	23.2	25.5
Moisture Content %	6.2	6.9	8.2	9.7	11.0	11.0	14.9	11.4	18.1	19.2
Average moisture content %	6.6		9.0		11.0		13.1		18.7	
Dry Density	1.90		2.01		1.98		1.91		1.76	

Appendix E5: Result for 3% Bitumen for Mix E

	TEST DATA									
Trial No:	1		2		3		4		5	
Wt. Wet Sample + Mold	5300		5416		5460		5438		5385	
Wt. of Mold	3412		3412		3412		3412		3412	
Wt. of wet Sample	1888		2004		2048		2026		1973	
Volume of sample	942		942		942		942		942	
Wet Density	2.00		2.13		2.17		2.15		2.09	
Cont.No.	13B	D	54	130	DG	6	ZA	25	ZA	25
Wt. Wet Sample + Cont	40.2	38	39	36.6	42.2	39.5	42.8	38.8	46.9	44.7
Wt. Dry Sample + Cont.	39.2	37.2	37.5	35.3	39.7	37.6	39.7	36.5	42.4	40.7
Wt. Water	1.0	0.8	1.5	1.3	2.5	1.9	3.1	2.3	4.5	4.0
Wt. Cont.	19.8	22.5	18.5	15.9	19.9	18.2	24.3	19.9	21.7	22.2
Wt, Dry Sample	19.4	14.7	19	19.4	19.8	19.4	15.4	16.6	20.7	18.5
Moisture Content %	5.2	5.4	7.9	6.7	12.6	9.8	20.1	13.9	21.7	21.6
Average moisture content %	5.3		7.3		11.2		17.0		21.7	
Dry Density	1.90		1.98		1.95		1.84		1.72	