THE EVALUATION OF CERAMIC WASTE AS PARTIAL REPLACEMENT OF COARSE AGGREGATE IN HOT MIX ASPHALT

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JULY, 2017

DECLARATION

I hereby declare that the work in this dissertation entitled "**The Evaluation of Ceramic Waste as Partial Replacement of Coarse Aggregate in Hot Mix Asphalt"** was carried out by me in the Department of Civil Engineering, Ahmadu Bello University, Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this work has been presented for another degree at any institution.

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(Name of Student) (Signature) Date

CERTIFICATION

This dissertation entitled "**The Evaluation of Ceramic Waste as Partial Replacement of Coarse Aggregate in Hot Mix Asphalt**" by **Silifat Mobisayo BAKARE** meets the regulation governing the award of Master of Science (MSc.) degree in Civil Engineering of the Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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ABBREVIATIONS AND NOTATIONS

- CDM - Compacted Density of the Mix
- SGM - Specific Gravity of the Mix
- SGMA - Specific Gravity of the Mix Aggregates
- VIM - Voids in the Mix
- VMA - Void Mixed with Aggregate
- VFB - Voids Filled with Bitumen
- V - Volume
- CWA – Ceramic Waste Aggregate

ABSTRACT

The study investigates the suitability of ceramic waste aggregate (CWA) as partial replacement for coarse aggregate in asphalt concrete. In order to achieve the aim of the study, consistency tests such as sieve analysis, aggregate crushing and impact value, water absorption, particle shape (flakiness and elongation) and specific gravity were conducted for coarse aggregate and ceramic waste aggregate. Asphalt briquettes, using 100% conventional coarse aggregate (control) and variations of ceramic waste aggregate from 10%, 20%, 30% 40% and 50% were prepared. The mechanical property (Marshall Tests) was conducted for all prepared briquettes. From the test results, it was observed that the stability value of conventional coarse aggregate (control) gave 4kN and that of CWA 20% and 50% gave 4.0kN and 3.59kN respectively as against 3.5kN as minimum value specified in Nigerian General Specification for Roads and Bridges (1990). The corresponding results for flow, voids in total mix and voids filled with bitumen for sample containing 0% CWA are: 2.88mm, 4.20% and 71.93% respectively. Samples containing 20% CWA had flow, voids in total mix and voids filled with bitumen values as 2.77mm, 4.8%, and 73.93% respectively and samples containing 50% CWA had flow, voids in total mix as 2.58mm and 10.80% respectively. This shows that the 0% to 20% falls under specification of VIM 3% - 5%. The optimum bitumen content of 6.0% and higher stability of 4kN was recorded at a variation of 20% CWA and 80% conventional coarse aggregate. From this study, it can be concluded that up to 20% ceramic waste aggregate can be utilized as coarse aggregate in asphalt concrete for lightly trafficked roads.

CHAPTER ONE

INTRODUCTION

1.1 Background

The overall relevance of asphalt concrete in civil engineering practice cannot be overemphasized. The growing concern of resource depletion and global pollution has challenged many researchers and engineers to seek and develop new materials relying on renewable resources. These include the use of by-products and waste materials in highway construction. Although there has been much research conducted on the structural performance of asphalt concrete, these are mostly confined to naturally occurring aggregates, manufactured aggregates and aggregates from industrial by-products. In recent years, initiatives have been instigated on a global and national level to control and regulate waste management. Regulations have become increasingly rigorous and consequently, options which are still rarely used at present, such as minimizing or recycling waste, are becoming economically attractive. All recycling and reuse of waste products involve research aimed at acquiring a full understanding of such products in order to determine suitable and specific applications (Sanchez *et al.,* 2007).

Highways are high cost structures, and for that reason, it is obligatory that the materials to be used for their constructions should be appropriately designed. Flexible pavements are designed so as to have a 20 years project life. For this reason, the load distributions that would occur on these structures should also be calculated and included in the design process (Serin, *et al.,* 2012).

The current research subject focuses on economically increasing the performance and life span of roads through the use of ceramic waste as a partial replacement for coarse aggregates. On one hand, the cost of deposition of ceramic waste in landfill will be saved and, on the other, raw materials and natural resources will be replaced, thus saving energy and protecting the

environment (Mehta, 2001). Wang *et al.* (2006) reported that the inclusion of higher percentages of ceramic waste as filler in asphalt concrete led to improvements in stability value and the Marshall stability. Evangelista and de Brito (2007) analysed the feasibility of reusing CDW as fine aggregate in concretes, in proportions of 30% in concrete without noting any relevant reduction in compressive strength. González and Martinez, (2005) established maximum proportions of ceramic waste as aggregate as 50% in concrete in order to achieve strength characteristics greater than 30 N/mm^2 with the need to increase the water/cement ratio by approximately 6% . Dennis, (2009) reported that the results of tests on the performance of asphalt binder mixed with fine fiber reinforcing plastic (FRP) powder and thermoplastic shows that the thermoplastic melted during mixing and separated from the asphalt after being cooled. There is therefore, need to use materials that do not melt to avoid changes in the performance of the binder.

1.2 Statement of Problem

Environmental wastes caused by technological and industrial development are increasing, whereas natural resource and disposal areas for those wastes are decreasing day by day. So recycling and reuse of waste materials has become crucial in terms of protection of environment and the economy. Using industrial waste material such as ceramic waste makes good economic sense for project owners and contractors since it is widely available. Industrial materials are often less expensive than the virgin materials they replace. Putting industrial materials such as ceramic waste to use in infrastructure projects will solve several environmental problems, on one hand avoiding the extraction of large quantities of raw materials from the earth and by reducing the landfill areas that otherwise would be occupied by these wastes.



Plate I. A view from ceramic waste landfill site of Ceramic Factory in Lagos.

1.3 Aim and Objectives

1.3.1 Aim

The aim of this research is to evaluate the use of ceramic waste as partial replacement of coarse aggregates in the production of asphalt concrete. The aim of the study will be achieved through the following objectives.

1.3.2 Objectives

i. To determine the physical properties of the coarse aggregates and ceramic wastes aggregates.

ii. To determine the consistency test on the bitumen used in the production of Hot Mix Asphalt.

iii. To conduct Marshall Stability tests in order to determine the optimum bitumen content of asphalt mix produced with conventional aggregate and CWA.

iv. To determine the effect of different percentages of ceramic waste as partial replacement to coarse aggregate in Hot Mix Asphalt.

1.4 Justification of the Study

Waste material recycling into useful products is one of the main ways of solving waste disposal problems. Many highway agencies are conducting wide range of studies and research on the

feasibility, environmental suitability, and performance of using recycled products in highway construction (Wang *et al.,* 2006). Some of the major environmental problems arise from the disposal of ceramic waste as being non biodegradable waste, landfill problems. The replacement of coarse aggregate with ceramic waste in asphalt production is an important environmental benefit. It avoids the extraction of large quantities of raw materials from the earth, also avoids energy costs and landfill problems.

1.5 Scope of Study

The scope of this research covers the study of mechanical properties of modified asphalt concrete with traditional coarse aggregate using ceramic waste of aggregates with variation percentage of 0%, 10%, 20%, 30%, 40% and 50%.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

A ceramic is an inorganic, non-metallic solid prepared by the action of heat and subsequent cooling. Ceramic materials may have a crystalline or partly crystalline structure, or may be amorphous (e.g. a glass). Because most common ceramics are crystalline, the definition of ceramic is often restricted to inorganic crystalline materials, as opposed to the non-crystalline glasses, a distinction followed here. According to Zephaniah (2008) the earliest ceramics made by humans were pottery objects, including 27,000 year old figurines, made from clay, either by itself or mixed with other materials, hardened in fire. Later ceramics were glazed and fired to create a coloured, smooth surface. Ceramics now include domestic, industrial and building products and a wide range of ceramic art. In the 20th century, new ceramic materials were developed for use in advanced ceramic engineering; for example, in semiconductors (Dennis, 2009).

Product from the ceramics industry comprises of the following: wall and floor tiles, sanitary ware, bricks and roof tiles, refractory materials, technical ceramics and ceramic materials for domestic and ornamental use. In the European Union and Spain, the production of wall and floor tiles represents the highest percentage with respect to the total, followed by bricks and roof tiles, and other products. Ceramic products are produced from natural materials containing a high proportion of clay minerals. Following a process of dehydration and controlled firing at temperatures between 700ºC and 1000ºC, these minerals acquire the characteristic properties of fired clay.

2.2 Ceramic Waste

Ceramic wastes come from two sources. The first source is the ceramics industry, and this waste is classified as non-hazardous industrial waste (NHIW). According to the Integrated National Plan on Waste 2008-2015, NHIW is all waste generated by industrial activity which is not classified as hazardous in Order MAM/304/2002, in accordance with the European List of Waste (ELW) and identified according to the following: Waste from the manufacture of ceramic products, bricks, roof tiles and construction materials, brick.

The second source of ceramic waste is associated with construction and demolition activity, and constitutes a significant fraction of construction and demolition waste (CDW), this kind of waste is classified by the ELW according to the following: Construction and demolition waste, Concrete, bricks, roof tiles and ceramic materials (EWC, 2015).

Nigeria is a developing country, with a land area of 923,768 km^2, and a population of about 140 million with growth rate of 2.38%. Nigeria is the most populous country in Africa and ninth most populous country in the world. With populations distributed at 48.3% urban and 57.7% rural and population density at 139 people per square km (Ogwueleka, 2009). The volume of solid waste being generated continues to increase at a faster rate than the ability of the agencies to improve on the financial and technical resources needed to parallel this growth. Having carried out a municipal solid waste characteristics and management in Nigeria, eight cities in the Federal Republic of Nigeria which are Maiduguri, Kano, Abuja, Onitsha, Nsukka, Makurdi, Ibadan and Lagos. The result shows that 35.6%, 32%, 38.6%, 33.8%, 20.2%, 25.8%, 13.5%, 36% respectively of solid waste were glass and ceramics (Ogwueleka, 2009).

Globally, the ceramics industry sector is unusual in that it is primarily found in regional concentrations where the majority of agents or industries involved in the system whereby the end ceramic product attains value are located. The development of these ceramic “clusters”, with

companies in the same or related sectors located in geographical proximity, has enabled the sector globally to attain a state-of-the-art level of progress and technological innovation. The main ceramic "clusters" are located in Brazil, with one in Santa Catarina and two in the state of Sao Paulo; in Portugal, in the Aveiro region; in Castellón, Spain; and in the province of Emilia Romagna, Italy. The ceramics industry in China has also begun to take on greater prominence, representing 35% of global production in recent years. The ceramics industry is comprised of the following subsectors: wall and floor tiles, sanitary ware, bricks and roof tiles, refractory materials, technical ceramics and ceramic materials for domestic and ornamental use. In both the European Union and Spain, the scale of production within these subsectors with regard to total production follows the same trends, where the production of wall and floor tiles represents the highest percentage with respect to the total, followed by bricks and roof tiles, and finally, the other subsectors. Ceramic products are produced from natural materials containing a high proportion of clay minerals. Following a process of dehydration and controlled firing at temperatures between 700ºC and 1000ºC, these minerals acquire the characteristic properties of fired clay. Ceramic factory waste is not sorted according to the reason for rejection, which may include: breakage or deformation and firing defects (Frías *et al*., 2008).

As regards waste generated by construction activity it is estimated that some 200 million tons of rubble is produced each year in the European Union (EU) as a result of the construction and demolition of buildings. According to data from the Spanish National Plan for Construction and Demolition Waste, 40 million tons are generated annually in Spain, the equivalent of 2 kg per inhabitant per day, which represents a higher figure than that for domestic waste. Within the EU as a whole, 28% of this waste is recycled. Pioneering European countries in this matter include the Netherlands, where 95% of construction waste is recycled, England, with 45% and Belgium with 87%, 17% of which is used in making concrete. In Spain, approximately 10% of total

construction and demolition waste is recycled, and reuse mainly consists of using the waste for road subgrade and subbase (Binici, 2007).

2.2.1 Recycling of Ceramic Waste

A lot of waste is generated while producing ceramic wares in the factory, which are usually referred to as rejects. These wastes are from finished products that have such deficiencies that would naturally make them unacceptable in the market because they could constitute health risk. The wares usually have such fault like internal cracks, dunting (cracking of pottery caused by stresses which form during firing and cooling) and bloating. The production moulds which are made of Plaster of Paris, usually under normal circumstances, expire after 90 product casts, though some are made to go far more than such tolerable limits. The expired moulds in most instances are dumped after they may have expired. These broken ceramic wares and the expired plaster moulds constitute environmental hazards at dumped sites and result in an unnecessary distraction (Zephaniah, 2008)

2.2.1.1 Ceramic Waste as Recycled Aggregate

As mentioned previously, one of the objectives of the new waste reuse and recycling policies in the construction and industrial sectors is to use recycled aggregates as a substitute for conventional natural aggregates, with the aim of reducing both use of natural resources and environmental impact caused by dumping. According to a Statistical Report by ANEFA (Asociación Nacional de Fabricantes de Áridos-Spanish Association of Aggregates Producers) (2008), consumption of aggregates in Spain in 2007 reached the figure of 479 million tons in the construction sector and 72 million tons in industrial applications (cement, glass and ceramics industries). Meanwhile, sources from the European Aggregates Association (UEPG) indicate that from the total volume of aggregates used by the construction sector in 2007, most (62.7%) was employed for manufacturing concrete, mortar and prefabricated blocks, followed by use in road

construction. In the case of industrial use, most (82%) was destined for the manufacture of cement, whilst the remainder was employed for different industrial applications such as the manufacture of lime and plaster, glass and ceramics, among others. A further important aspect for analysis, as mentioned at the beginning, is the energy factor. The processes involved in cement manufacture, in ceramics production, or in transport, endow construction materials with energy, called *embodied energy* (Construction Research Institute, 2000). It has been estimated that of all the embodied energy incorporated in a building, only around 20% corresponds to the construction phase. Therefore, when a defective construction material is discarded, or a building demolished, a huge quantity of embodied energy is wasted. The maximum substitution percentage is basically due to the high absorption coefficient of this kind of material, although they also established the possibility of reuse in combination with enhanced natural aggregates, and for structural concretes with a compressive strength equal to or less than 50 MPa. Along the same lines, studies have established maximum proportions at 50% (González and Martinez, 2005), although they also emphasized the high absorption coefficient and the need to increase the water/cement ratio by approximately 6% with respect to the reference concrete in order to achieve strength characteristics greater than 30 N/mm^2. Likewise, Domínguez *et al.* (2004) reported the viability of recycled aggregate reuse in concretes with strengths of 150, 200 and 250 kg/cm^2, establishing the possibility of reuse via a small increase in the quantity of cement employed (2.5%), whilst at the same time stressing the consequent environmental and economic advantages. Along the same lines, Evangelista and de Brito (2007) analysed the feasibility of reusing CDW as fine aggregate in concretes, in proportions of 30% with respect to the reference concrete without noting any relevant reduction in compressive strength.

2.2.2 Using Sanitary Ware Waste as Recycled Aggregate in Structural Concrete

Spain is the world leader in the ceramic sanitary ware market. The industry produces over 7 million items a year and generates approximately 24 tons of waste a month, which is simply dumped. The percentage of products considered unsuitable for sale, and thus rejected, depends on the kind of installation concerned and the corresponding product requirements. The reuse of ceramic waste from the sanitary ware industry as a partial substitute for conventional coarse aggregates requires a simple treatment process comprising crushing, using a jaw-crusher, and subsequent washing and sieving. Two fractions are obtained from crushing; the fine fraction of less than 4 mm in size, and the coarse fraction, over 4 mm in size. Reuse of this kind of waste has many advantages, not least of which are the economic advantages, including job creation in companies specializing in the selection and recycling of this kind of material. It goes without saying that reuse is better than recycling; thus, there are considerable environmental benefits to using materials with such a high level of *embodied energy*, such as a reduction in the number of natural spaces employed as refuse dumps and a decrease in the quarrying necessary to extract conventional natural aggregates. Indirectly, all the above contributes to a better quality of life for citizens (Andres *et. al.*, 2010).

- It avoids the use of new raw materials
- It reduces waste generation.

2.2.3 Ceramics Wastes and the Environmental Issues

As previously mentioned continuous landfill of ceramic waste after a period of time usually creates environmental problems especially in Nigeria where environmental laws are not properly enforced (Anthony, 2007). The use of black oil and wood required for generating required energy for ceramics kiln firing leaves a lot to be desired with the international consciousness and

hazard of global warming. Deforestation is at a high rate while attempting to generate enough firewood for wood kiln operation without adequate replacement is already leading to desertification. The felling of the trees may seem to improve quality of human life from what they are used for without the carrying capacity of supporting the eco-system. The excavation and mining of raw materials without adequate technology to complete the refill, depreciates the environment. The task of putting back the problems created from the mining site through refilling, compressing, and reclaiming by government agency will create more jobs while the task of forestation through massive tree planting could help boost the capacity building among the unemployed women within the environment; thereby increasing their productivity and alleviating poverty among them. The gas flaring in the Niger Delta can be processed into useable gas in the ceramics industries thereby creating more jobs for the restless youth in the Niger Delta areas of Nigeria. Environmental sustainability with Nigerian local ceramic earth resources, long term, would have cultural, economic, and environmental health vitality with emphasis on linking the social, financial, and environmental well being. That is, a positive change where environmental and social systems are not under scored by building equitable, productive, and participatory structures to increase economic empowerment of communities and their surroundings. The greatest challenge today in Nigeria and Africa at large therefore is to start to think sharply at transforming challenges to opportunities in the area of environmental management so they can more efficiently meet up with the faster growth and strengthened institutions in the developed nations outside Africa (Binici, 2007).

Sanitary ceramics, as with all other ceramic products, are produced from natural materials which generally contain kaolin, china clay, feldspar, potassium, and quartz. In research teams, material of ceramic origin has been used as road fill, as a partial substitute for natural aggregate in concrete, either as coarse aggregate or as fine aggregate, and as a substitute – in varying

proportions – for cement in mortar and concrete. A detailed analysis of the results obtained in the various researches has led to the following conclusions:

- Recycled aggregates obtained from industrial waste produced by the sanitary ceramics industry are suitable for the manufacture of concrete.

- Recycled concrete obtained through partial substitution of natural coarse aggregate is suitable for structural purposes (Cao, 2007).

2.2.4 Use of Ceramic Waste in Asphalt and Road Work.

The higher order roads like National highway, State Highway and Major Urban Arterials and Sub Arterials possess the bituminous concrete at the top and need filler contents. Generally, lime, cement or fine dusts are used. As ceramic industries produce ceramic powder as waste in huge quantity, it necessitates the disposal of such materials. The alternate option is to use it in construction activities. A comparative study was carried out for two different filler materials i.e. lime and Ceramic waste powder. The Marshall tests were conducted on the bituminous mixes containing 3-5% ceramic waste & lime. It was reported that the inclusion of higher percentages of ceramic waste and lime led to improvements in stability value and the Marshall stability.

Using ceramic waste in Hot Mix Asphalt (HMA) is an effective way to prevent environmental pollution. So instead of being an environmental pollution, CW aggregates can be used in pavement construction for sustainable environment (Koyuncu *et. al.* 2004). There are few studies in the literature related to the use of ceramic waste in concrete and HMA as aggregate, Torkittikul *et. al.* 2010, analysed usability of ceramic waste and fly ash as fine aggregate in Portland cement concrete production. The results show that with the addition of ceramic waste in the specimens, the workability is increased. Also, the compressive strength in concrete with CW increased with increasing CW ratio (Torkittikul and Chaipanich, 2010). Pacheco *et. al*.2010, studied the feasibility of ceramic waste usage in concrete as aggregates. Results identified that

compressive strength values of concrete specimens were increased with increasing ceramic waste ratio. Results also showed that addition of ceramic aggregates provide better performance properties to HMA (Pacheco *et. al.,* 2010). Van de Ven *et al*. (2011) examined the possibility of using ceramic waste from electrical insulators, plastic waste and household waste. From the results, it was shown that sintered household waste, plastic waste, ceramic waste can be used as coarse aggregate in HMA. Likewise with ceramic waste addition Marshall Stability and Flow values increased as compared to the control samples (Van de Ven *et al.,* 2011). Silvestre *et al.* 2013 investigated the performance characteristics of the waste tile usage in HMA. It was found that the bitumen ratio, void content and plastic deformation values were increased with increasing WC. Additionally it was observed that mixtures with ceramic aggregates perform worse than the control mixtures concerning compressive strength and worse moisture susceptibility and up to 30% of natural aggregates can be replaced by recycled ceramic for binder course and wearing course according to Spanish Specifications (Silvestre et al., 2013a, b). Kara, C. *et. al.*,2015 also concluded that waste ceramic aggregate could replace, for binder course up to 30% and mixture which contains 30% CW was lighter (11%) than the conventional mixtures in equal volume. It means that trucks can carry HMA more than before (Kara *et. al.*, 2015).

2.3 Asphalt Concrete

Asphalt concrete is a combination of aggregate and asphalt cement. The aggregate acts as the structural skeleton of the pavement and the asphalt cement as the glue of the mixture. The mineral aggregate, including coarse and fine particles in asphalt paving mixtures, encompasses approximately 90% of volume of Asphalt concrete. The properties of the aggregate have direct and significant effect on the performance of asphalt pavements. Asphalt concrete is the most

commonly used material in pavement due to its superior service performance in providing driving comfort, stability, durability and water resistance.

2.3.1 Materials for Improvement of Asphalt Pavement

Several materials have been used to improve the quality of Asphalt concrete. A few of these are stated below:

1) As asphalt admixtures are mixed at high temperatures, we need to investigate whether any toxic gases are emitted in relation to the decomposition process or the characteristics of the recycled admixture to which the waste plastic is added. Although most plastic generated from industrial waste is sorted into types, plastics from general waste tend to include various types, meaning that it is highly likely there will be fluctuations in material quality when the plastic is mixed and melted with asphalt. Therefore, there is also a high possibility that the product's usefulness as a binder improvement material will be restricted (Gomes *et al.*, 2009).

2) It is necessary to pay close attention to compatibility, affinity, and low-temperature brittleness in relation to the asphalt or aggregate when a new thermoplastic is used as an improvement material, and the same applies in cases where waste plastic is used (Chatveera *et al.*, 2011).

3) The results of tests on the performance of asphalt binder mixed with fine fiber reinforcing plastic (FRP) powder and thermoplastic indicate that, in many cases, the thermoplastic that is melted during mixing separates from the asphalt after it has been cooled. Certain types do not melt at all, and these are thought to be the types that do not cause changes in the performance of the binder (Dennis, 2009).

Also, the results of tests on admixture properties show a tendency for the compaction density values and Marshall Stability values to be lower for admixtures to which FRP powder and rubber crumb have been added. Test results have showed that mixtures that used 50% Rice Husk Ash and 50% Lime Stone of Filler Rates (FR 2.5% RHA and 2.5% LS) have had the best Marshall

Stability when evaluated in terms of Marshall Stability. As a result, especially in areas where there is widespread rice husk ash waste, it can be used instead of limestone in asphalt concrete mixtures as mineral filler (Chatveera *et al.*, 2011).

2.4 Aggregates

Aggregates usually are categorized as crushed rock, sand, and filler. The rock material is predominantly coarse aggregate retained on sieve No. 8 sieve (2.38mm), sand is predominantly fine aggregate passing the No. 8 sieve, and filler is predominantly mineral dust that passes the No. 200 sieve. It is customary for gradations of the combined aggregate and the individual fractions to be specified. Table 2.1 gives suggested grading requirements of aggregate material based on Federal Ministry of works design manual. The first phase in any mix design is the selection and combination of aggregates to obtain a gradation within the limits prescribed. This sometimes is referred to as mechanical stabilization (FMWHM, 2013).

Table 2.1: Grading Requirements of Aggregate Material

Particle Size (mm)	19.1	12.7	9.52	4.76	2.38	0.59	0.297	0.119	0.074
Sieve size	¾	½	3/8	No. 4	No.8	No. 30	No. 50	No. 100	No. 200
% Passing	100	80 – 100	70– 90	50 - 70	33 - 50	18 - 29	13 – 23	8 - 16	4 - 10
Mean Grading	100	90	80	60	42	23	18	12	7

Source: FMWHM (2013)

2.5 Brief History of Bituminous Materials

Asphaltic materials have been known and used in road construction, water proofing, mortar and adhesives since 3800 B.C (Gurcharan, 2006). The earliest known bitumen occurred naturally in pools and lakes. This natural asphalt is formed when petroleum rises to the surface and the

volatile components vaporize. The bitumen lake in Trinidad Island and Bermudez deposit in Venezuela, are the largest known sources of natural bitumen. In parts of the world, bitumen is found in porous rocks such as Sandstone and Limestone; and in rock veins or crevices such as Gilsonite. With the advent of automobiles and air planes, which requires smooth all-weather pavement, the demand grew for producing bitumen from crude petroleum.

The chemical composition of bitumen cement is the controlling factor regulating the products uniformity and durability. Among the first to develop a chemical analysis procedure and place definite values on chemical components were Rostler and White (1962) in their analysis of 119 samples of 85-100 penetration bitumen cements obtained for study from the Bureau of Public Roads. The Researchers used ASTM D-2006-62-T test method in the analysis to separate each sample into five (5) chemical components: asphaltenes, nitrogen bases, first acidaffins, second acidaffins, and paraffins. The last four components listed are known as maltenes and have considerable bearing upon the durability of bitumen cement (Wallace & Martin, 1997).

2.6 Constituent Materials Characterisation

According to Department of Scientific and Industrial Research of the Road Research Laboratory, London (1962), the main factors associated with the constituent materials which by extension affect the resistance to plastic deformation of bituminous surfacing (assuming good adhesion between the binder and aggregates) are:

(1) Temperature and binder viscosity

(2) Quality of binder

(3) Type and quantity of

    (a) Coarse aggregate

    (b) Fine aggregate

(c) Filler

(4) Degree of compaction

2.6.1 Effect of Temperature and Binder Viscosity

The dependence of the flow properties of bituminous mixtures on temperature is due to the changes in the rheological properties of the binder, the dominating factor being the great dependence of viscosity on temperature. Thus, the resistance to deformation of asphaltic materials decreases rapidly with increase in temperature. Therefore, the maximum temperature experienced in a road surfacing should be taken into account when giving requirements for stability.

Also, various preliminary tests have been developed for control of quality of bitumen and assessing the suitability of bitumen for specific applications. Basically, these tests should measure consistency, which is vital to mixing and placing; durability, which makes it remain effective in hostile environments; rate of hardening, which is vital to construction operations and workability, and finally, safety test (flash and fire point). The procedural details of the above tests should be carried out according to the relevant sections of ASTM standard to show the practical significance of the binder.

a) Ductility Test (ASTM D113)

Ductility is a property of bitumen that is usually linked with adhesion and temperature susceptibility. A bitumen sample having high ductility has high adhesion and susceptibility. Susceptibility is a measure of change in consistency for change in temperature. Ductility is the distance in centimeters that a standard briquette of bitumen cement will stretch before breaking. The minimum cross section of the briquette is $1cm^2$, the test is made at a temperature of 25°C and the rate of pulling of the two ends of briquette is 5cm/min.

b) Penetration (ASTM D5)

This test is very vital to empirical measurement of consistency of bitumen. The test, a measure of hardness, is performed by allowing a needle of specified dimensions, which is loaded to 100g to penetrate into the material for a period of 5 seconds. Penetration is measured by the distance the needle sinks into the bitumen, in units of 1/100cm. The higher the penetration, the softer the bitumen. Bitumen with penetration grade of 60-70 or 60/70 means that the penetration of the needle in bitumen is in the range of 60 to 70 at standard test condition.

c) Softening Point (ASTM D36)

This is a measure of temperature susceptibility and a measure of flow of bitumen in service. It is a form of consistency test that determines the melting point of bitumen and is used for control in refining operation. The test for determining softening is called ball-and-ring softening point. In the test, asphalt is placed in a small ring and chilled. The ring is then immersed in water or glycerin; a small steel ball is placed on the asphalt and heat is applied to the liquid. As the temperature is raised, a point where bitumen softens and the ball sink to the bottom of container is the temperature corresponding to softening point.

d) Flash and Fire Point (ASTM D92)

The flash point of bituminous product is the temperature at which, during heating, its vapor will temporarily ignite, when a small flame is brought into contact with them. While not specified, the fire point is the higher temperature at which the bitumen will support combustion. Flash and fire point is safety related which suitable caution should be taken to eliminate fire hazards during heating and manipulation of bitumen.

e) Solubility Test (ASTM D4)

It is desirable that bitumen contain a negligible amount of salt, dirt, carbon and minerals. Such matters are insoluble in solvents like carbon disulphide, carbon tetrachloride and trichloroethylene. The test is performed by simply dissolving a measured portion of the bitumen in the solvent and then filtered. The solution is dried and weighed to determine the amount of impurity present. The minimum proportion of bitumen soluble in carbon disulphide is 99%.

f) Specific Gravity Test (ASTM D70)

This is the ratio of the mass of a given volume of bitumen to the same of an equal volume of water. It is usually determined either by using pycnometer or by preparing a cube shape specimen of solid state and weighing in air and water. Generally, the specific gravity of pure bitumen is in the range of 0.97 to 1.02, but that of cutback may be lower depending on the type. Tar, one of the products of destructive distillation of coal, has specific gravity range of 1.10 to 1.25.

g) Viscosity Test (ASTM D88)

Viscosity is an inverse of fluidity which is resistance to flow. It is another means of grading bitumen apart from conventional penetration units. The degree of fluidity of the binder at the application temperature greatly influences the strength characteristics of the resulting paving mixes. There is an optimum value of viscosity for each aggregate gradation and bitumen grade, high or low viscosity during mixing or compaction has been observed to result in lower stability value. The viscosity is determined by measuring the time taken by 50ml of bitumen to flow from a cup through a specified orifice under standard test conditions and specified temperature.

2.6.2 Effect of Binder Content

Suitable binder content choice for a given aggregate grading is one of the main problems of bituminous mixtures from deformation point of view, it is pertinent to find the highest binder content that can be used in mix design without unduly risking plastic deformation under prevailing conditions of traffic loading and temperature. Excessive bitumen content causes the aggregates to loose internal friction and hence, the stability of the structure is affected. To achieve the maximum possible resistance to deformation, the bitumen content should just be enough to give cohesion and to enable adequate compaction to be achieved, although, for combine view points of durability and permeability, it would generally be important to choose binder content lower than that in practice above.

2.6.3 Effect of Type and Quantity of Coarse Aggregate

The addition of small quantities of coarse aggregates to a sand/filler/bitumen mixture has little effect on the stability of the mixture, unless the maximum size of stone is of the same order as the thickness to which the material is laid. The proportion of the coarse aggregate required to establish this structure and strength of the structure when made will depend on the shape and surface texture of the aggregated materials. The aggregates carry imposed load on the pavement, accompanied by frictional resistance and interlocking between the individual particles of aggregates.

BS 594:1958 verified that bituminous mixtures containing no coarse aggregate have a maximum stability of 354kg, ones with 25% coarse aggregates have a 545kg maximum stability and those with 55% coarse aggregates have maximum stability value increased to 772kg. In this connection, wheel tracking tests on mixtures of dense tar surfacing with varying contents of coarse aggregates and containing the bitumen content showed that the maximum interlock giving

maximum resistance to deformation occurs with about 65% of coarse aggregates. Generally, therefore, to provide a stable, dense, workable and skid resistant mixture, it is essential that the coarse aggregate do not exceed a specified percentage above. Also, the aggregate must be of approved source- tough, clean (dust, clay and organic matter-free), angular in shape, but not flaky.

2.6.3.1 Aggregate Desirable Properties

1. Strength

The aggregates used in top layers are subjected to (i) Stress action due to traffic wheel load, (ii) Wear and tear, (iii) crushing. For a high quality pavement, the aggregates should possess high resistance to crushing, and to withstand the stresses due to traffic wheel load.

2. Hardness

The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic. The aggregates should be hard enough to resist the abrasive action caused by the movements of traffic. The abrasive action is severe when steel tyred vehicles moves over the aggregates exposed at the top surface.

3. Toughness

Resistance of the aggregates to impact is termed as toughness. Aggregates used in the pavement should be able to resist the effect caused by the jumping of the steel tyred wheels from one particle to another at different levels causes severe impact on the aggregates.

4. Shape of aggregates

Aggregates which happen to fall in a particular size range may have rounded, cubical, angular, flaky or elongated particles. It is evident that the flaky and elongated particles will have less

strength and durability when compared with cubical, angular or rounded particles of the same aggregate. Hence too flaky and too much elongated aggregates should be avoided as far as possible.

5. Adhesion with bitumen

The aggregates used in bituminous pavements should have less affinity with water when compared with bituminous materials; otherwise the bituminous coating on the aggregate will be stripped off in presence of water.

6. Durability

The property of aggregates to withstand adverse action of weather is called soundness. The aggregates are subjected to the physical and chemical action of rain and bottom water, impurities there-in and that of atmosphere, hence it is desirable that the road aggregates used in the construction should be sound enough to withstand the weathering action.

7. Freedom from deleterious particles

Specifications for aggregates used in bituminous mixes usually require the aggregates to be clean, tough and durable in nature and free from excess amount of flat or elongated pieces, dust, clay balls and other objectionable material. Similarly aggregates used in Portland cement concrete mixes must be clean and free from deleterious substances such as clay lumps, silt and other organic impurities.

Traffic load repetition causes aggregate degradation and wearing. Soft, weak or friable aggregate particles undergo degradation (a process where fines are degenerated by aggregate breakdown during the placement or the use of the material). To resist the stress due to repeated traffic loads and avoid the degeneration, aggregates must exhibit strength and toughness to function for their intended purpose.

Hardness is defined by the resistance to wear and is measured by Abrasion test, while strength and toughness of aggregate is defined as the resistance to fracture under loading and is measured by the Crushing and Impact tests respectively.

a) Crushing and Impact Tests

It is necessary for aggregates to be strong and tough enough so that it can support roller weight during placing and laying of the asphalt concrete and during the repeated impact and crushing actions of the traffic.

For Crushing test, dry aggregates (coarse aggregates) were filled in a cylindrical mould of 11.5mm diameter by 180mm height in three layers. Each layer is tampered 25 times with a standard tamping rod and at the end weighed. The specimen is subjected to a compressive load of 40tonnes gradually applied at the rate of 4 tonnes per minute. Then crushed aggregates are then sieved through 2.36mm sieve and weight of passing material (W_2) is expressed as percentage of the weight of the total sample (W_1) which is the aggregate crushing value.

$$\text{Aggregate crushing value} = \frac{W_2}{W_1} * 100\% \qquad 2.1$$

A value less than 10 signifies an exceptionally strong aggregate while above 35 would normally be regarded as weak aggregates.

For Impact test, the material (coarse aggregates) is filled in 3 layers where each layer is tamped for 25 numbers of blows. Metal hammer of weight 13.5 to 14 Kg is arranged to drop with a free fall of 38.0 cm by vertical guides and the test specimen is subjected to 15 numbers of blows. The crushed aggregate is allowed to pass through 2.36 mm sieve. And the impact value is measured as percentage of aggregates passing sieve (W_2) to the total weight of the sample (W_1).

$$\text{Aggregate impact value} = \frac{W_2}{W_1} * 100\% \qquad 2.2$$

For aggregates to be used for wearing course, the impact value shouldn't exceed 30 percent.

2.6.4 Specific Gravity (Coarse & Fine Aggregates)

The specific gravity of an aggregate is considered as a measure of the quality of the material in terms of strength. Stones having higher water absorption value are porous and weak. It can be determined by displacement method.

The specific gravity of rock aggregates vary from 2.6 to 2.9, while aggregates having more than 0.6 percent water absorption are considered unsatisfactory.

2.6.5 Effect of Type and Quantity of Fine Aggregate

For dense asphaltic materials, sand/filler/binder mortar can play an important role in determining the resistance to plastic flow. A test of four different types of fine aggregates- flit gravel sand, limestone sand, crushed rock fine, and blast furnace slag fine; carried out by the DSIR, London (1962), showed that smooth gravel sand gave lower resistant to deformation than crushed rock or slag. This could be attributed to surface texture and mineralogical properties of the materials.

2.6.6 Effect of Type and Proportion of Filler

Addition of filler to a binder increases the viscosity and the tensile strength. The elastic moduli of mineral aggregates are higher than those of bituminous binders, so that the stiffness of a mineral-binder matrix is expectedly greater than pure binder. In the rich dense mortar of asphalts, the angle of internal friction is very small and the resistance to deformation comes from the mortar. For such materials and those dense tar surfacings and rolled asphalts with a high content of filler, a study of the flow properties of filler/binder system is of fundamental importance. From tensile, compression, and simple shear tests, it was found that the proportional or relative increase in viscosity of a binder when a mineral filler was added was dependent upon two

physical parameters and was to a first approximation independent of the mineral source of the filler. The two physical parameters were:

- The relative compaction of the filler and
- The effective size of the pore of the compacted filler.

2.6.7 Degree of Compaction

Except mastic asphalt, being of high bitumen content used for roofing, flooring, paving or tanking, all other bituminous materials require to be compacted before they can develop mechanical strength. As shown in table 2.2, the choice of stability or strength is achieved by carefully selecting low bitumen content, dense aggregate grading and applying high compacting effort. It must be noted that compaction is not only that applied by mechanical roller at construction stage but is furthered when the road is opened up to traffic.

2.7 Design Methods For Bituminous Mix

Mix design depends primarily on aggregate gradation and asphalt content. Each of the constituent has a unique function in the asphalt mixture and mix design is the process of ensuring that none of the functions suffer neglect in the overall mixture. However, design procedures which yield paving mixtures embodying all the basic properties- stability, flexibility, durability and skid resistance; are numerous and varying, but sound pavements are constructed where materials and methods are by using time-tested test and specifications as well as engineering judgements to couple with so-called design method (Derrick, 1989).

It must be emphasized that no matter how the road engineer chooses and controls the properties and proportions of materials, fundamental changes due to environmental factors and loading condition deteriorates the structure. The problem of environment can only be minimized by

adopting “dense” surfacing but the traffic forces still remains to be minimized by periodic or routine maintenance.

The desirable characteristics to optimize asphaltic mixtures properties as well as the general requirements for asphalt content, aggregate gradation and degree of compaction, according to Asphalt Institute (1979), are shown in Table 2.2. While a dense gradation with a high degree of compaction will satisfy most of the desirable properties, the choice bitumen content requires a compromise among the various properties. This involves finding basis for the selection of the aggregates, the binder, the filler and test to be utilized.

Table 2.2: Desirable Characteristics to Optimize Mixture Properties

MIXTURE PROPERTIES	BITUMEN CONTENT	AGGREGATE GRADATION	DEGREE OF COMPACTION
Stability	Low	Dense	High
Durability	High	Dense	High
Workability	High	Open	-
Flexibility	High	Open	-
Fatigue Resistance	High	Dense	High
Skid Resistance	Low	Dense/Open	High
Imperviousness	High	Dense	High
Fracture Strength	High	Dense	High

Asphalt Institute (1979)

Noting the dependent nature of the desirable mixture properties of asphaltic surfacing materials on the stability and proportions of the constituents, much of the research of the mechanical behaviours of asphaltic mixtures has been carried out using empirical tests to access the stability or establish suitable proportions for the constituents (Abarshi, M.D., 1988). The focal points of various assessments of pavement mix includes, among other things:

1. To provide some appropriate assessment of the resistance of the material to permanent flow.
2. To determine suitable proportions of constituents and the suitability rating of any given constituents considered.

3. To rate the constituent materials properties in terms of the overall strength and stability as a derivative of the inherent properties of the individual component of the constituents.
4. To control the manufacture of a mix.

Some of the methods used for bituminous mix are Marshall Method, Hveem method, Hubbard-Field method, Superpave method, and Smith triaxial method. Marshall Method has assumed a universal position, but the choice of a particular method depends largely on the availability of equipments, aggregate maximum size, aggregate thickness, test environment (whether on-site or in the laboratory), and bitumen type (liquid and/or penetration grade)

2.7.1 Marshall Method

This method of designing paving mixtures was formulated by Bruce Marshall, formerly bituminous engineer with the Mississippi State Highway Department. Subsequent improvements were done by American Army Corps of Engineers to evolve the mix design criteria. The method is applicable only to hot-mix asphalt paving mixtures using penetration grades of bitumen and containing aggregates with maximum sizes of 1in. (25.4mm) or less. The method may be used for both laboratory design and field control of asphalt paving mixtures in which a cylindrical specimen of 101.6mm in diameter by 63.5mm approximate height is compressed radially at a constant rate of strain of 50.8mm per min. The maximum load sustained by the specimen in kilograms or pounds is recorded as the Marshall Stability value and deformation at failure, in 0.25mm units is recorded as the Marshall Flow value. Marshall Stability value of each specimen is corrected by multiplying by the appropriate corrections factor if there are deviations from the standard 101.8mm diameter and 63.5mm height of a sample. The correction factor is as shown in Table 2.3.

The apparatus consists of a cylindrical mould, 101.6mm diameter and 63.5mm height, with a base plate and collar. A compaction pedestal and hammer are used to compact a specimen of mix proportioned 1.2kg mix (including coarse and fine aggregates, filler and bitumen) by 4.54kg weight hammer from a falling height of 457mm. An extrusion plate is used on the sample extractor to pneumatically remove the sample from the mould.

The coarse aggregates, fine aggregates and filler materials are mixed and preheated to a temperature of 175-190°C. The bitumen is equally preheated to a temperature of 121-145°C and the required quantity according to intended trial amounts (say 4.5, 5.5, 6.5, and 7.5%) is mixed with the aggregate fraction to a temperature of 154 to 160°C. The mould, base plate and the compaction hammer, too, are heated to 93.3 to 148.9°C. The mix is placed in the pre-heated mould at a temperature of 138-149°C and compacted to the required number of blows according to the traffic situation (say 50blows for medium traffic) as shown in table 2.4. Three or four samples may be prepared for trial bitumen content. The diameter and mean height of the specimen are measured and then they are weighed in air and then weighed suspended in water.

The specimens are kept immersed in water in a thermostatically controlled water bath at 60°C for 30 to 40 minutes. The specimens are taken out one by one, placed in the Marshall Test head and tested to determine Stability Value which is the maximum load in kg before failure and Flow Value which is the deformation of the specimen in 0.25mm up to the maximum load.

Essentially, the principal features of the Marshall method are that the following are determined:

- Stability, Flow and Stiffness Value
- Bulk Density
- Voids Analysis

Figure 2.1 illustrates the steps involved in Marshall Test. The values so determine from the test are assessed using the Marshall Criteria according to Asphalt Institute (1979) in Tables 2.4 and 2.5.

Table 2.3: Marshall Stability Correction Ratio (Asphalt Institute, 1979).

Volume of Specimen (cm^3)	Thickness of Specimen (mm)	Correction Ratio
200-213	25.4	5.56
214-225	27.0	5.00
225-237	28.6	4.55
238-250	30.2	4.17
251-264	31.8	3.85
265-276	33.3	3.57
277-289	34.9	3.33
290-301	36.5	3.03
302-316	38.1	2.78
317-328	39.7	2.50
329-340	41.3	2.27
341-353	42.9	2.08
354-367	44.4	1.92
368-379	46.0	1.79
380-392	47.6	1.67
393-405	49.2	1.56
406-420	50.8	1.47
421-431	52.4	1.39
432-443	54.0	1.32
444-456	55.6	1.25
457-470	57.2	1.19
471-482	58.7	1.14
483-495	60.3	1.09
496-508	61.9	1.04
509-522	63.5	1.00
523-535	64.0	0.96
536-546	65.1	0.93
547-559	66.7	0.89
560-573	68.3	0.86
574-585	71.4	0.83
586-598	73.0	0.81
599-610	74.6	0.78
611-625	76.2	0.76

Table 2.4: Typical Marshall Mixture Design Criteria (Asphalt Institute, 1979)

Mix Criteria	Light Traffic (< 10^4 ESALs)		Medium Traffic (10^4-10^6 ESALs)		Heavy Traffic (>10^6 ESALs)	
	Min.	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
Compaction (No. of blows on each end of the samples)	35		50		75	
Stability (Minimum) N	2224		3336		6672	
Flow (0.25mm or 0.01inch) [mm]	8 [2]	20 [5]	8 [2]	18 [4.5]	8 [2]	16 [4]
Percent Air Voids	3	5	3	5	3	5

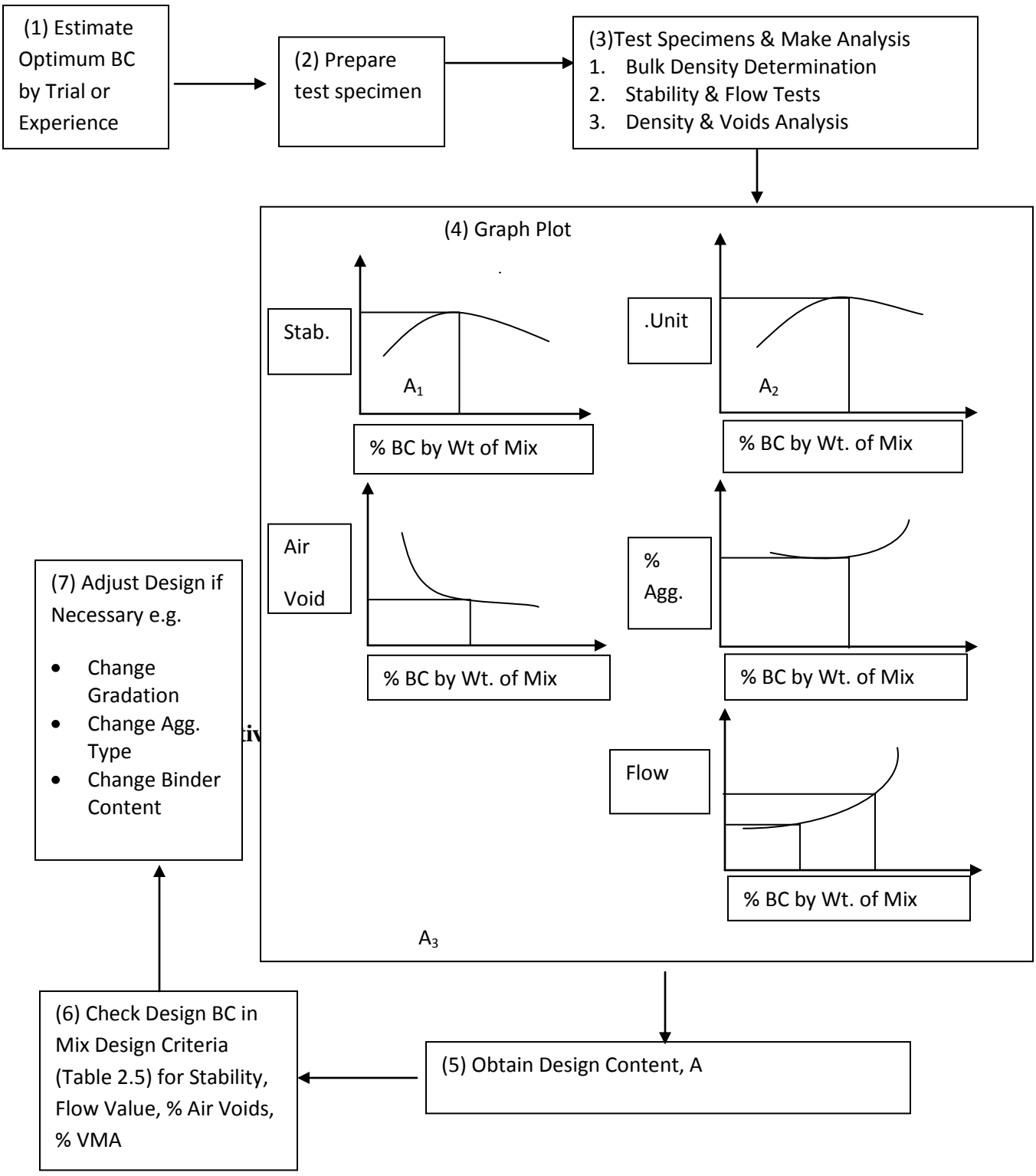


Figure 2.1: Illustrative Steps of Marshall Test (Asphalt Institute, 1979).

Table 2.5: Typical Marshall Minimum VMA (Asphalt Institute, 1979)

Nominal Maximum Particle Size (mm)	(inch)	Minimum VMA (Percent)
63	2.5 inch	11
50	2.0 inch	11.5
37.5	1.5 inch	12
25	1.0 inch	13
19	0.75 inch	14
12.5	0.5 inch	15
9.5	0.375 inch	16
4.75	No. 4 sieve	18
2.36	No. 8 sieve	21
1.18	No.16 sieve	23.5

2.7.1.1 Analysis of Results from Marshall Test

The properties that are of interest include the bulk specific gravity otherwise known as the compacted density of the mix, compacted density of mix aggregate, percentage air voids , percentage void in mixed aggregate, and percent voids filled with bitumen.

The bulk specific gravity G_m or the compacted density of the mix (CMD) is the specific gravity considering air voids and is found by:

$$\text{CMD} = G_m = \frac{Wm}{Wm - Ww} \qquad 2.3$$

Where W_m = Weight of specimen in air

W_w = Weight of specimen in water

Note that $W_m - W_w$ = Volume of mix. Sometimes, when open graded aggregate is used, it is necessary to coat specimens with paraffin wax before measuring weight in water for bulk

specific gravity and this however, requires the calculation of weight and volume of wax to get accurate result.

The compacted density of mixed aggregates (CMDA) is given by:

$$\text{CDMA} = \frac{CDM}{1+{}^{B}/_{100}} \qquad 2.4$$

where B = Bitumen content

The specific gravity of the mixed aggregates (SGMA) is given by:

$$\text{SGMA} = \frac{100}{\frac{Wc}{Gc}+\frac{Wf}{Gf}+\frac{Wmf}{Gmf}} \qquad 2.5$$

where W_c = Weight of coarse aggregate in the total mix

W_f = Weight of fine aggregate in the total mix

W_{mf} = Weight of filler in the total mix

G_c = Apparent specific gravity of coarse aggregate

G_f = Apparent specific gravity of fine aggregate

G_{mf} = Apparent specific gravity of filler

While the specific gravity of the mix (SGM) is calculated by:

$$\text{SGM} = \frac{100}{{}^{Pa}/_{SGMA}+{}^{BC}/_{G_b}} \qquad 2.6$$

where $P_a = 100 - B$ = % aggregate fraction (coarse + fine aggregates + filler)

BC = % binder content

Void in the mix (VIM) is the percentage of air voids by volume in the specimen and is given by:

$$VIM = \frac{(SGM - CDM) * 100}{SGM} \quad 2.7$$

Voids in mineral aggregate, VMA, is the volume of voids in the aggregates and is the sum of air voids and volume of bitumen i.e.

$$VMA = \frac{(SGMA - CDMA) * 100}{SGMA} \quad 2.8$$

Void filled with bitumen, VFB, is the voids in the mineral aggregate frame work filled with the bitumen and is given by:

$$VFB = \frac{(VMA - VIM) * 100}{VMA} \quad 2.9$$

The volumetric analysis of the calculation is illustrated in Figure 2.2:

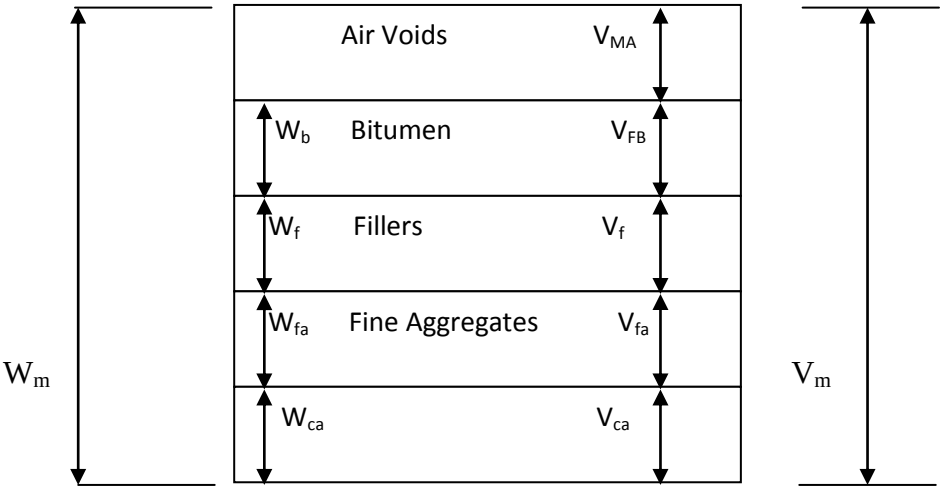


Figure 2.2: Phase Diagram of a Bituminous Mix (Asphalt Institute, 1979).

2.7.1.2 Problems of Marshall Stability

Marshall Stability method provides adequate information required to assess the engineering properties of bituminous pavement surfacing. In addition to the method being a reflection of

strength or stability, the estimated flows is indicative of flexibility, the percent air voids reflects bleeding tendency and degenerative skid problems; and the voids in minerals as well as percent aggregate voids filled with binder are indices of moisture susceptibility and durability. However, some demerits associated with the method are:

i. Actual field condition shows that pressure due to loading is confined which Marshall method does simulate.
ii. The direction of Marshall loading for values of stability and flow negates the mix compaction direction.
iii. The compactor used to stabilize the material is just a fair representation of the actual field rolling process, not an exact similitude.

To remedy the problems above, Abarshi (1988) suggested that Marshall stiffness, which is the ratio of Marshall Stability to Flow could be a better measure of mix stability characteristic at failure. Also, in order to reflect the fracture characteristics of mixture, tensile strength test is recommended. Nevertheless, the aforementioned information of Marshall method – stability, flow, specific gravity, voids in mineral aggregate (VIM) and percentage void filled with bitumen (VFB) are enough to assess the suitability or otherwise of the constituent materials.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Preamble

All the tests were carried out in the department of Civil Engineering, Ahmadu Bello University, Zaria. The materials that were used for this research includes; bitumen, coarse aggregate, ceramic waste aggregate, fine aggregate and ordinary Portland cement. The ceramic waste aggregate used in this research was sourced from a demolished building and rehabilitation of civil engineering department, Ahmadu Bello University.

Ceramic waste is usually available as a waste product from ceramic industries and demolished buildings. The ceramic waste were crushed and subjected to all preliminary tests on coarse aggregates such as sieve analysis (BS 1377), aggregate crushing value test, aggregate impact value test (BS 812), and specific gravity test (ASTM C136).

3.2 Materials

3.2.1. Bitumen: The bitumen was sourced from NNPC refinery, Kaduna and the laboratory test conducted includes; specific gravity, softening point, flash and fire point, solubility, penetration, viscosity and ductility test according to the American Standard of Testing Materials (ASTM), 2005, clauses D70, D36, D92, D4, D5, D4402 and D113 respectively. The characterisation is shown in Table 3.1.

Table 3.1: Characterisation of the Bitumen Utilized

Test	Test Method (ASTM)	Specification by codes for Penetration Grade*			Results Obtained
		40/50	60/70	80/100	
Penetration at 25 °C	D5	40-50	60-70	80-100	70
Softening point (°C)	D36	49-59	46-56	42-51	46.5
Flash point and Fire point (°C) Min.	D92	232	232	219	205
Solubility in trichloroethylene (%) Min.	D2042	99	99	99	99
Specific gravity at 25°C Min.	D70	0.97-1.02	0.97-1.02	0.97-1.02	0.99
Ductility at 25°C Min.	D113	-	50	75	80
Viscosity at 60°C (mm^2/s)	D4402	220-400	120-250	75-150	173

3.2.2. Coarse Aggregate: The coarse aggregates were obtained from quarry site in Zaria, Kaduna state and the laboratory test conducted on the coarse aggregates includes; sieve analysis (BS 1377, [1.2]), water absorption (BS 812 part 2: 1975), particle shape (flakiness and elongation) test (ASTM C33 and BS 812: 1982), aggregate crushing value test (BS 812), aggregate impact value test (BS 812), and specific gravity test (ASTM C136). The characterisation is shown in table 3.2.

3.2.3. Fine Aggregate: The fine aggregate was obtained from a block production industry in Samaru, Zaria, Kaduna State. The fine aggregates sizes ranges from 4.75mm (sieve No. 4 to 75μm (sieve No. 200). The laboratory test conducted on it includes the sieve analysis and the specific gravity test. Characterisation is shown in Table 3.2.

Table 3.2: Characterisation of the Aggregates

Test	Code Used	Result Obtained	Value according to codes
Aggregate Crushing Value (CWA) %	(BS 812 Part 112)	23.3	<30
Aggregate Impact Value (%)	(BS 812 Part 111)	17.8	<30
Aggregate Crushing Value (CA) (%)	BS 812	22.85	<30
Specific Gravity (Coarse Aggregate)	(ASTM C127)	2.67	2.6-2.9
Specific Gravity (CWA) g/cc	(ASTM C127)	2.63	2.6-2.9
Specific Gravity (Fine Aggregate) g/cc	(ASTM C128)	2.65	2.6-2.9
Specific Gravity (Cement) g/cc	ASTM C188	3.15	3.15
Water Absorption (Coarse Aggregate)	ASTM 127	0.3	0.2 – 0.6
Water Absorption (CWA)	ASTM 127	0.6	0.2 – 0.6
Flakiness index (Coarse aggregate)	ASTM C33, BS 812	22	11 -35
Flakiness index (CWA)	ASTM C33, BS 812	29	11 -35
Elongation index (Coarse aggregate)	ASTM C33, BS 812	21	10 – 37
Elongation index (CWA)	ASTM C33, BS 812	32	10 – 37

3.2.4. Mineral Filler: Ordinary Portland Cement was used in the experiment. Some preliminary tests like setting time and soundness tests were carried out on the cement in accordance with the provision of BS EN196, Part 3 (1995). The properties are shown in Table 3.3.

Table 3.3: Summary of Physical Properties of Cement

Test	Code Used	Average result	Code recommendation
Initial Setting Time	BS EN196, Part 3 (1995)	121minutes	> 45minutes
Final Setting Time	BS EN196,Part 3 (1995)	3hrs 26minutes	< 10hours
Specific Gravity Test	BS EN196, Part 3 (1995)	3.15	

3.3 Methodology

3.3.1. Consistency Test

3.3.1.1 Setting Time Test: The test was conducted in accordance with BS EN196, Part 3 (1995) Using Vicat apparatus with steel needle, the Initial and the final setting time was determined by observing the needle penetration into the cement paste of standard consistence inside the mould until it reaches a specified value. The results are shown in Tables 3.4 and 3.5.

Table 3.4: Initial Setting Time of Cement samples

Cement	Starting time	Finishing time	Initial Setting Time (min)
Sample I	10:20am	12.22pm	122
Sample II	10:25am	12.25pm	120
Sample III	10:30am	12:31pm	121
Average	10:25am	12:26pm	121

Table 3.5: Final Setting Time of Cement samples

Cement	Starting time	Finishing time	Final Setting Time (min)
Sample I	10:20am	03:05pm	285
Sample II	10:25am	03:14pm	289
Sample III	10:30am	03:14pm	284
Average	10:25am	03:11pm	286

Specific Gravity Test (g/cm^3): This is the physical properties of the material which is defined by mass of a unit volume of a material substance, expressed as grams per cubic centimetre (g/cm^3). The test was conducted in accordance with BS 4550-3:1978, using the density bottle (Pycnometer method). Table 3.6 shows the specific gravity of the filler. The specific gravity test was also carried out on fine, ceramic waste and coarse aggregate. A pycnometer was filled up with distilled water and weighed as P, the aggregate was measured and placed in the pycnometer, entrapped air was eliminated by rotating the pycnometer on its side and allowed to soak for about 24 hours and weighed as Ps. The aggregate was removed from water and was placed in the

sample into a container , the sample was dried to a constant weight at 110°C, cooled for 1 to 3 hours, and then weigh the oven-dried sample, B. the specific gravity and the percentage of absorption were calculated by the following formulas:

$$\text{Specific Gravity} = \frac{B}{P + B - P_s} \qquad 3.1$$

$$\text{Water absorption} = \frac{(P_s - P)}{B} * 100\% \qquad 3.2$$

This was done in accordance with ASTM C127. Tables 3.7, 3.8 and 3.8b show the details.

Table 3.6: Specific Gravity of Filler

Serial No.	Observation	Trial 1	Trial 2
1.	Weight of Specific gravity bottle, W_1 (g)	28.5	28.5
2.	Weight of Specific gravity bottle and dry sample W_2 (g)	54.8	55.3
3.	Weight of Specific gravity bottle + Cement Samples + Kerosene W_3 (g)	87.07	87.57
4	Weight of Specific gravity bottle and Kerosene W_4 (g)	69.2	69.2
5	Weight of Cement Samples only A (g) = $W_2 - W_1$	26.3	26.8
6	Weight of Kerosene used B (g) = $W_3 - W_2$	32.27	32.27
7	Weight of Kerosene only C (g) = $W_4 - W_1$	40.7	40.7
8	Specific gravity of the Cement Sample = A/(C-B)	3.12	3.18
9	Average Specific gravity	3.15	

Table 3.7: Specific gravity of fine aggregates

Total Weight of the sample = 500g	TRIAL		
SPECIMEN	**I**	**II**	**III**
Wt of pycnometer + water (P)	1280	1280	1280
Wt of Sand + pycnometer + water (P_s)	1580	1584	1580
Wt of Sand (B)	500g	500	500
Specific gravity = $\frac{B}{P + B - P_s}$	2.60	2.65	2.60
Average Specific gravity		2.65	

Table 3.8: Specific gravity of coarse aggregate

Weight of the sample (g)	**TRIAL**		
SPECIMEN	**I**	**II**	**III**
Wt of glass jar + water (P)	2520	2520	2520
Wt of Sample +glass jar + water (P_s)	3150	3142	3156
Wt of Sample (B)	1000	1000	1000
Specific gravity = $\frac{B}{P + B - P_s}$	2.76	2.65	2.69
Average Specific gravity		2.67	

Table 3.8b: Specific gravity of ceramic aggregate

Weight of the sample (g)	**TRIAL**		
SPECIMEN	**I**	**II**	**III**
Wt of glass jar + water (P)	2120	2010	2090
Wt of Sample +glass jar + water (P_s)	3100	3045	3080
Wt of Sample (B)	1860	1700	1890
Specific gravity = $\frac{B}{P + B - P_s}$	2.62	2.64	2.64
Average Specific gravity		2.63	

3.3.1 Aggregates (Coarse and Ceramic waste)

The ceramic waste was obtained from a landfill and from renovation works carried out at the department of Civil Engineering, Ahmadu Bello University, Zaria. The waste ceramics sample were pulverized, washed and air dried to remove impurities. To ascertain its suitability, the following analysis were carried out: particle size distribution analysis, specific gravity, water absorption, flakiness and elongation index, aggregate crushing and impact value test. The Tables 3.9, 3.10, 3.11, 3.12, 3.13 show the details in accordance to BS 812 part110; 1990.

Table 3.9: Aggregate impact value Analysis

Specimen	**I**	**II**
Wt of Sample A (g)	500	500
Wt of samples remaining after weighing B (g)	130	144
Wt of sample passing sieve 2.36mm C (g)	65	64
AIV = $\frac{C}{(A - B)} \times 100$ (%)	17.6	18.0
Average AIV (%)	**17.8**	

Table 3.10: Aggregate crushing value Analysis

Specimen	I	II
Wt of Sample A (g)	5000	5000
Wt of left over sample B (g)	1630	1300
Wt of sample passing sieve 2.36mm C (g)	889	754
ACV = $\frac{C}{(A-B)} \times 100$ (%)	26.3	20.3
Average ACV (%)	23.3	

Table 3.11: Coarse Aggregate Sieve Analysis

BS Sieve Size	Cumulative Percent passing
1" (25.4mm)	100.00
¾" (19mm)	95.8
½" (12.7mm)	64.53
3/8" (9mm)	43.20
¼" (6mm)	22.87
(4.76mm)	13.80
No.7 (2.36mm)	0

Table 3.12: Ceramic waste Aggregate Sieve Analysis

BS Sieve Size	Cumulative Percent passing
1" (25.4mm)	100.00
¾" (19mm)	96.80
½" (12.7mm)	63.07
3/8" (9mm)	40.40
¼" (6mm)	23.90
(2.76mm)	14.4
No.7 (2.36mm)	0

Table 3.13: Fine Aggregate Sieve Analysis

BS Sieve Size	Cumulative Percent passing
¼" (6mm)	100
No.7 (2.36mm)	90.43
No.14 (1.18mm)	60.48
No.25 (0.60mm)	38.91
No.52 (0.30mm)	20.33
No.100 (0.15mm)	9.79
No.200 (0.075mm)	3.20
Pan	0.00

Table 3.14: Proportioning and combination of aggregates and filler

BS Sieve Size	Coarse Aggregate %Retained x (55%)	Fine Aggregate %Retained x (37%)	Filler % Retained x (8%)	Material Summation (%)	Cumulative Material Passing (%)
R25.4	-	-	-	-	**100**
P25.4 – R19	4.2*0.55 =2.31	-	-	2.31	**97.69**
P19 – R12.7	31.27*0.55 = 17.1985	-	-	17.1985	**80.49**
P12.7 – R9.5	21.33*0.55 = 11.7315	-	-	11.7315	**68.76**
P9.5 - R6	20.33*0.55 = 11.18	-	-	11.18	**57.58**
P6 – R4.76	9.07*0.55 = 4.99	-	-	4.99	**52.59**
P4.76 – R2.36	13.8*0.55 = 7.59	9.57*0.37 = 3.54	-	11.13	**41.46**
P2.36 – R1.18	-	29.95*0.37 = 11.0815	-	11.0815	**30.38**
P1.18 – R0.60	-	21.57*0.37 = 7.9809	0.98*0.08 = 0.078	8.059	**22.32**
P0.60 – R0.3	-	18.58*0.37 =6.8746	0.8*0.08 =0.064	6.9386	**15.38**
P0.30 – R0.15	-	10.54*0.37 =3.8998	3.81*0.08 =0.3048	4.2046	**11.18**
P0.15 – R0.075	-	6.59*0.37 = 2.4383	12.64*0.08 = 1.0112	3.4495	**7.73**
P0.075 – Pan	-	3.20*0.37 = 1.184	82.34*0.08 = 6.5872	7.7712	

Table 3.14b: Proportion of material fractions in mix design

Aggregate Fraction	Aggregate Percentage
Coarse aggregate	55
Fine aggregate	37
Filler	8

Source: (Otuoze 2014).

Thus, in the bituminous mix considering the percentage mix given earlier, it implies that the coarse/CWA aggregates constitute 55 percent, fine aggregates will constitute 37 percent and filler (cement) will constitute 8 percent. Consequent upon this result, the combination of coarse aggregate, fine aggregate, and filler in the mix is the summation of the percentage of individual materials retained on the particular sieve having passed the larger sieve. The details of these are shown in appendix.

3.4 Marshall Mix Design

The aggregates (conventional aggregates and ceramic waste aggregate) were first dry sieved, into the desired size fractions. The amount of each size fraction required to produce a batch that will give a high compacted specimen is then weighed in a separate pan for each test specimen; this is about 1.2 kg of dry aggregates. Three specimens were prepared for each combination of aggregates and bitumen. The pans were then placed in an oven until the dry aggregates achieved the required mixing temperature. When the batched aggregates as shown in Plate II have reached the mixing temperature, a mixing bowl was charged with the heated aggregates, the required quantity of bitumen was added, and mixing was carried out as shown Plate III until all the aggregate particles are fully coated. For light design traffic category which was designed for, 35 blows were applied, with the compaction hammer to each end of the specimen. After compaction, the specimens were allowed to cool in air at room temperature as shown in Plate IV until no deformation results when removing each from the mould. Each compacted test specimen is subjected to the stability and flow test, density and voids analysis as shown in Plate V. For the stability and flow testing, the specimens were immersed in a water bath at 60^{o}C for 30 to 40 minutes. The Marshall testing machine, a compression testing device, was designed to apply loads to test specimens through cylindrical segment testing heads at a constant rate of vertical strain of 51 mm per minute. Loading was applied until specimen failure occurs. The Marshall

testing machine is equipped with a calibrated proving ring for determining the applied testing load. The force in Newton required to produce failure of the test specimen was recorded as its Marshall Stability value and the magnitude of deformation of the specimen at the point of failure was recorded as the flow value. The point of failure was defined by the maximum load reading obtained. Samples were prepared according to Marshall Method using the mix proportion shown in Table 3.14. The result of the parameters estimated from the specimen which includes stability, flow, compacted density of the mix (CDM), void in the mix (VIM), voids in mineral aggregates (VMA) and voids filled with bitumen are summarized and presented in Tables 3.15 – 3.26.



Plate II: Batching of Aggregates by Weight



Plate III: Mixing of Batched Aggregates



Plate IV: Compacted Specimen



Plate V: Marshall Stability Test

Table 3.15: Summary of Marshall Analysis at 0% CWA/100% CA (Control)

Bitumen Content (%)	Stability (kN)	Flow (mm)	CDM (g/cm^3)	VIM (%)	VMA (%)	VFB (%)
5	3.66	2.30	2.20	4.2	17.53	61.49
5.5	3.63	2.33	2.21	4	17.99	71.93
6	4.00	2.53	2.17	3.85	19.46	65.33
6.5	3.65	2.88	2.09	3.66	22.16	61.17
7	3.38	3.03	2.00	3.5	25.77	50.16

Table 3.16: Summary of Marshall Analysis at 10% CWA/90% CA

Bitumen Content (%)	Stability (kN)	Flow (mm)	CDM (g/cm^3)	VIM (%)	VMA (%)	VFB (%)
5	3.62	2.21	2.33	4.5	12.51	91.45
5.5	3.54	2.24	2.38	4.2	11.53	114.85
6	3.94	2.54	2.24	3.92	16.70	78.70
6.5	3.44	2.87	2.07	3.8	23.04	55.44
7	3.18	3.02	1.89	3.68	29.67	41.28

Table 3.17: Summary of Marshall Analysis at 20% CWA/80% CA

Bitumen Content (%)	Stability (kN)	Flow (mm)	CDM (g/cm^3)	VIM (%)	VMA (%)	VFB (%)
5	3.83	2.27	2.01	4.8	24.49	40.31
5.5	3.63	2.37	2.06	4.52	23.13	47.92
6	4.00	2.48	1.95	4.25	27.62	41.36
6.5	3.65	2.57	1.88	4	30.54	39.00
7	3.38	2.77	1.80	3.8	33.7	36.59

Table 3.18: Summary of Marshall Analysis at 30% CWA/70% CA

Bitumen Content (%)	Stability (kN)	Flow (mm)	CDM (g/cm^3)	VIM (%)	VMA (%)	VFB (%)
5	3.77	2.28	1.90	5.9	28.83	32.27
5.5	3.75	2.50	2.00	5.2	25.47	46.17
6	3.91	2.65	1.80	4.9	32.96	32.10
6.5	3.60	2.88	1.75	4.5	34.97	32.38
7	3.39	2.89	1.73	4.35	35.62	31.47

Table 3.19: Summary of Marshall Analysis at 40% CWA/60% CA

Bitumen Content (%)	Stability (kN)	Flow (mm)	CDM (g/cm^3)	VIM (%)	VMA (%)	VFB (%)
5	3.71	2.22	1.82	8.2	31.57	28.34
5.5	3.71	2.50	1.88	7.85	29.65	34.22
6	3.93	2.63	1.83	7.45	31.89	33.71
6.5	3.65	2.70	1.81	6.5	33.04	34.74
7	3.42	3.20	1.80	5.89	33.61	36.58

Table 3.20: Summary of Marshall Analysis at 50% CWA/50% CA

Bitumen Content (%)	Stability (kN)	Flow (mm)	CDM (g/cm^3)	VIM (%)	VMA (%)	VFB (%)
5	2.28	2.08	1.83	10.8	31.20	28.83
5.5	2.54	2.41	1.84	10.5	31.62	34.13
6	3.59	2.48	1.82	9.65	32.35	33.01
6.5	3.30	2.58	1.81	8.8	32.71	35.83
7	2.37	2.33	1.79	7.5	33.61	34.40

Table 3.21: Optimum parameters for 0% CWA and binder content

Optimum Parameter	Value	Optimum Binder Content (%)
Stability (kN)	4.0	6.0
CDM (g/cm^3)	2.21	5.5
VIM (%)	4.0	5.5
Average Binder Content		5.7

Table 3.22: Optimum parameters for 10% CWA and binder content

Optimum Parameter	Value	Optimum Binder Content (%)
Stability (kN)	3.94	6.0
CDM (g/cm^3)	2.38	5.5
VIM (%)	4.0	5.9
Average Binder Content		5.8

Table 3.23: Optimum parameters for 20% CWA and binder content

Optimum Parameter	Value	Optimum Binder Content (%)
Stability (kN)	4.0	6.0
CDM (g/cm^3)	2.06	5.5
VIM (%)	4.0	6.5
Average Binder Content		6.0

Table 3.24: Optimum parameters for 30% CWA and binder content

Optimum Parameter	Value	Optimum Binder Content (%)
Stability (kN)	3.91	6.0
CDM (g/cm^3)	2.0	5.5
VIM (%)	4.0	-
Average Binder Content		5.8

Table 3.25: Optimum parameters for 40% CWA and binder content

Optimum Parameter	Value	Optimum Binder Content (%)
Stability (kN)	3.93	6.0
CDM (g/cm^3)	1.88	5.5
VIM (%)	4.0	-
Average Binder Content		5.8

Table 3.26: Optimum parameters for 50% CWA binder content

Optimum Parameter	Value	Optimum Binder Content (%)
Stability (kN)	3.59	6.0
CDM (g/cm^3)	1.84	5.5
VIM (%)	4.0	-
Average Binder Content		5.8

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction: Having presented the materials and methods to carry out the research, the properties of constituent materials used which includes Cement, fine aggregates, coarse aggregates and CWA as compared with their standard requirement as per codes specification and the results and discussion are presented in the following sections.

4.1.1 Tests on Bitumen: Table 3.1 shows the characteristics of the preliminary test carried on the bitumen and it shows that the penetration grade bitumen is within 60mm minimum to 70mm maximum penetration grade. Hence, the Bitumen used is 60/70 type. The specific gravity which is 0.99 shows that it belongs to the grade 60/70 bitumen. The test values are within the range specified in the Nigerian general specification (1990).

4.1.2 Properties of Filler

The properties of cement as compared with standard specifications are presented in Table 3.3. It shows that the cement samples satisfies the provision of code of practice in term of consistency, Initial and final setting time, specific gravity and soundness.

Therefore, the filler used satisfied the code specifications for ordinary Portland cement.

4.1.3 Aggregate (Fine, Coarse and Ceramic waste aggregate)

The aggregate physical properties are within the code limit and can be used for bitumen mixing.

4.1.4 Particle Size Distribution for Aggregates

The graphs of particle size distribution performed on the aggregates and fillers are presented in figures 4.1 to 4.4. These comparisons show that the materials are well graded and proportioned for the mix design.

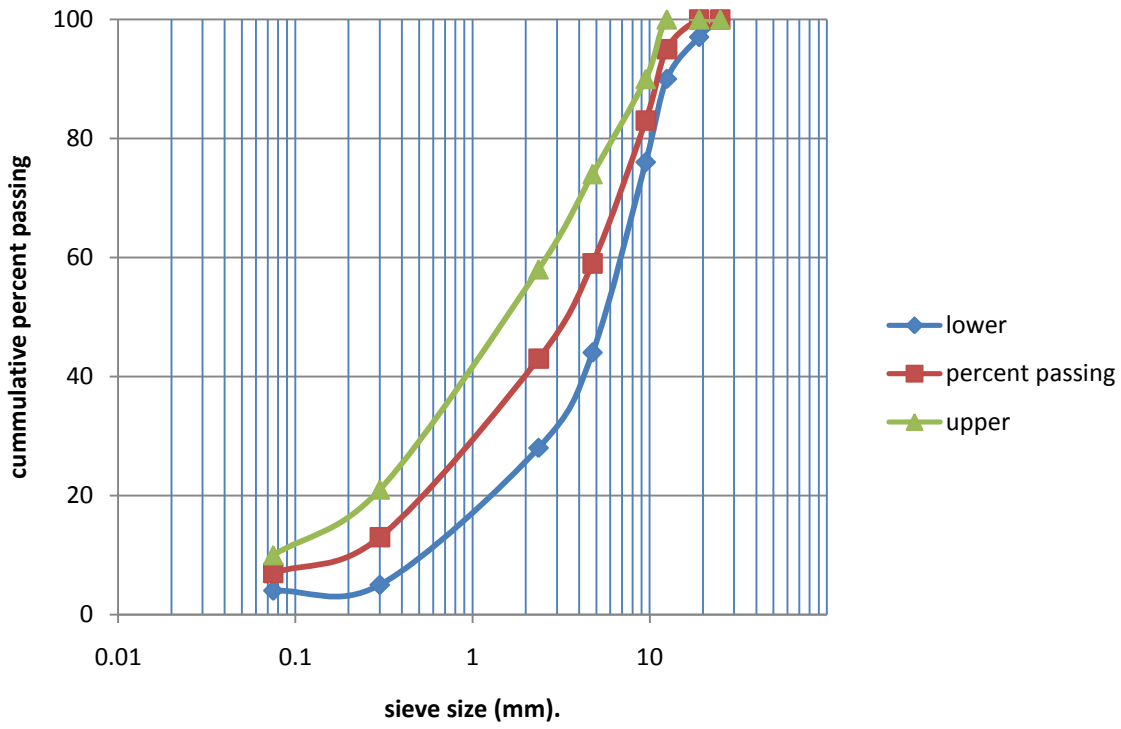


Figure 4.1: Particle Size Distribution Curve - Coarse Aggregate

The above graph shows the particle size distribution curve of the conventional coarse aggregates which shows that the grading falls within the limit. This implies that the aggregate is suitable for the design.

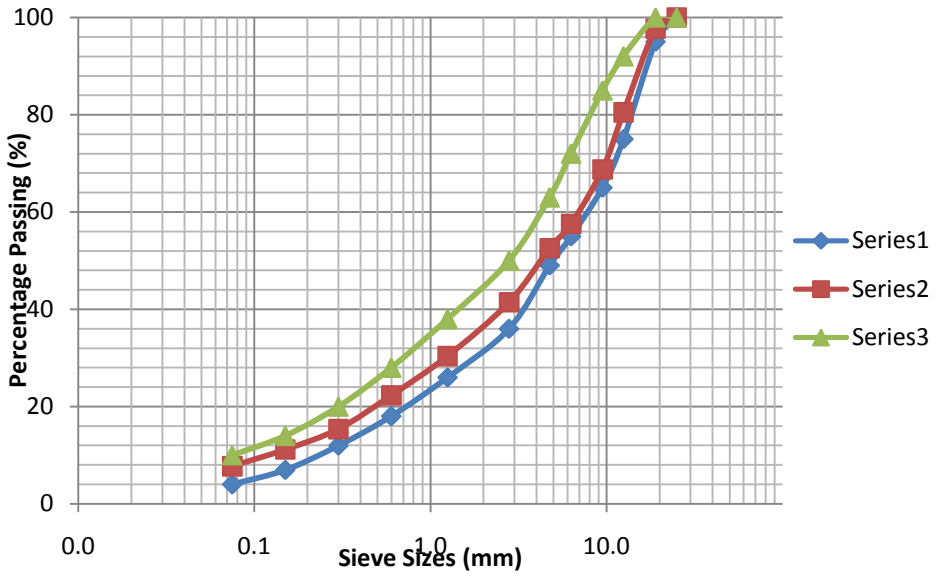


Figure 4.2: Particle Size Distribution Curve of Ceramic waste Aggregate

The particle size distribution of the ceramic waste aggregates shown in Fig. 4.2 shows the particle size distribution curve of the ceramic waste aggregates which shows that the grading also falls within the limit. This implies that the aggregate is also suitable for the design in accordance to BS 812: Part 103; 1985.

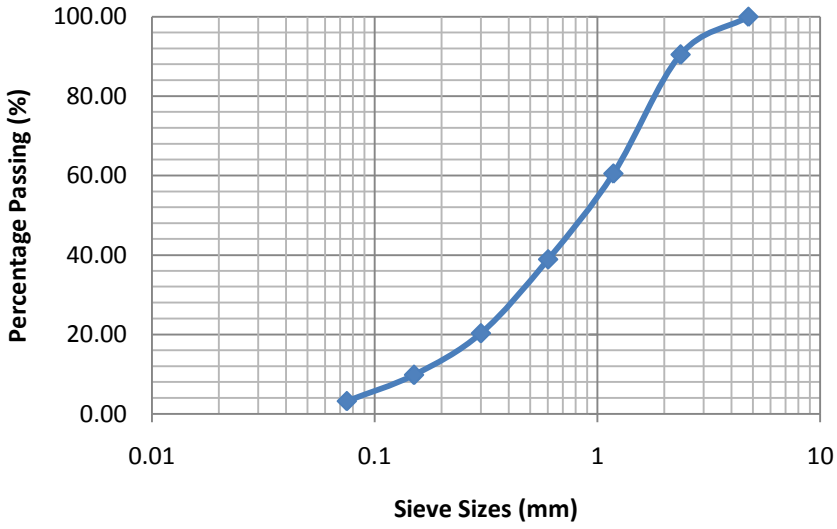


Figure 4.3: Particle Size Distribution curve of Fine Aggregate

Figures 4.3 and 4.4 are the particle size distribution of both the fine aggregate and the filler, respectively. The curves are in conformity with the required criteria as given in BS 812: Part 103; 1985.

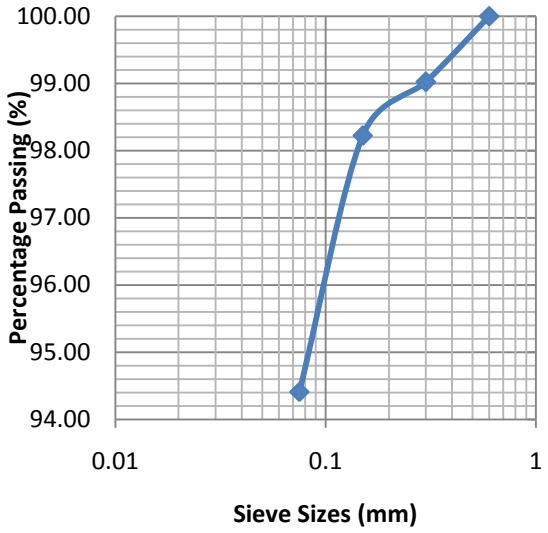


Figure 4.4: Particle Size Distribution curve - (Filler)

4.2 Effect of Ceramic Waste Aggregate on Stability

The stability of the asphalt concrete without CWA was 4kN. On addition of 10% CWA, the stability value decreased to 3.94kN, this decrease may be attributed to the low specific gravity of CWA of 2.63 as compared to the specific gravity of coarse aggregate of 2.67. However, with increasing CWA up to 20%, maximum stability value of 4kN was achieved; this could be due to the high aggregate crushing value of the CWA of 23.3 which exceeds the aggregate crushing value of the coarse aggregate of 22.85. The relationship between Stability and Ceramic Waste Aggregate is shown in Figure 4.5.

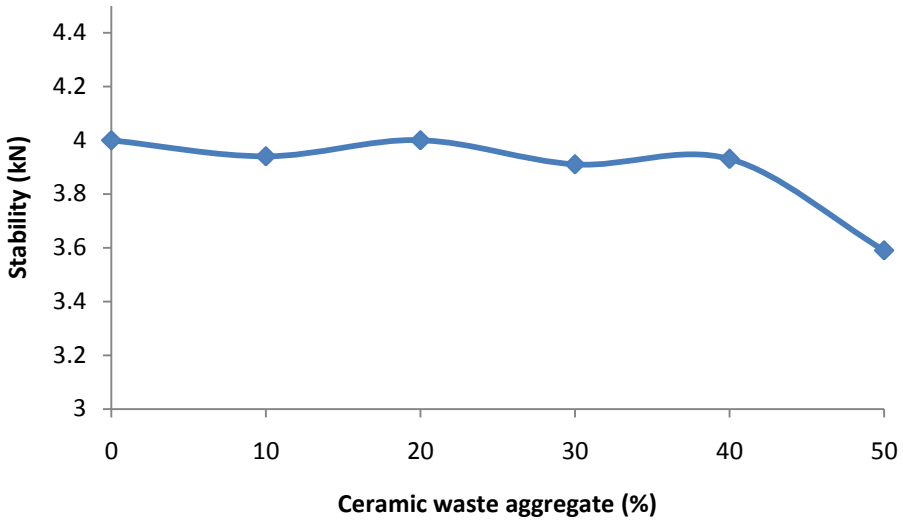


Fig 4.5: Variation of Stability with Ceramic waste aggregate content

4.3 Effect of ceramic waste aggregate on flow

The flow values decreased with increase in CWA content from 0% to 20%, this could be due to the flakiness index of CWA which was obtained to be 29 as compared to 22 which eased the bonding at 20% CWA. However, as the percent of CWA increased, the flow increased, this may be as a result of the elongation index of the CWA obtained to be 32 as compared to 21 of coarse aggregate which led to an increase in the flow values. The relationship between Flow and Ceramic Waste Aggregate is shown in Figure 4.6.

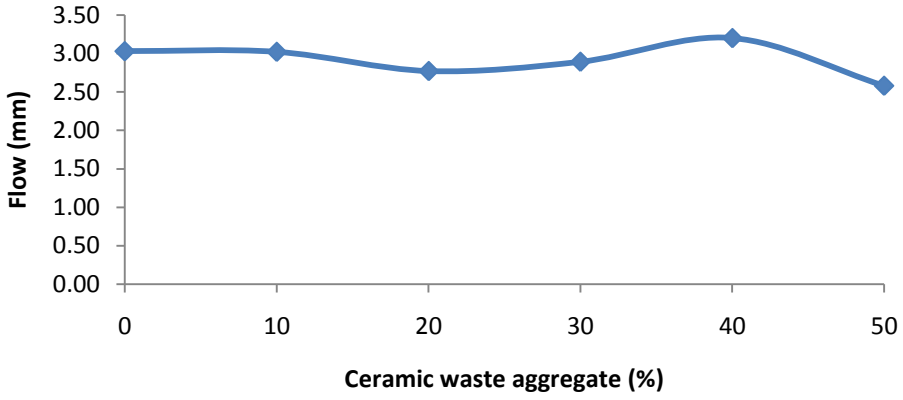


Fig 4.6: Variation of Flow with Ceramic waste aggregate content.

4.4 Effect of ceramic waste aggregate on compacted density of mix (CDM)

The compacted density of mix of the sample decreased with increasing CWA content. This may be due to the specific gravity of CWA of 2.63 as against the specific gravity of coarse aggregate of 2.67 and the higher flakiness index of ceramic waste aggregate of 29 as against the flakiness of the coarse aggregate of 22. The relationship between compacted density mix and Ceramic Waste Aggregate is shown in Figure 4.7.

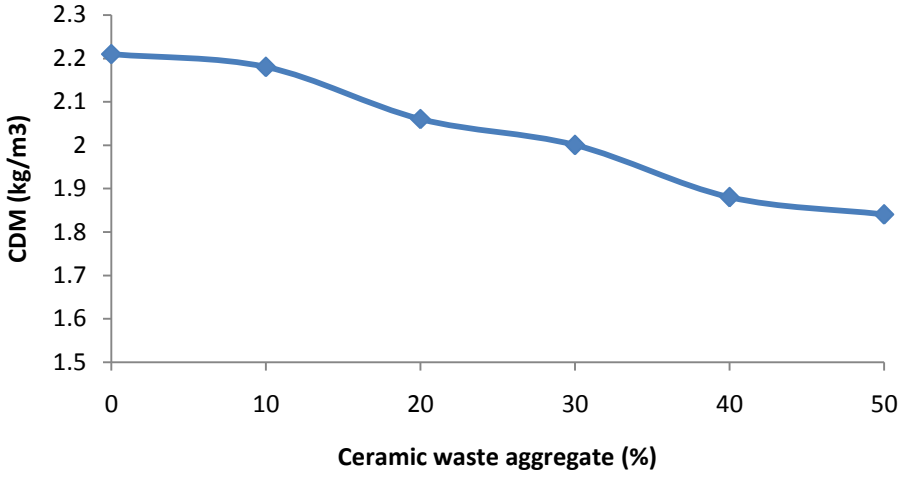


Fig 4.7: Variation of Compacted density with the percentage of CWA content

4.5 Effect of ceramic waste aggregate on voids in total mix (VIM)

The air voids increased as the percentage of the ceramic waste aggregate increased, this could be as result of the flakiness and elongation index of CWA of 29 and 32 respectively as against 22 and 21 of coarse aggregate, due to the higher elongation index, as the percent of the ceramic waste aggregate increases, the bond gives way which increases the void in mix of sample having higher percent of CWA as compare to sample of 0% CWA. The relationship between voids in total mix and Ceramic Waste Aggregate is shown in Figure 4.8.

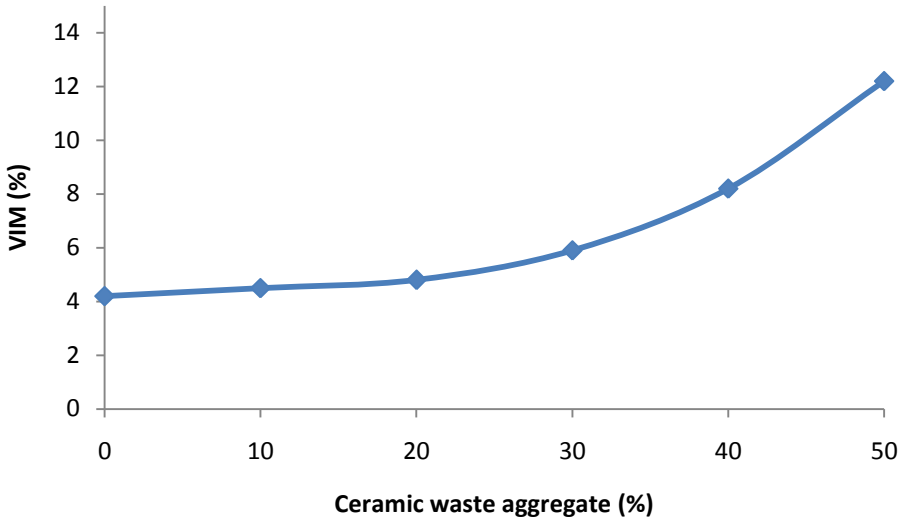


Fig 4.8: Variation of VIM with percentage of CWA.

4.6 Effect of ceramic waste aggregate on the voids in mineral aggregate (VMA)

The voids in mineral aggregate increased as the content of the ceramic waste aggregate increased, this may be attributed to what happened to the voids in total mix as the flakiness and elongation index of the ceramic waste aggregate which is 29 as against 22 of coarse aggregate, affects the bonding and interlocking of the aggregate mix. The ceramic waste aggregate having higher flakiness and elongation index does not have a perfect interlock as the CWA increases in the mix thereby creating more voids. The relationship between voids in mineral aggregate and Ceramic Waste Aggregate is shown in Figure 4.9.

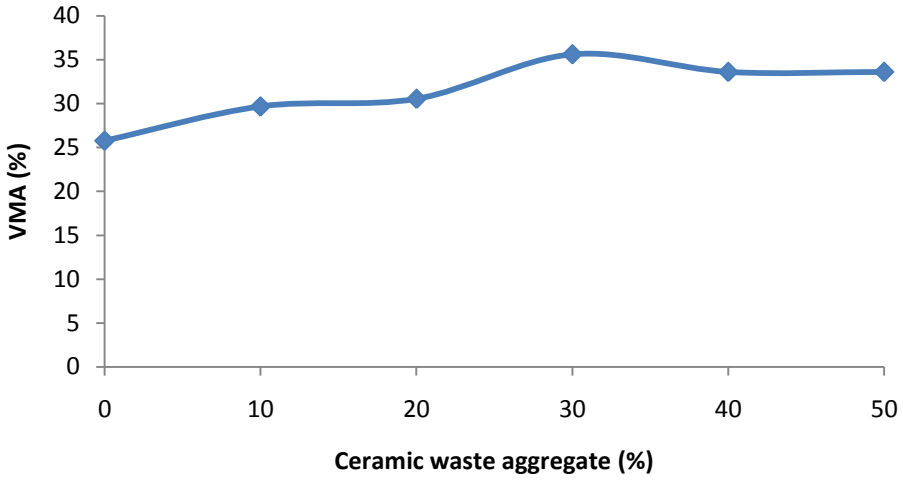


Fig 4.9: Variation of VMA with percentage of CWA.

4.7 Effect of ceramic waste aggregate on voids filled with bitumen (VFB)

The VFB increased steadily as the ceramic waste increased, the steady increased in voids could be attributed the percentage of bitumen in the mix but the property of the increased ceramic waste aggregate create a larger voids not totally filled by the bitumen this shows that the ceramic waste increased the strength decreases as a result of large voids in the mix. The relationship between voids filled with bitumen and Ceramic Waste Aggregate is shown in Figure 4.10.

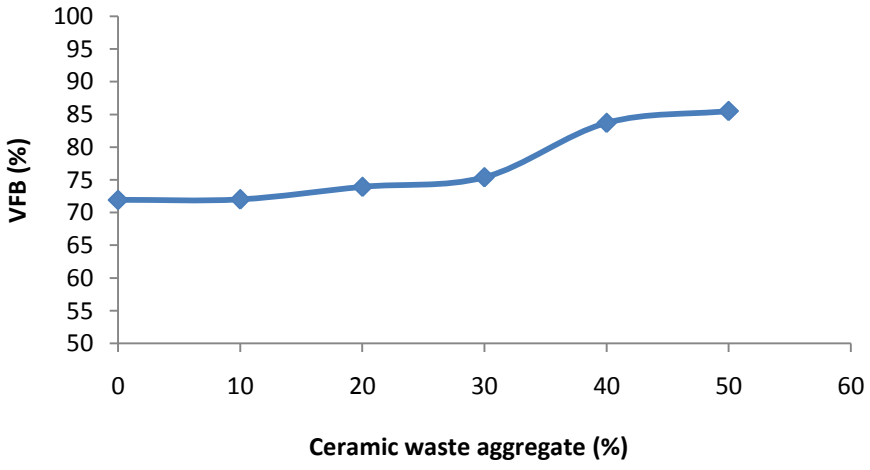


Fig 4.10: Variation of VFB with percentage of CWA.

4.8 Optimum Bitumen Content

Bitumen or binder content is a very important parameter in Marshall Mix design. The basic parameters in mix design are selected and the corresponding binder content was determined. Such parameters include Stability, CDM and VIM. The above parameters and their corresponding averages of bitumen contents for various CWA contents are shown in Tables 3.21 to 3.26. According to the Nigerian general specification for roads and bridges, it shows that as the ceramic waste aggregate increases the void in total increases which decreases the stability and also the average optimum bitumen content cannot be obtained because the VIM is beyond the optimum parameter value speculated that is 4%.

The Combined Graphs: The combined graphs for the various parameters discussed are shown. Figure 4.11 shows that as the bitumen content increases the stability increases to optimum bitumen content of 6.0% then decreases for all content of the ceramic waste aggregate. This is attributed to the strength property (aggregate crushing and impact value) of the ceramic waste content mix with the bitumen but due to the density property (specific gravity) of the ceramic waste which is lesser compare to the coarse aggregate, as the bitumen content increases with increase in ceramic waste, the stability of the sample decreases, note that the highest CWA content had the lowest stability.

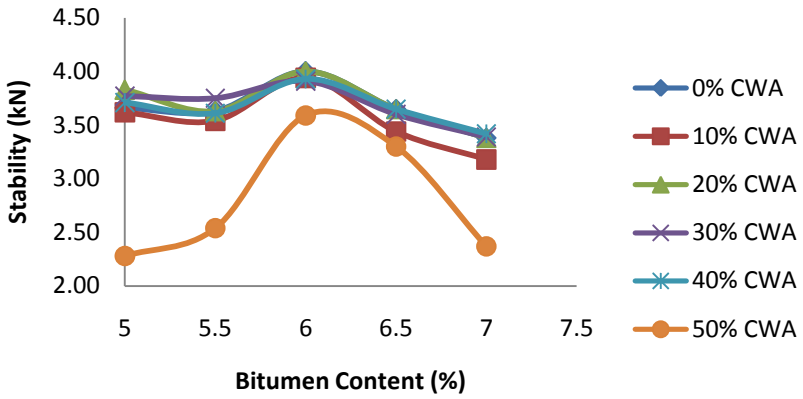


Figure 4.11: Variation of Stability with bitumen content at varying CWA content

Figure 4.12 shows, the flow increasing with increasing bitumen content for all percentage of the ceramic waste aggregate except for the 50% CWA where the flow increases and later decreases with increasing bitumen content which may be as a result of the stiffness of the bitumen in the mix, when the mixes becomes less flexible and the resistance to deformation increases then the flow value decreases.

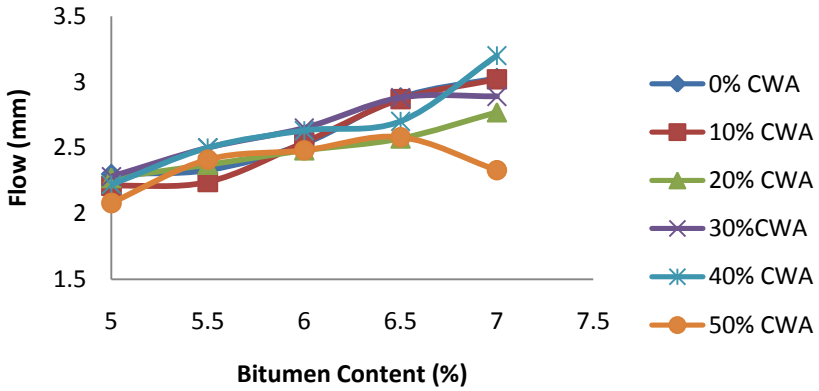


Figure 4.12: Variation of Flow with bitumen content at varying CWA content

Figure 4.13 shows that the density of the mix increased slightly as the bitumen content increased at 5.5% then later decreased subsequently with increasing the bitumen content. The initial increase at 5.5% bitumen content may be attributed to the absorption rate and strong bonding

between the aggregate but as the bitumen content increased and the CWA content increased the bond elapse which leads to less density. Thereby, for the decrease implies that as the bitumen content increased there was no one on one contact of the aggregate particles and as load was transmitted by hydrostatic pressure through the bitumen, the strength of the mix reduced.

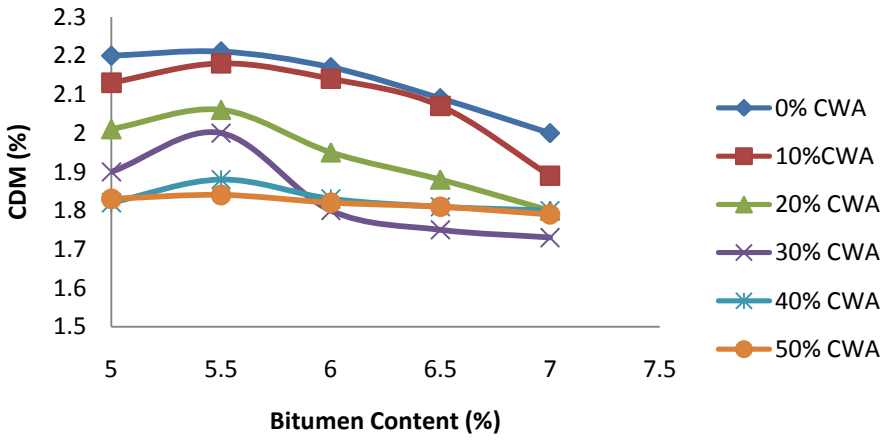


Figure 4.13: Variation of CDM with bitumen content at varying CWA content

Voids in air decreased as the bitumen content increased as shown in Fig. 4.14, at 5% bitumen content as the ceramic waste aggregate content exceeds 20% CWA the voids in air increases to the extent of exceeding the maximum property of voids in total mix specified by the Nigerian Specification for Roads and Bridges. These may be due to the low specific gravity of the CWA. From the graph, it can also be observed that at the optimum air void which is 4%, for content of ceramic waste aggregate above 20%, there was no corresponding optimum bitumen content.

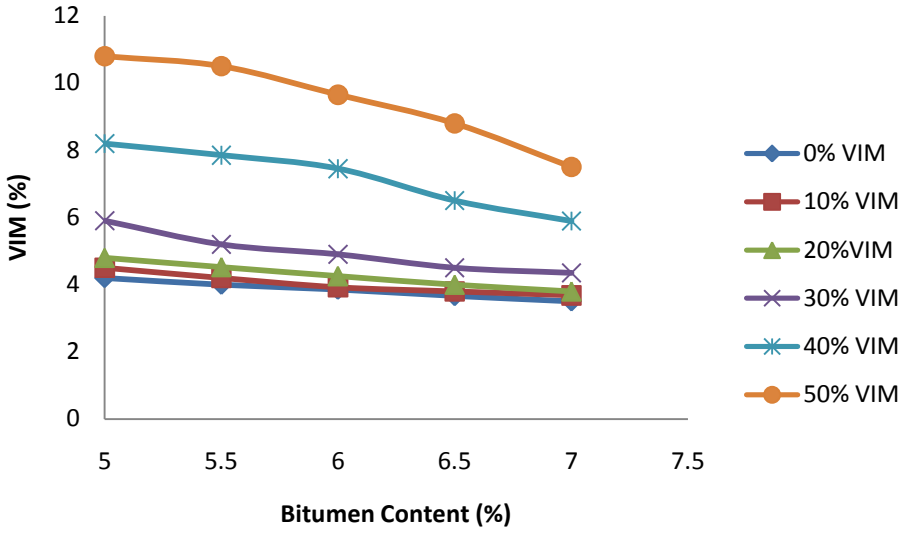


Figure 4.14: Variation of VIM with bitumen content at varying CWA content

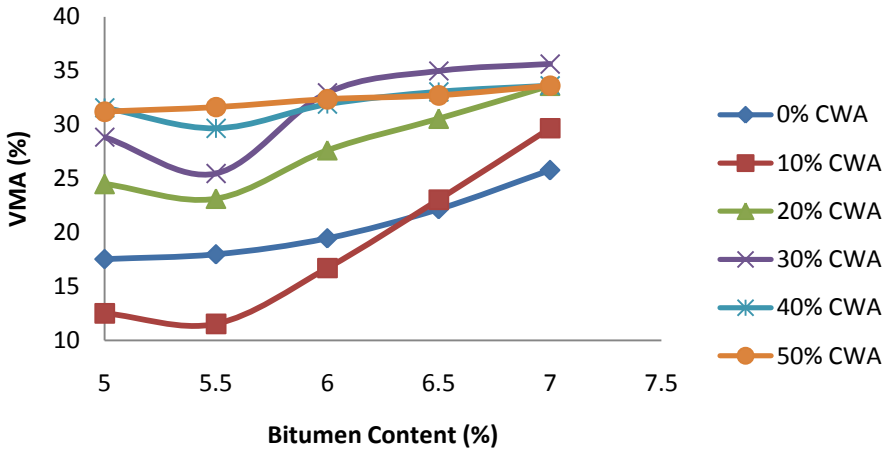


Figure 4.15: Variation of VMA with bitumen content at varying CWA content

The Voids in mineral aggregate and Voids filled with bitumen increased with increasing bitumen content as shown in Fig. 4.15 and 4.16 respectively. The increased in voids for the mix may be as a result of the low specific gravity of the ceramic waste aggregate and the decreased of the bitumen thickness between the aggregate which may lead to high temperature cracking and low durability of the asphalt concrete.

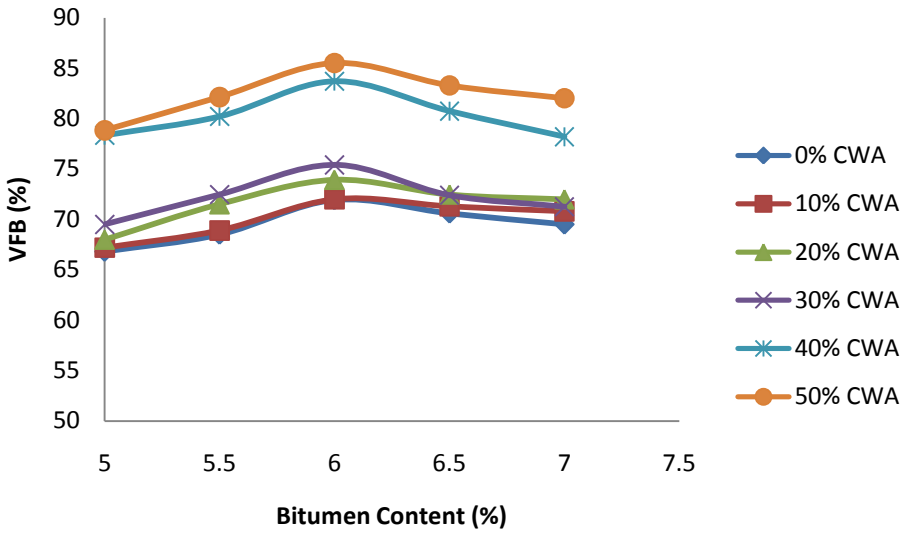


Figure 4.16: Variation of VFB with bitumen content at varying CWA content

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

From the test results as well as the analysis and discussion in chapter four, the following conclusion can be made.

1. From the results of physical properties tests carried out on the coarse and fine aggregates, and the ceramic waste aggregates, it was observed that the values obtained are within the limit specified by ASTM 127 (2013) with ceramic waste aggregate and coarse aggregate having specific gravity of 2.63kg/m^3 and 2.67kg/m^3 respectively, flakiness and elongation index as 29% and 32%, 22% and 21% respectively, water absorption as 0.6% and 0.3% respectively.
2. The consistency test performed on the bitumen used, showed that it is of 60/70 grade and can be used for bituminous mix design.
3. Inclusion of ceramic waste aggregates at 20% gave optimum stability of 4kN at optimum bitumen content of 6%.
4. At 20% ceramic waste aggregates, the stability, the flow value, void in total mix and the void filled with bitumen values are 4kN, 2.48mm, 4.25% and 73.93% respectively corresponding to the standard speculated by the Nigeria General Specification for Roads and Bridges (1990).

5.2 Recommendation

Based on results of investigations carried out, the partial replacement of Coarse aggregate with 20% CWA is recommended for use in the production of asphalt for lightly trafficked Highway. The use of CWA as coarse aggregate could reduce construction cost.

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APPENDIX

I: Filler Sieve Analysis Result

BS Sieve Size	Cumulative Percent passing
No.14 (1.18mm)	100
No.25 (0.60mm)	99.02
No.52 (0.30mm)	98.22
No.100 (0.15mm)	94.41
No.200 (0.075mm)	81.77
Pan	0.00

II: Sieve Analysis of Fine Aggregate

Weight of Sample = 1200g

SIEVE SIZE (mm)	WEIGHT RETAINED (g)	PERCENTAGE RETAINED (%)	PERCENTAGE CUMULATIVE RETAINED (%)	PERCENTAGE PASSING (%)
6.35	0	0	0	100
4.75	102	8.5	8.5	91.5
2.36	135	11.25	19.75	80.25
1.18	219	18.25	38	62
0.60	249	20.75	58.75	41.25
0.30	380	31.67	90.42	9.58
0.15	79.6	6.63	97.05	2.95
Pan	35.4	2.95	100	0

III: Sieve Analysis of Coarse aggregate
Weight of Sample = 3000g

SIEVE SIZE (mm)	WEIGHT RETAINED (g)	PERCENTAGE RETAINED (%)	PERCENTAGE CUMULATIVE RETAINED (%)	PERCENTAGE PASSING (%)
38.1	0	0	0	100
19.05	126	4.2	4.2	95.8
12.7	928	30.93	35.13	64.87
9.52	640	21.33	56.46	43.54
6.35	700	23.33	79.79	20.21
4.76	272	9.07	88.86	11.14
Pan	334	11.14	100	0.00

IV: Marshall Stability Experimental plan

Sample Identification	% CWA as Proportion of Coarse aggregate Content	Bitumen Content (% of Total Mix Weight)	Number of Samples
1	0% CWA/100% CA	5	3
2	0% CWA/100% CA	5.5	3
3	0% CWA/100% CA	6	3
4	0% CWA/100% CA	6.5	3
5	0% CWA/100% CA	7	3
1b	10% CWA/90% CA	5	3
2b	10% CWA/90% CA	5.5	3
3b	10% CWA/90% CA	6	3
4b	10% CWA/90% CA	6.5	3
5b	10% CWA/90% CA	7	3
1c	20% CWA/80% CA	5	3
2c	20% CWA/80% CA	5.5	3
3c	20% CWA/80% CA	6	3
4c	20% CWA/80% CA	6.5	3
5c	20% CWA/80% CA	7	3
1d	30% CWA/70% CA	5	3
2d	30% CWA/70% CA	5.5	3
3d	30% CWA/70% CA	6	3
4d	30% CWA/70% CA	6.5	3
5d	30% CWA/70% CA	7	3
1e	40% CWA/60% CA	5	3
2e	40% CWA/60% CA	5.5	3
3e	40% CWA/60% CA	6	3
4e	40% CWA/60% CA	6.5	3
5e	40% CWA/60% CA	7	3
1f	50% CWA/50% CA	5	3
2f	50% CWA/50% CA	5.5	3
3f	50% CWA/50% CA	6	3
4f	50% CWA/50% CA	6.5	3
5f	50% CWA/50% CA	7	3

IV: Marshall Stability Experimental plan (continues)

Sample Identification	% CWA as Proportion of Coarse Content	Bitumen Content (% of Total Mix Weight)	Number of Samples
1g	60% CWA/40% CA	5	3
2g	60% CWA/40% CA	5.5	3
3g	60% CWA/40% CA	6	3
4g	60% CWA/40% CA	6.5	3
5g	60% CWA/40% CA	7	3
1h	80% CWA/20% CA	5	3
2h	80% CWA/20% CA	5.5	3
3h	80% CWA/20% CA	6	3
4h	80% CWA/20% CA	6.5	3
5h	80% CWA/20% CA	7	3
1j	100% CWA/0% CA	5	3
2j	100% CWA/0% CA	5.5	3
3j	100% CWA/0% CA	6	3
4j	100% CWA/0% CA	6.5	3
5j	100% CWA/0% CA	7	3
-	-	-	Total = 135

V: Marshall Analysis Result for 0% CWA (Control) Specimens

Specimen No.	Binder Content (%)	Specimen Weight (g) In Air	Specimen Weight (g) In H_2O	CDM (g/cm^3)	CDMA (g/cm^3)	SGMA	SGM	VIM	VMA	VFB	Volume (Cm^3)	Correction Factor	Stability (kN)	Adjusted Stability (kN)	Flow (mm)
1A	5.0	1158	587	2.03	-	-	-	-	-	-	543	0.93	4.1	3.81	2.4
	5.0	1162	625	2.16	-	-	-	-	-	-	565	0.86	3.5	3.01	2.3
	5.0	1165	680	2.40	-	-	-	-	-	-	484	1.09	43.8	4.14	2.2
Av.	5.0	-	-	2.20	2.09	2.54	2.36	6.75	17.53	61.49	-	-	-	4.3	2.3
2A	5.5	1113	593	2.14	-	-	-	-	-	-	513	1.04	4.1	4.26	2.2
	5.5	1138	630	2.24	-	-	-	-	-	-	561	1.0	4.0	4.0	2.3
	5.5	1137	628	2.24	-	-	-	-	-	-	530	1.04	3.5	3.64	2.5
Av.	5.5	-	-	2.21	2.08	2.54	2.32	5.05	17.99	71.93	-	-	-	3.97	2.33
3A	6.0	1116	597	2.15	-	-	-	-	-	-	503	1.04	4.1	4.26	2.5
	6.0	1121	618	2.23	-	-	-	-	-	-	516	1.0	4.2	4.2	2.6
	6.0	1143	604	2.12	-	-	-	-	-	-	503	1.04	3.4	3.54	2.5
Av.	6.0	-	-	2.17	2.04	2.54	2.32	6.75	19.46	65.33	-	-	-	4.0	2.53
4A	6.5	1043	585	2.28	-	-	-	-	-	-	486	1.04	3.9	4.25	3.3
	6.5	1123	531	1.90	-	-	-	-	-	-	519	1.0	3.5	3.5	2.8
	6.5	1109	583	2.11	-	-	-	-	-	-	473	1.14	2.8	3.19	2.5
Av.	6.5	-	-	2.09	1.97	2.54	2.29	8.60	22.16	61.17	-	-	-	3.65	2.87
5A	7.0	1071	514	1.92	-	-	-	-	-	-	508	1.04	3.1	3.22	3.3
	7.0	1007	540	2.16	-	-	-	-	-	-	465	1.19	3.4	4.05	3.0
	7.0	1107	528	1.91	-	-	-	-	-	-	525	0.96	3.0	2.88	2.8
Av.	7.0	-	-	2.0	1.88	2.54	2.29	12.8	25.77	50.16	-	-	-	3.38	3.03

VI: Stability values at various percentage of CWA

Bitumen content (%)	0% CWA	10% CWA	20% CWA	30% CWA	40% CWA	50% CWA
5	3.66	3.62	3.83	3.77	3.71	2.28
5.5	3.63	3.54	3.63	3.75	3.61	2.54
6	4.00	3.94	4.00	3.91	3.93	3.59
6.5	3.65	3.44	3.65	3.60	3.65	3.30
7	3.38	3.18	3.38	3.39	3.42	2.37

VII: Compacted Density Mix values at various percentage of CWA

Bitumen content (%)	0% CWA	10%CWA	20% CWA	30% CWA	40% CWA	50% CWA
5	2.2	2.13	2.01	1.9	1.82	1.83
5.5	2.21	2.18	2.06	2	1.88	1.84
6	2.17	2.14	1.95	1.8	1.83	1.82
6.5	2.09	2.07	1.88	1.75	1.81	1.81
7	2	1.89	1.8	1.73	1.8	1.79

VIII: Flow values at various percentage of CWA

Bitumen content (%)	0% CWA	10% CWA	20% CWA	30%CWA	40% CWA	50% CWA
5	2.3	2.21	2.27	2.28	2.22	2.08
5.5	2.33	2.24	2.37	2.50	2.50	2.41
6	2.53	2.54	2.48	2.65	2.63	2.48
6.5	2.88	2.87	2.57	2.88	2.70	2.58
7	3.03	3.02	2.77	2.89	3.20	2.33

IX: Void in total Mix values at various percentage of CWA

Bitumen content (%)	0%	10%	20%	30%	40%	50%
5	4.2	4.5	4.8	5.9	8.2	10.8
5.5	4	4.2	4.52	5.2	7.85	10.5
6	3.85	3.92	4.25	4.9	7.45	9.65
6.5	3.66	3.8	4	4.5	6.5	8.8
7	3.5	3.68	3.8	4.35	5.89	7.5

X: Void in Mineral Aggregate values at various percentage of CWA

Bitumen content (%)	0% CWA	10% CWA	20% CWA	30% CWA	40% CWA	50% CWA
5	17.53	12.51	24.49	28.83	31.57	31.2
5.5	17.99	11.53	23.13	25.47	29.65	31.62
6	19.46	16.7	27.62	32.96	31.89	32.35
6.5	22.16	23.04	30.54	34.97	33.04	32.71
7	25.77	29.67	33.6	35.62	33.61	33.61

XI: Void Filled with Bitumen values at various percentage of CWA

Bitumen content (%)	0% CWA	10% CWA	20% CWA	30% CWA	40% CWA	50% CWA
5	66.8	67.2	68	69.5	78.34	78.83
5.5	68.5	68.9	71.5	72.46	80.22	82.13
6	71.93	72	73.93	75.4	83.71	85.52
6.5	70.59	71.3	72.46	72.4	80.74	83.3
7	69.5	70.8	72	71.26	78.2	82.03