A STUDY OF CRUMB RUBBER MODIFIED ASPHALT SLURRY SEAL EMULSIONS.

By

ZAKARI UMAR FAROUQ

M.Sc /Eng/11288/2008 – 2009

DEPARTMENT OF CIVIL ENGINEERING,
FACULTY OF ENGINEERING,
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NIGERIA

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A THESIS SUBMITTED TO THE
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DEPARTMENT OF CIVIL ENGINEERING,
FACULTY OF ENGINEERING,
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NIGERIA

MAY 2014

DECLARATION

I **ZAKARI UMAR FAROUQ** hereby declare that this thesis titled "**Modified Emulsified Asphalt Slurry Seal Using (Crumb rubber)"** is a record of my own research carried out in the Department of Civil Engineering, Ahmadu Bello University Zaria, under the supervision of **Dr. A.T. Olowosulu** and **Engr**. **Dr. Joel Manasseh.** This work has not been accepted in any previous application for higher degree. In the course of the research numerous literature were consulted and the information derived from them has been duly acknowledged in the text and list of references.

_____

ZAKARI UMAR FAROUQ

CERTIFICATION

This thesis titled "**Modified Emulsified Asphalt Slurry Seal Using Crumb rubber",** meets the regulations governing the award of degree of Master of Science (Highway and Transportation Engineering) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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Dean, School of Postgraduate Studies	Signature	Date

DEDICATION

This wonderful work is dedicated to the following personalities;

My Spiritual Leader **'BAYE NYASS R.T.A'**

My parents late Maolana Sheick Mohammad Anas R.T.A

Sheick Khalifa Abdullahi Baba Taofiq R.T.A and Hajiya Hauwa Mohammad.

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The success of this work is not only a product of my effort, zeal and desire, but it is a gift from the most high ALLAH (SWT). Who enabled assistance from others. With the greatest encomium to ALLAH the almighty, the ultimate, the endless and the most gracious. Who gave me the wisdom, the will, the zeal and the strength to see this work through successfully, against all odds and obstacles. I say praise be to ALLAH the lord of all universe.

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ABSTRACT

The suitability of Crumb Rubber (CR) to partially modifying bitumen in Asphalt Emulsion production for use as slurry seal was investigated. Bitumen was replaced with 0%, 5%, 10%, 15%, 20% and 25% Crumb Rubber, and subjected to methyl blue, sand equivalency, cohesion, wet track abrasion (WTA) and loaded wheel tracks (LWT) tests. Preliminary tests: using Penetration, Softening point, Viscosity and Flash and Fire point tests were also performed on the bitumen. Based on the result of the tests, optimum CR content of 17.5% was recommended for use, because it achieved a smooth texture, within mixing time of 200 Seconds and Cohesion at 30 and 60minutes of 23 and 28 Kg-cm respectively. WTA Loss of 365.2g/m^2, are within the limits specified by the International Slurry Seal Association. Above the Optimum Crumb Rubber the texture of the mixture was not smooth enough for use as slurry sealant. Successful use of CR will serve as an effective way of converting rubber waste to beneficial use, thereby saving the environment and conserving bitumen.

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LIST OF ABBREVIATIONS AND ANNOTATION

AASHTO	American Association of States Highway & Transportation Officials
ASTM	America Society for Testing & Material
AI	Asphalt Institute
BS	British Standard
CR	Crumb Rubber
CRM	Crumb Rubber Modifier
CRMB	Crumb Rubber Modified Bitumen
CSS	Control Slow Setting
CQS	Control Quick Setting
DOT	Department of Transportation
Hi Nat	High Natural Rubber
HMA	Hot Mix Asphalt
HVS	Heavy Vehicle Simulator
ISSA	International Slurry Seal Associate
LWT	Loaded Wheel Track
MB	Modified Binder
MS	Medium Setting
OCR	Optimum Crumb Rubber
OPC	Ordinary Portland Cement
PAV	Pressure Aging Vessel
PHR	Per Hundred Rubber
PMB	Polymer Modified Bitumen
PRF	Pavement Reinforced Fabric
RAC	Rubberized Asphalt Concrete
RS	Rapid Setting
SAMI	Stress Absorbing Membrane Interlayer
SBR	Styrene –Butadiene Rubber
SS	Slow Setting

WTA	Wet Track Abrasion

CHAPTER ONE

INTRODUCTION

1.0 Background

Roads are built by a high-tech process that involves the use of aggregate, heavy machinery, and the hard work of road crews. Carefully constructed roads last for decades. However, the performance of the roads may be affected by wheel load pressure. To overcome the adverse effect of traffic on pavement, there is need for regular maintenance, whether it's crumbling at the edges, developing pot holes, or cracking across the middle. One of the most important measures used in road maintenance is Crack Sealing. There are several crack sealing materials in use in pavement; each designed to keep the road smooth and safe during its life. (Atkinson, 1997)

Roads endure enormous stress and strain as vehicle tires continually push and pull at paved surfaces. The faster or heavier the vehicle, the more the pavement is compressed and then tensioned. Temperature changes, within 24-hour can cause expansion and contraction of the pavement sheet. Traffic and temperature create small surface cracks. When water seeps through such cracks to the base materials it weakens the pavement, resulting in more crack formation which becomes wider if not repaired.

Crack sealing is an inexpensive routine maintenance treatment that will significantly delay roadway deterioration. It is done through the use of local road crews that apply sealing material directly into cracks before cracks become too large or before the roadway is subject to failure. Flexible rubberized asphalt sealants bond to crack walls and move with the pavement, preventing

water from entering the road base. Thereby extending the life span of roads and reducing the cost of maintenance. (Atkinson, 1997)

Pavement cracks can be repaired with either cold or hot sealants. Cold applied materials include liquid asphalt and polymer-modified liquid asphalt. Hot applied materials include bitumen, mineral-filled bitumen, fiberized asphalt, asphalt rubber, rubberized asphalt, and low-modulus rubberized asphalt. To effectively seal a crack, the material must move with the road surface and remain adhered to crack walls. Mixtures of asphalt and rubber are long-wearing and can move with pavement during weather changes. One such mixture, commonly called "asphalt-rubber," is a special mixture of bitumen and used car tires. Asphalt-rubber is especially effective on roads subject to high traffic volume and heavy loads.

Other mixtures are effective for wide (high severity) cracks. These include polymer-modified liquid asphalt, rubberized asphalt, and low-modulus rubberized asphalt. Polymer-modified liquid asphalt is a mixture of natural and synthetic compounds with liquid bitumen. Rubberized asphalt and low-modulus rubberized asphalt are made by adding rubber to asphalt for flexibility. The choice of material depends on the type and amount of rubber in the mixture, and the type of asphalt used. Some materials, although often used because they are inexpensive, have little flexibility. These include bitumen, liquid asphalt, mineral-filled asphalt cement, and fiberized asphalt.

1.1.1 Asphalt Cement (Bitumen)

Asphalt cement or (Bitumen) is a viscous liquid or solid material, black or brown in colour, having adhesive qualities, consisting essentially of hydrocarbons, derived from petroleum or

occurring in natural asphalt and soluble in carbon disulphide. They are usually fairly hard at normal temperatures. When heated, they soften and flow. When mixed with aggregates in their fluid state, and then allowed to cool, they solidify and bind the aggregates, forming a pavement surface. (Kendrick et al., 2009.) Bitumen can be obtained in fluid form as cutback bitumen or an emulsion of interest to this study is consisting of 62 percent bitumen, 38 percent water and an emulsifier, mixed with crumb rubber.

1.1.2 Fine Aggregates

Aggregates are granular mineral particles used either in combination with various types of cementing material to form concretes, or alone as road base, backfill, etc. Typical areas where aggregates are used are; Portland cement concrete, asphalt concrete, asphalt surface, crack sealing material, road base and sub-bases, rail road ballast, concrete blocks, water filtration beds, drainage structures, riprap, and gabion materials. (Atkinson, 1997)

1.1.3 Crumb rubber

Crumb rubber is obtained from grounded used car tires, added to asphalt in a given proportion to form "Asphalt-rubber". Asphalt-rubber as sealant is effective on roads subject to high volume of traffic and heavy axle loads. (Eyo, 2007)

TYPES OF CRM

I. **Ground crumb rubber modifier** – irregularly shaped, torn scrap rubber particles with a large surface area, generally produced by a cracker mill.

II. **High natural rubber (Hi Nat)** – scrap rubber product that includes 40-48 percent natural rubber or isoprene and a minimum of 50 percent rubber hydrocarbon according to Caltrans requirements. Sources of high natural rubber include scrap tire rubber from some types of

heavy truck tires, but are not limited to scrap tires. Other sources of high natural rubber include scrap from tennis balls and mat rubber.

III **Buffing Waste: –** High quality scrap tire rubber that is a byproduct from the conditioning of tire carcasses in preparation for re-treading. Buffing contain essentially no metal or fiber.

IV **Tread Rubber:** – Scrap tire rubber that consists primarily of tread rubber with less than approximately less than 5 percent sidewall rubber.

V **Tread Peel:** – Pieces of scrap tire tread rubber obtained as by-product of tire re-treading operations that contain little if any tire cord.

IV **Whole Tire Rubber:** – Scrap tire rubber that includes tread and sidewalls in proportions that approximate the respective weights in an average tire.

1.1.4 Ordinary Portland cement (OPC)

This is manufactured from readily available bedrock or shell deposits. The main minerals required for the production of Portland cement are lime (Ca0), Silica ($Si0_2$), Alumina (Al_20_3) and Iron oxide (Fe_20_3). The main component is lime (60 – 65%), which accounts for the location of cement manufacturing company close to the source of this raw material.

(Atkins, 1997)

1.2 Problem Statement

The problems of pavement distresses and failures are inherent in pavement structures due to traffic loading and environmental degradation. To worsen the above problem of natural deterioration, one major concern in road construction is the funding and the rising trend of material cost. Effort are been made by researchers to source for materials of minimal value to

augment the existing materials which are fast depleting. Used tyres and other polymer materials constitute colossal waste in the environment. California State Department of Transportation (Caltrans) conducted a research on used tyres and discovered its engineering properties include increased pavement longevity, smoothness and noise reduction and by 1999 research determined that asphalt rubber rehabilitation and maintenance strategies are more cost effective compare to conventional Asphalt concrete.

This work is a strategy to reduce cost of maintenance (using preventive maintenance strategy) and reduce environmental hazard of indiscriminate disposal of used tyres. Several other researchers on used have been conducted worldwide (Caltrans, 2003). In Nigeria there are a lots of used tyres that have not been properly disposed. The researcher on used tyre for pavement design, maintenance and rehabilitation present a scope for optimum utilization of waste product (used tyres) to create wealth (asphalt rubber pavement).

1.3 AIM AND OBJECTIVES

This study is aimed at identifying the proportion of Crumb rubber when added to asphalt cement (bitumen) that can give the best performance in production of crack sealant. The objectives of the study are;

To design an appropriate mix for Crumb Rubber / Asphalt cement (bitumen) using Slurry Seal Mix Design and also to estimate optimum binder content (Bitumen/Rubber) based on results of the Slurry Mix Design. Finally to evaluate the performance of the Modified Slurry Seal on cracks for road maintenance purposes.

1.4 SCOPE OF WORK

The work is restricted to assessing the possibility of adapting Crumb rubber as a partial replacement for bituminous binder in incremental order of 5 percent, ranging from 0 – 25 percent, using a Slurry Seal Mix Design with acceptable crushed rock / quarry dust and CQS-1H emulsion to meet standard specification.

1.5 JUSTIFICATION OF STUDY

The primary reason for using modified slurry seal is that it provides significantly improved engineering properties over conventional slurry seal. It last longer in Crack sealing than the conventional one.

In an era where budgetary allocations are very limited compare to the volume of maintenance work required, there is the need for an alternative approach to road maintenance using locally sourced materials that is cost effect and can achieve the same or better result as conventional material and method using preventive maintenance.

It is pertinent to know that Modified Slurry Seal is durable, flexible in terms of production and disallowed water from penetrating into to the road base. (ISSA, 2003). It reduces aging and it contribution significantly to the reduction of waste tyres; which is the additive used in the production of Modified Slurry seal. This recycled tyre rubber (CRM), mixed with bitumen emulsion brings about a better emulsion. The use of CRM rubber will help to minimize the disposal of waste automobile tyres that have become a menace to the environment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

Bituminous crack sealants are used for the preventive maintenance of asphalt concrete pavements. The selection of a durable sealant can be difficult, due to lack of correlation between standard sealant specifications and field performance. Hence, approved list of materials based on past performance are sometimes used to select sealants. Notwithstanding, sealant durability and performance vary over time. (Masson et al., 2005.)

Blais, (1984;) Belangie and Anderson, (1985;) Chehovits and Manning, (1984;) Chong and Phang, (1988;) Turgeon, (1989;) Smith et al., (1991;) Wolters, (1973), in their study attempted identifying the appropriate means of sealing cracks. Their study focused on aspect that apply to the sealing of cracks in bituminous pavements. Most of the research was conducted, with a few exceptions, in regions subjected to fairly harsh winters (Utah, Minnesota, Ontario, Delaware, Georgia, Montana, and Tennessee) and, in most cases, excessive moisture. Their findings may be considered as representative of conditions in which the environment has the most severe effect on pavement performance. (Velinsky, 1993).

The development of asphalt rubber for use as joint sealers, patches and membrane began in the late 1930s. By early 1950s, Lewis and Wel-born of Bureau of Public Road (BPR) conducted an extensive laboratory study to evaluate ("The effects of various Rubbers on the properties of petroleum Asphalt" (Caltrans, 2003).

In a study conducted by the above mentioned, in the study (14) varieties of rubber powder and three asphalts, including "a California asphalt of low –gravity, low sulphur, and low asphatenes types" were used. The results were published in October 1954 issue of Public Road along with laboratory study of rubber-Asphalt paving mixtures" conducted by Rex at bureau of Public Road (Caltrans, 2003).

The mixtures studied focused on a wide range of vulcanized and unvulcanized rubber materials including tread from scrap tyres, styrene – buta –dienes rubber (SBR) natural rubber, polybuta-diene reclaimed (devulnanized) rubber, and at both wet and dry methods of adding to the zinc chloride (ZC) mixtures.

The city of Phoenix, Arizona worked extensively with asphalt materials in the 1960s and 1970s and was instrumental in the development of wet "wet process" (called the McDonald process) of producing asphalt rubber. The use of asphalt rubber in hot mix patching and surface treatments for repairs and maintenance was first demonstrated in the city. Asphalt rubber chip seals served effectively as the city's primary pavement maintenance and preservation strategy for arterial road ways for nearly twenty years until traffic volumes forced a change to thin asphalt concrete (AC) overlays (Caltrans,2003).

By 1968, the Arizona Department of Transportation began numerous and diverse research and development project involving asphalt – rubber under the direction of Gene Morris, the director of Arizona Transportation Research Center (Epps et al., 1980.) and by 1975 crumb rubber was successfully incorporated into hot mix asphalt. Florida developed an asphalt rubber binder with lower rubber content to avoid the patents in the 1980s. (Douglas, 1999).

Asphalt rubber is used as a binder in various type of asphalt pavement construction including surface treatment and hot mixes. It is also used as crack sealants. Asphalt rubber has been found to be most effective in hot mixes where it is most commonly used in gap-graded and open-graded mixes, particularly for surface courses and for thin overlays ≤ 60mm thick. Terminal blends and modified binder have been used in dense and gap-graded mixes. The most common spray application is a chip seal, also called a stress absorbing membrane (SAM). Chip seals are primarily used for maintenance and pavement preservation. Asphalt rubber chip seals may also be overlaid with densely graded asphalt (DGAC) or rubberized asphalt (RAC), making them interlayer's, typically called stress-absorbing membrane interlayer-Rubber (SAMI-R). (Caltrans,2003).

The gap-graded mix allows for a higher binder content and when combined with the crumb rubber result in a pavement with much greater flexibility and durability. Caltrans has constructed over 750 successful reduced thickness projects which led to the development of a "Reduced Thickness Design Guide" in 1992 for asphalt rubber pavement. (Caltrans, 2003).

Asphalt mixtures have been used by man for thousands of years. Natural asphalts were used in road surfaces by the ancient Babylonians, Egyptians, Greeks, and Romans. Widespread use of asphalt mixtures as paving materials did not occur until the early 1900s when modern petroleum refining techniques were developed [Asphalt Institute SP-1 (AI SP-1), 1995]. In 1988, there were approximately 6.4 million kilometers of roads in the United States, of which 3.7 million were surfaced with asphalt or concrete. Of those 3.7 million kilometers, about 3.5 million kilometers were surfaced with asphalt mixes (Roberts et al., 1991). It is clear from the above numbers that asphalt concrete mixes contribute significantly to the development of road surfacing material.

The wet process consists of adding crumb rubber to the asphalt prior to delivery to the plug mill mixer and has proven to be the most desirable method. In this process, the crumb rubber is added to the paving asphalt in a blending tank. After blending is achieved, the mixture is pumped to a reaction tank where it is kept at 190.56˚C for 35 to 45 minutes before being sent to the plug mill mixer. Aggregate and asphalt mixing temperature must be higher than normal to deliver an asphalt rubber mix at 148.98^{o}C to project site. In California, asphalt rubber is specified to include 18% to 22% crumb rubber modifier (CRM) by total mass of the asphalt rubber blend. The CRM must include 25±2% by mass of high natural rubber content scrap rubber that may come from scrap tyres or other sources. Various petroleum distillate or extender oil may be added to viscosity, facilitate spray applications and promote workability. (Caltrans, 2003).

In 1988 American Society for Testing and Material (ASTM) published the definition of asphalt rubber. ASTM D8-88 read "… a blend of asphalt cement, reclaimed tyre rubber and certain additives in which the rubber component is less than 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles". Widespread use of the material was limited based on its experimental status and patent restrictions. However, as many as twenty – three states had placed test sections using asphalt rubber by 1990. Extensive research was completed in 1992 through the construction productivity Advancement Research Programme sponsored by the Army Corps of Engineers and Private Industry (Anderton, 1992). Additionally, a pooled fund study of crumb rubber modifier (CRM) in asphalt pavement sponsored by the Federal Highway Maintenance Administration (FHMA) and several states was initiated in 1995 (Anderton, 1992).

Although the pooled fund study was not completed, a summary of practices in Arizona, California and Florida was published by the Transportation Research Institute of Oregon State University (Hick et al, 1995) as well as an Interim Report Guidance (Hanson et al, 1996).

2.1.1 Wet Process

The method of modifying asphalt binder with CRM produced from scrap tire rubber and other components as required before incorporating the binder into the asphalt paving materials is known as the Wet process. Caltrans requires the use of extender oil and addition of high natural CRM. The wet process requires thorough mixing of the crumb CRM in hot asphalt cement (375ºF to 435ºF, 190ºC to 224ºC) and holding the resulting blend at elevated temperatures (375ºF to 425ºF, 190ºC to 218ºC) for a designated minimum period of time (typically 45 minutes) to permit an interaction between the CRM and asphalt. Caltrans specification requirements include an operating range for rotational viscosity and cone penetration, and minimum values of softening point and resilience,

The wet process can be used to produce a wide variety of CRM modified binders that have corresponding respective ranges of physical properties. However the most important distinctions among the various blends seem to be related to rotational viscosity of the resulting CRM-asphalt cement blend at high temperature (threshold is 1,500 centipoises (cPs) or 1.5 Pa•sec at 375ºF (190ºC) depending on governing specification) and whether or not the blend requires constant agitation to maintain a relatively uniform distribution of rubber particles. Viscosity is strongly related to the size of the scrap tire CRM particles and tire rubber content of the CRM-modified blend. CRM gradations used in the wet process are typically minus No. 10 (2 mm) sieve size or finer. CRM-modified binders with viscosities ≥ 1,500 cPs at 375ºF (190ºC) should be assumed to

require agitation. (Caltrans, 2006). Advantage of Wet process is; various petroleum distillates or extender oil may be added to reduce viscosity, facilitate spray applications, and promote workability.

2.2 A Brief Review of History of Asphalt Rubber as joint sealers.

Development of asphalt rubber materials for use as joint sealers, patches, and membranes began in the late 1930s**.** In the early 1950s, Lewis and Welborn of the Bureau of Public Roads (BPR) conducted an extensive laboratory study to evaluate "The Effect of Various Rubbers on the Properties of Petroleum Asphalts." They used 14 types of rubber powders and three asphalts, including "a California asphalt of low-gravity, low-sulfur, low-asphaltenes type." The results were published in the October 1954 issue of *Public Roads* along with results of a companion "Laboratory Study of Rubber-Asphalt Paving Mixtures," conducted by Rex and Peck at BPR. The mixtures study looked at a wide range of vulcanized and unvulcanized rubber materials including tread from scrap tires, styrene-butadiene rubber (SBR), natural rubber, polybutadiene,and reclaimed (devulcanized) rubber and at both wet and dry methods of adding them to AC mixtures. Interest and work in this area continued to grow, as did the number of patent applications. In March 1960, the Asphalt Institute held the first Symposium on Rubber in Asphalt in Chicago, IL. It consisted of five paper presentations and discussion. Charles H. McDonald of the City of Phoenix Arizona worked extensively with asphalt and rubber materials in the 1960s and 1970s and was instrumental in development of the "wet process" (also called the McDonald process) of producing asphalt rubber. He was the first to routinely use asphalt rubber in hot mix patching and surface treatments for repair and maintenance. Asphalt rubber chip seals served effectively as the City's primary pavement maintenance and preservation

strategy for arterial roadways for nearly twenty years, until traffic volumes forced a change to thin AC overlays. Gap-graded asphalt rubber concrete mixtures were developed as a successful substitute.

In 1975, Caltrans began experimenting with asphalt rubber chip seals in the laboratory and small test patches located at 03-Yol-84-PM 16+ and 03-Sac-99-PM 20+, with generally favorable results. In 1978, the first Caltrans dry process rubber-modified AC pavement was constructed on SR 50 at Meyers Flat. It included one percent ground rubber by mass added to the dry aggregate prior to mixing with the paving asphalt. Performance was rated good. The first Caltrans rubberized asphalt concrete (RAC) pavements made with early versions of "wet-process" asphalt rubber binder and dense-graded aggregate were constructed in 1980 at Strawberry (SR 50) and at Donner Summit (I-80). The Strawberry project was an emergency repair to a dramatically failed pavement. The repair included pavement reinforcing fabric (PRF), and a 2.4-inch (0.2 ft, 60 mm) layer of dense-graded HMA to restore structural capacity, under the thin (1.2 inches, 0.1 ft, 30 mm) RAC wearing course. The first three projects are all located in "snow country" at high elevations where tire chains are used in winter. The RAC pavements reportedly performed well in resisting chain abrasion and reflective cracking.

The Ravendale project (02-Las-395) constructed in 1983 significantly changed Caltrans' approach to the use of asphalt rubber. This project presented a typical dilemma. The cost of rehabilitation by overlaying with dense-graded HMA was prohibitive, so less costly alternatives were considered, including thinner sections of RAC. The project was designed as a series of 13 test sections that included two different thicknesses each of wet process (dense-graded) and dry process (gap-graded) RAC with SAMI (4 sections), wet and dry RAC at 1.8 inches (0.15 ft, 46

mm) thick without SAMI (2 sections), four control sections with different thicknesses of dense graded.

HMA from 1.8 to 6 inches (46 to 152 mm), two sections surfaced only by double asphalt rubber chip seals, and one section surfaced with a single asphalt rubber chip. The test sections were monitored over time. The dry process section at this site lasted over 19 years before it was overlaid in 2002, but performance of such pavements elsewhere has varied. By 1987, it was clear that the thin RAC pavements were performing better than thicker conventional dense graded HMA. Caltrans built more RAC projects and continued to study the performance of RAC constructed at reduced thickness relative to dense-graded HMA structural requirements. Through 1987, Caltrans constructed one or two RAC projects a year. Dense- or open-graded RAC mixes were placed as surface courses at compacted thicknesses that ranged from 1 inch (25 mm) for open-graded to 3 inches (75 mm) for RAC-D. Some projects included pavement reinforcing fabric (PRF) and/or a leveling course, and some others included asphalt rubber stress absorbing membrane interlayer (SAMI) under the asphalt rubber mixes.

In March 1992 Caltrans published a "Design Guide for Asphalt Rubber Hot Mix-Gap Graded (ARHM-GG)" based on these studies and project reviews. The Guide presented structural and reflection crack retardation equivalencies for gap-graded asphalt rubber mixtures (now designated RAC-G) with respect to dense-graded HMA, and with and without SAMI. These equivalencies were considered to be field validated and were incorporated in Chapter 6 (Tables 3 and 4) of the Caltrans Flexible Pavement Rehabilitation Manual (June 2001). Caltrans considered that RAC-G could generally be substituted for dense-graded HMA at about one-half the thickness.

By 1995, over 100 Caltrans RAC projects had been constructed. Cities and counties in California had by then constructed more than 400 asphalt rubber projects, including asphalt rubber chip seals. However some problems occurred, including some cases of premature distress. Caltrans engineers reviewed RAC performance on the Caltrans projects, selected California city and county projects, and 41 Arizona DOT projects. Some of the problems observed were clearly construction related; many of the contractors involved in those projects had little if any experience working with the RAC mixtures. The Caltrans review indicated that asphalt rubber materials can perform very well when properly designed and constructed, and that Caltrans should continue using and studying asphalt rubber. A very important finding was that the distresses observed in RAC pavements generally appeared to progress at a much slower rate than would be expected in a structurally equivalent conventional dense-graded HMA pavement. In many of the cases where premature RAC distress (particularly cracking) had occurred, relatively little maintenance was required to achieve adequate pavement service life because the subsequent distress developed slowly. One-third of the Strawberry RAC was reportedly still exposed and performing after 15 years, with less maintenance resources and time expended than for all pavements in that district with the exception of another RAC section. Caltrans was also instrumental in developing specifications for modified binders containing crumb rubber. The Modified Binder (MB) specification was developed in the early 1990s as part of a continuing movement towards performance-based specifications from method type or "recipe" specifications. It has been suggested that the specification be renamed as "RMB," Rubber Modified Binder. Based on analysis of rheological measurements of samples of asphalt rubber

binders and limited evaluations of their field performance, Caltrans researchers developed two new parameters for specifying rubberized binders, using residual aged in the Pressure Aging Vessel (PAV). These are;

• Shear susceptibility of the phase angle delta, SSD, which is related to elastic properties, and

• Shear susceptibility of viscosity, SSV, which is related to stiffness.

Ten pilot projects were constructed between December 1997 and November 1999 to evaluate the performance of materials meeting the MB specification. The MB pilots are located mostly in the coastal regions of California and include both dense-graded and gap-graded mixtures placed over a range of structural sections. These projects were reviewed in 2002 by a joint Caltrans-Industry group: eight were rated as "good," one as fair, and one that exhibited base failure and pumping as poor. Caltrans has prepared a report on these MB pilot projects. However findings to date are limited and use of MB products has been limited to test sections and a warranty project. Heavy vehicle simulator (HVS) trials are being conducted at the University of California Berkeley Richmond Field Station but have not yet been completed.

By mid-2001, over 210 Caltrans RAC projects had been constructed throughout California. Municipalities and counties also continued to use asphalt rubber for hot mixes and surface treatments with generally good performance. However some of the old problems with product selection, design, and construction continued to arise. Districts 7 and 8 reportedly experienced several major RAC failures. From 2002 through 2004, Caltrans built five pilot RAC overlay projects through its rehabilitation program that include a 5-year warranty on the RAC materials, workmanship, and performance.

Warranty conformance is determined by periodic distress surveys of designated performance

evaluation sections. The special provisions list specific distress triggers for repairs. The overall objective of these RAC warranty pilot projects was to provide a "level playing field" for wet process (field-produced high viscosity and terminal blend no agitation CRM-modified asphalt binders) and for dry process (CRM as an aggregate substitute) rubber-modified mixes that contain a minimum of 15% CRM (by total mass of binder). No dry process mixes were bid, and only one project used a terminal blend binder in the mix. Performance evaluations to date indicate the overlays are generally in good condition.

Test sections for CRM-modified paving materials were subsequently incorporated by change order into two Caltrans projects constructed in 2004 and 2005. The primary purpose was to assess relative field and laboratory performance of dense-graded HMA control mixes, gap graded RAC and RUMAC mixes, and dense- and gap-graded MB mixes. Constructability of the respective types of CRM-modified mixes was also evaluated. Both projects are to be monitored over a 5-year period. Field and laboratory performance were compared with findings from the HVS study for similar CRM-modified mixtures. The Firebaugh project was constructed in 2004 on SR 33 in Fresno County just north of the town of Firebaugh. It included a full-thickness (3.5 inches, 90 mm) control section of conventional dense-graded HMA and eight test sections as follows:

• RAC-G (wet process high viscosity field blend, gap-graded) at full (3.5 inches, 90 mm) and half (1.75 inches, 45 mm) thickness

• RUMAC (dry process, gap-graded) at full (3.5 inches, 90 mm) and half (1.75 inches, 45 mm) thickness

• MB-G (wet process terminal blend, no agitation, gap-graded) at full (3.5 inches, 90 mm) and half (1.75 inches, 45 mm) thickness

• MB-D (wet process terminal blend, no agitation, dense-graded) at full (3.5 inches, 90 mm) and half (1.75 inches, 45 mm) thickness. The District 1 RAC experimental project on State Route 20 in Mendocino County consisted of a control and three test sections:

• Dense-graded HMA Control (4.13 inches, 105 mm)

• RAC-G mix (wet process high viscosity field blend, 2.36 inches (60 mm))

• RUMAC-G mix (dry process, 2.36 inches (60(mm))

• MB-D mix (wet process, no agitation terminal blend, 2.36 inches (60 mm))

Emission tests were performed at the District 1 project to determine pollutant emission rates for each mix as requested by the North Coast Mendocino and Lake County Air Quality Management Districts. No problems were reported during mix production or construction.

Research was conducted in 2005 on the structural equivalency of RAC-G to dense-graded HMA. Although reflective cracking was not the subject of the research, the study indicated that the practice of using a reduced RAC-G overlay thickness to retard reflective cracking is still warranted. Limited laboratory test results indicate that the gravel factor (Gf) for RAC-G is similar to but slightly lower than that of dense-graded HMA. Mechanistic-empirical analysis indicates that these two very different types of mixes are structurally similar at thicknesses ranging from 1.2 to 2.4 inches (30 to 60 mm). **Therefore, RAC-G should not be used at half thickness when it is intended to provide a structural equivalent to dense-graded HMA.** The research indicates that as the thickness of RAC-G increases above 2.4 inches (60 mm), the gravel equivalency of RAC-G begins to decrease relative to dense-graded HMA.

These research findings have been adopted by Caltrans. For new construction, Caltrans recommends that RAC-G should not be thicker than 2.4 inches (60 mm) and should be placed on a layer of conventional HMA rather than directly on an unbound base course. RAC-O should not be thicker than 1.8 inches (45 mm) and should be used only as a surface course. Up to 1.8 inches (45 mm) of RAC-O may be placed on top of 2.4 inches (60 mm) of RAC-G. Also for new construction, the overall pavement thickness may not be reduced when RAC is used (Caltrans, 2006b).

2.3. Chemical Composition of Tyre

The chemical composition of tyre and the component materials used in its manufacturing is as shown in Table 2.1 and 2.2 respectively. Truck tyres contain more natural rubber than car tyres (Truck tyres have 65% natural rubber and 35% synthetic rubber, Passenger Car tyres have 25% natural rubber and 75% synthetic rubber).

Table 2.1: Composition of car (automobile) and truck tyres (% weight).

Material	Automobile %	Trucks %
Rubber/Elastomers	48	45
Carbon black and silica	22	22
Metal	15	25
Textile	5	-
Zinc Oxide	1	2
Surphur	1	1
Additives	8	-

Source: (Epp. Jon, 1994).

Table 2.2: Material used in the manufacturing of Tyres.

MATERIALS	SOURCES	PERCENTAGE OF MATERIALS
Natural Rubber	Natural rubber is predominantly obtained from the sap of the *Hevea brasiliensi* tree.	Natural rubber currently accounts for about 30% to 40% of a car tyre and 60% to 70% of a truck tyre.
Synthetic Rubber	All synthetic rubber are made from petrochemicals	Synthetic rubber accounts for about 60% to 70% of car tyre and 30% to 40% of truck tyre.
Steel cord and bending including the coating materials and activators, copper/tin zinc/chromium	The steel is premium grade and is only manufactured in a few plants around the world due to its high quality requirements.	Steel is used to provide rigidity and strength to the tyres. It accounts for about 15% of the weight of a car tyre.
Other reinforcing fabrics	Predominantly derived from petrochemicals	Used for structural strength and rigidity. It accounts for about 5% of a radial tyre.
Carbon black	Derived from petroleum stock	It provides durability and resistance against wear and tear. It accounts for about 28% of a car tyre.
Zinc oxide	A mineral.	Zinc is added to provide resistance to Uv degraded and vulcanization control. Zinc oxide accounts for about 1.2% of a passenger tyre.
Sulphur (including compounds)	Sulphur is used to vulcanize the rubber.	Makes up about 1% of a passenger tyre.
Other additives and solvents age resistor, processing aids, accelerators, vulcanizing agents softeners and fillers.	The other additives are used in the various rubber compounds to modify handling manufacturing and end product properties.	The additives make up about 8% by weight of a passenger tyre
Recycled rubber	Recovered from used tyres or other rubber products	Used in some rubber compounds in the manufacturing of 'new' rubber products and retread materials.

Source: (Epp. Jon,1994)

Table 2.3: Rubber Compounds for Tyre

	Tread (PHR)	Base (PHR)	Sidewall PHR)	Innerliner PHR)
Natural Rubber	50.0	100.0	75.0	
Styrene-Butadiene Rubber	50.0		25.0	
Isobutylene-Isoprene Rubber				100.0
Carbon Black (Grade N110)	50.0	15.0	20.0	
Carbon Black (Grade N330)		25.0	35.0	
Carbon Black (Grade N765)				50.0
Processing Oil	7.5	5.0	5.0	3.0
Antioxidant	1.0	0.75	1.0	1.0
Antioxidant Wax			2.0	
Stearic Acid	2.0	4.0	3.0	1.5
Zinc Oxidant	5.0	5.0	5.0	5.0
Accelerator (High)		1.0	0.7	
Accelerator (Middle)	1.25			0.4
Accelerator (Low)				0.4
Sulfur	2.5	3.0	2.8	2.0

*PHR = Per Hundred Rubber

*Carbon grade = ASTM grading = Particle size and structure of carbon are different.

Source: (James et Al., 1994.)

2.4 Asphaltic cement (Bituminous Binders)

Bituminous binders used in pavement construction works include bitumen and tar. Bitumen is a petroleum product obtained by distillation of petroleum crude where-as tar is obtained from the destructive distillation of coal wood. Both bitumen and tar have similar appearance, black in colour though they have different characteristic. Bitumen is hydrocarbon material of either natural or pyrogenous origin, found in gaseous, liquid, semisolid form and is completely soluble in carbon disulphide and in carbon tetra chloride. Bitumen is a complex organic material and occurs either naturally or may be obtained artificially through the distillation of crude oil. 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 parafins. The last four components listed are known as maltenes and have considerable bearing upon the durability of bitumen cement (Wallace & Martin, 1967).
After completing the five-component separation, the chemical composition or maltene-distribution-ratio was calculated for each bitumen cement as:

$(N + A_1) / (P + A_2)$

Where N = Percent of nitrogen bases

A_1 = Percent of first acidaffins

A_2 = Percent of second acidaffins and P = Percent of parafins.

2.5 Current Asphalt Mix Design Procedures

Asphalt mixes were developed to provide a stable and inexpensive surface for vehicles. Asphalt concrete or hot mix asphalt (HMA) is made up of various types of asphalt cements and mineral aggregates. The type and quality of asphalt cement or aggregate may change the properties of the asphalt mix [Asphalt Institute SP-2 (AI SP-2), 1995]. Objectives of asphalt pavement design and construction are to support traffic loads, protect the base and subbase from moisture, provide a smooth but skid resistant surface, and to resist weathering (Peurifoy, et al 1996). The following few sections describe currently used materials and asphalt mix design procedures.

2.5.1 Asphalt Cement

Asphalt cement is the glue that holds aggregate together in an asphalt mix. It also waterproofs the mixture. Aggregate provides a skeleton that gives the mixture strength. Overall properties of the system depend on asphalt cement and aggregate, and their combined reaction (AI SP-2, 1995). Asphalts used today are either natural or petroleum asphalts. Natural asphalts are relatively soft and can be found at various locations around the world such as Trinidad, Venezuela, and the La Brea "Tar" Pits near Los Angeles, California. Petroleum asphalts are obtained by refining crude petroleum and removing lighter fractions such as gasoline, kerosene, diesel, and gas oil. Practically all asphalt used in the United States comes from refineries (Roberts et al., 1991).

Properties of asphalt cement are temperature susceptible; meaning behavior of the material can change with temperature. Asphalt cement is a viscoelastic material because it has viscous and elastic characteristics at a given temperature. At low temperatures, asphalt cement behaves most

like elastic solid, rebounding to its original shape after being loaded and unloaded. At high temperatures, asphalt cement acts more like a viscous liquid. Asphalt cement properties also can change with age of the material through oxidation. As asphalt oxidizes, it becomes more brittle. Oxidation occurs more rapidly at higher temperatures. A considerable amount of aging occurs during HMA production. The material will continue to age throughout the life of the pavement (AI SP-2, 1995).

Since asphalt cement comes from naturally occurring materials, there is great variation in its properties. Attempts have been made to distinguish among asphalts with different properties based on the consistency of the material at a given temperature. Asphalt cements have been classified by penetration, which is a measure of the depth of penetration by a standard needle into asphalt cement at 25^0C at five seconds (Peurifoy et al., 1996). Viscosity also has been used for classification, which is a measure of the flow of asphalt cement through a viscometer tube at 60^0C and 135^0C. Other information on asphalt characteristics are determined from additional tests related to aging and safety (Roberts et al., 1991).

2.5.2 CRACKS AND TYPES

The development of cracks on pavement surface can be due to expansion arising from variation in weather, stress from excessive wheel load, settlement of the base material, etc. The most common types of cracks on the pavement are: Transverse, Longitudinal, diagonal Corner and Alligator or Miscellaneous cracks. The width of cracks at the pavement surface is classified as narrow if less than 0.5mm, medium if 0.5mm – 1.5mm and wide if greater than 1.5mm. Source (FHWA-RD-99-147).

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The methodology adopted in this research include series of laboratory tests performed on materials obtained as specimen samples, the result was analyzed and used in making appropriate deductions.

Processed Crumb Rubber was collected from Federal Road Maintenance Agency (FERMA) Abuja, and used to evaluate the desirable engineering properties of the rubberized slurry seal produced against control. This was further assessed using established engineering standard to affirm the reliability of the result. The various tests used for evaluation are, Slurry Mix Design, Wet Track Abrasion, Cohesion, Sand Equivalent, Methyl Blue and Loaded Wheel Tracks.

3.2 Sampling of Materials and Preliminary tests.

Preliminary material tests were carried out on the strength / mechanical properties on aggregate materials and the strength bitumen. The tests under this item of work are Sieve Analysis, Viscosity, Penetration, Ductility, Flash and Fire point, Softening point, Solubility and Specific gravity on the bitumen. These tests were used to ascertain the consistency, purity and safety of the material.

3.2.1 Sampling of Materials

3.2.2 Fine Aggregate

Aggregates are granular mineral particles used either in combination with various types of cementing material to form concretes, or alone as road base, backfill, etc. Typical areas where

aggregates are used are; Portland cement concrete, asphalt concrete, asphalt surface, crack sealing material, road base and sub-bases, rail road ballast, concrete blocks, water filtration beds, drainage structures, riprap, and gabion materials. (Atkinson, 1997)

3.2.3 Crumb rubber

Crumb rubber is obtained from grounded used car tires, added to asphalt in a given proportion to form "Asphalt-rubber". Asphalt-rubber as sealant is effective on roads subject to high volume of traffic and heavy axle loads. (Eyo, 2007)

TYPES OF CRM

I **Ground crumb rubber modifier** – irregularly shaped, torn scrap rubber particles with a large surface area, generally produced by a cracker mill.

II **High natural rubber (Hi Nat)** – scrap rubber product that includes 40-48 percent natural rubber or isoprene and a minimum of 50 percent rubber hydrocarbon according to Caltrans requirements. Sources of high natural rubber include scrap tire rubber from some types of heavy truck tires, but are not limited to scrap tires. Other sources of high natural rubber include scrap from tennis balls and mat rubber.

III **Buffing Waste: –** High quality scrap tire rubber that is a byproduct from the conditioning of tire carcasses in preparation for re-treading. Buffing contain essentially no metal or fiber.

IV **Tread Rubber:** – Scrap tire rubber that consists primarily of tread rubber with less than approximately less than 5 percent sidewall rubber.

V **Tread Peel:** – Pieces of scrap tire tread rubber obtained as by-product of tire re-treading operations that contain little if any tire cord.

VI Whole Tire Rubber: – Scrap tire rubber that includes tread and sidewalls in proportions that approximate the respective weights in an average tire.

3.2.4 Ordinary Portland cement (OPC)

This is manufactured from readily available bedrock or shell deposits. The main minerals required for the production of Portland cement are lime (Ca0), Silica ($Si0_2$), Alumina (Al_20_3) and Iron oxide (Fe_20_3). The main component is lime (60 – 65%), which accounts for the location of cement manufacturing company close to the source of this raw material.

(Atkins, 1997)

3.2.5 Modified Asphalt (Bitumen)

Certain additives or blend of additives called as bitumen modifiers can improve properties of Bitumen and bituminous mixes. Bitumen treated with these modifiers is known as modified bitumen. Polymer modified bitumen (PMB)/ crumb rubber modified bitumen (CRMB) should be used only in wearing course depending upon the requirements of extreme climatic variations. The detailed specifications for modified bitumen have been issued by IRC: SP: 53-1999. It must be noted that the performance of PMB and CRMB is dependent on strict control of temperature during construction. The advantages of using modified bitumen are as follows

- Lower susceptibility to daily and seasonal temperature variations
- Higher resistance to deformation at high pavement temperature
- Better age resistance properties
- Higher fatigue life for mixes
- Better adhesion between aggregates and binder
- Prevention of cracking and reflective cracking

3.3 Slurry Seal Mix Design and Production with Crumb Rubber Modifications.

The second phase was the test of well batched slurry seal mix design to determine the optimum proportion of the crumb rubber in bitumen mix process. The test was designed to cover arbitrarily varying percentage of crumb rubber from 0%, 5%, 10%, 15%, 20% to 25% as additive in slurry seal mix design. The best proportion was determined by comparing the results of the wet track abrasion test, cohesion test, sand equivalent test, methyl blue test and loaded wheel tracks test that was carried out on each Slurry seal designed and produced.

The materials used and tests performed is as listed and described below.



Fig. 3.1: Crumb Rubber Sample



Fig. 3.2: Blended Emulsion Sample



Fig. 3.3: Slurry Seal Mix design Trial Sample



Fig. 3.4: Slurry Seal Mix design Trial Sample in Oven

3.4.0 THE TESTS REQUIRED ON SLURRY SEAL

The preliminary tests performed on the Modified Emulsion include;

I. **Asphalt emulsion Sieve test ASTM D6933**

II. **Settlement Storage Stability**

III. **Particle Charge**

IV. **Residue Content (By Distillation and By Evaporation)**

V. **Viscosity test using Saybolt Furol**

VI. **Penetration**

VII. **Softening Point**

VIII. **Flash and Fire Point**

The tests performed on the Slurry Seal include:

I. **Methyl blue**
II. **Sand equivalency**
III. **Classification**
IV. **Cohesion**
V. **Mixing Time**
VI. **Set Time**
VII. **Wet track abrasion**
VIII. **Loaded wheel tracks**

In order to obtain the mentioned factors and achieve the desired result, a step-by-step procedure as given below was adopted.

3.4.1 Asphalt Sieve test (ASTM D6933)

Asphalt emulsion sieve test was performed to identify emulsion stability, The test was performed in accordance with the procedure in ASTM D6933 use to calculate the weight percentage of Asphalt particle that will not pass 850µm screen (No 26); given as equation 3.1

$$\%\text{Sieve} = \frac{Residue\ retained\ on\ the\ 850\mu m\ screen(g) x\ 100\%}{Emulsion\ sieve\ (g)} \quad --- 3.1$$

The apparatus used in the test were; 850µm (26) sieve, Catch pan, Weight Balance, Oven, Emulsion, Container and Desiccators.

Procedure:

The sieve and catch pan was weighed and record, after which the emulsion was sieved into the container and record at the temperature at which the viscosities are measured. The Mixing grade emulsion at 77^{o}F and Spray grade emulsion was at 122 ^{o}F

The excess emulsion was washed off from the sieve and weighed again, and then the sieve was placed inside the oven to dry. The sieve was removed from the oven and placed inside the desiccators to cool. After cooling, it was removed from the desiccators and weighed, and then the amount sieved was calculated.

3.4.2 Storage Stability And Settlement Test. (ASTM D6930)

These two tests give an indication of long time storage stability of the emulsion. Some large scale emulsion manufacturers have other ways of agitating their emulsion to avoid settlement. However, it should be noted that if emulsion is kept in equipment for a long period of time, either due to rain or other logistical delay, thorough blending of the emulsion may be required to endure uniform properties throughout the emulsion.

The 24-hrs storage stability or 5-days settlement test was performed in accordance with ASTM D6930, the result obtained was used to calculate the degree of settlement of the asphalt solids aver a period of time. This was done by comparing the residue content in approximately the bottom 10% of that same sample.

The apparatus used in the test are; 500ml glass cylinder, a siphon, Vacuum pump, a balance, Containers and Hot plate.

Procedure:

500ml of sample was poured into the cylinder, after which the cylinder with the content was allowed to stay undisturbed at room temperature for a given period of time. Then about 55ml of the sample was siphoned from the cylinder. 50g of the siphoned sample from the cylinder was poured into the container for top sample. The bottom 55ml was stirred and 50g out of it was pour into a container for bottom residue sample. The hot plate and evaporation was used to dry off water from the sample, the sample was allowed to cool. Then the sample was weighed and recorded, after which the settlement was calculated.

3.4.3 Asphalt Residue Test, Evaporation: (ASTM D6934)

Asphalt content is not the same as residue, but asphalt content refers specifically to the amount of solid in the emulsion. The residue comprises of asphalt solids from emulsifier and solids from the polymer. The reason for knowing the residue is to ensure that, the specification requirement by the user agency is met in addition to ensuring that viscosity is not affected.

The emulsion residue percentage was determined using different methods. The most common equipment is the hot plate burner, which was used in this study.

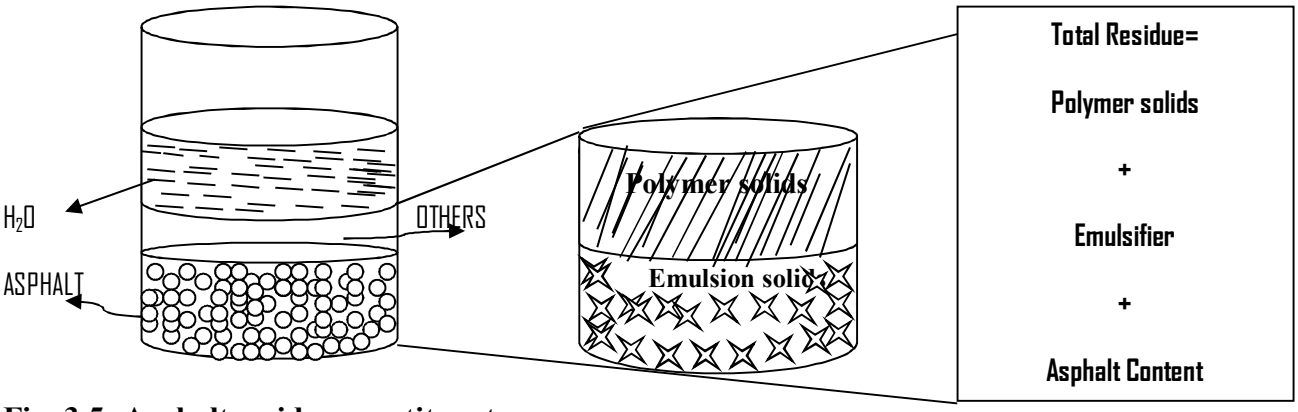


Fig. 3.5: Asphalt residue constituent

Procedure:

The test was performed in accordance with ASTM D6934, in which a known weight of emulsion was placed in a container, and then the container was placed on the hot plate and heat. The content was stirred until all the water is boiled off. The content was weighed again and the total residue was calculated, using equation (3.2).

$$\%\text{Residue} = \frac{Residue\ (g)}{Emulsion\ (g)} \text{ x } 100\% \quad --- \quad 3.2$$

(i) Oil Distillate Residue (ASTM D6997)

The apparatus used in the test are; Alumni alloy steel, Water cool condenser, Graduated cylinders, Heat source, Balance and Emulsion.

Procedure:

The test was performed in accordance with ASTM D6997**.** About 200ml of emulsion alumni was weighed in the cylinder. The cylinder was coupled into the test apparatus set. The emulsion was heated up to 500^{o}F at a specified period of time and held there for about 15 minutes.

Note: Low amount of temperature was maintained for a polymer modified emulsion in other not to destroy the polymer.

The distiller was collected into the graduated cylinder to calculate the oil portion as a percentage of the original emulsion and the distilled content was weighed. The asphalt content was calculated using the weight of the distilled.



Fig. 3.6: Emulsion Residues Recovery Process



Fig. 3.7: Blended Emulsion Residue

(ii) Residue by Evaporation (ASTM D6934)

The apparatus used in the test are; 3 large beaker steel cans, 3 glasses stir rods, Oven, Balance.

Procedure:

The test was performed in accordance with ASTM D6934. About 50g of emulsion sample was placed in each can with stir rod. The 3 cans were placed in an oven at 325^{o}F. After 2 hrs, the residue was removed and stirred then returned to the oven again. After another hour the cans was removed and cooled. The content was weighed to determine the residue as in equation 3.3 and the result compared with ASTM specification

$$\%\text{Residue} = \frac{Residue\ (g)}{Emulsion\ (g)} \text{ x } 100\% \quad - - \ - 3.3$$

ASTM Residue Specification:-

Mixing Grades of SS, CSS, CQS > 57% and

Spray Grades of RS, HFRS, CRS > 63% OR 65%

$$\text{Oil distillate} = \frac{Oil\ distillate, (ml)}{Emulsion\ (g/ml)} \text{ x } 100\% \ -- \ -3.4$$

ASTM Oil Distillation Specification.

CRS of 3% max

CMS of 12% max and

HFMS of 1-7%

3.4.4 Viscosity Test. *(SAYBOLT FUROL VISCOSITY TEST D244)*

The flow characteristics of emulsion are important for its applications and use. For spray grade type, the emulsion must be thin enough for uniform application through the spray bar via the distributing truck, but thick enough so that they may not flow from the crown to the edge of the road.



Fig. 3.8: Viscosity Test Apparatus

Saybolt Furol Viscosity Test D244:

Saybolt furol viscosity is measured according to the method found in section 17-21 of ASTM D244. The emulsion was heated to test temperature and the time in seconds that was required to fill up the viscosity receiving flask, was measured. The time was designated as saybolt furol viscosity.

The apparatus used for the test are; Viscometer bar, Received flask, Thermometer and 850µm sieve.

Procedure:

The test was performed in accordance with ASTM D244. The emulsion was slightly heated above test temperature and the sample was sieved through 850µm sieve into viscometer tube. After which the emulsion was stirred until test temperature was reached. Then, the plug of the viscometer that held the emulsion was pulled. The time from the moment it reached the mark indicated on the flask to the time emulsion start to fill the flask was recorded.

The time was reported as viscosity saybolt furol seconds. SFS.

- Saybolt furol viscosity : 29 SFS

  ASTM specifications

  Mixing grades of SS, CSS, CQS

  $77^{O}F \longrightarrow$ 20 – 100 seconds.

  Spray Grades of SS, CSS, CQS at

  $122^{O}F \longrightarrow$ 100 – 400 seconds.

3.4.5 Penetration (ASTM D5)

This test is very vital to empirical measurement of consistency of bitumen. The test, is a measure of hardness, it was 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 was 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.

3.4.6 Softening Point (ASTM D36)

This is a measure of temperature susceptibility and a measure of flow of bitumen in service. The test was performed in accordance with ASTM D36. 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 point is called Ball-and-ring / Softening point test. In the test, asphalt is placed in a small ring and chilled. The ring was then immersed in water or glycerin; a small steel ball was placed on the asphalt and heat was applied to the liquid. As the temperature was raised, the temperature at which the bitumen softens and the ball sinks to the bottom of container was the temperature corresponding to softening point.

3.4.7 Flash and Fire Point (ASTM D92)

This test was performed in accordance with the provision in 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 higher temperature at which the bitumen will support combustion. Flash and Fire point is safety

related aim at ensuring caution should be taken to eliminate fire hazards during heating and manipulation of bitumen.

3.4.8 Gradation/Classification Test

Aggregate possess a series of physical and chemical properties, which together with grading; determine the suitability of aggregate for use. An understanding of these properties is essential as a basis for development of empirical test and for evaluation and selection for use under specific condition.

3.4.9 Sand equivalent test ASTM (D2419)

This test was performed in accordance with the provision in ASTM D2419. The sand equivalent test (Figure 3.9 - 3.12) is a rapid field test to show the relative proportions of fine dust or clay-like materials in fine aggregate (or granular soils). The term "sand equivalent" expresses the concept that most fine aggregates are mixtures of desirable coarse particles (e.g., sand) and generally undesirable clay or plastic fines and dust (ASTM, 2003).These materials can coat aggregate particles and prevent proper asphalt binder-aggregate bonding.

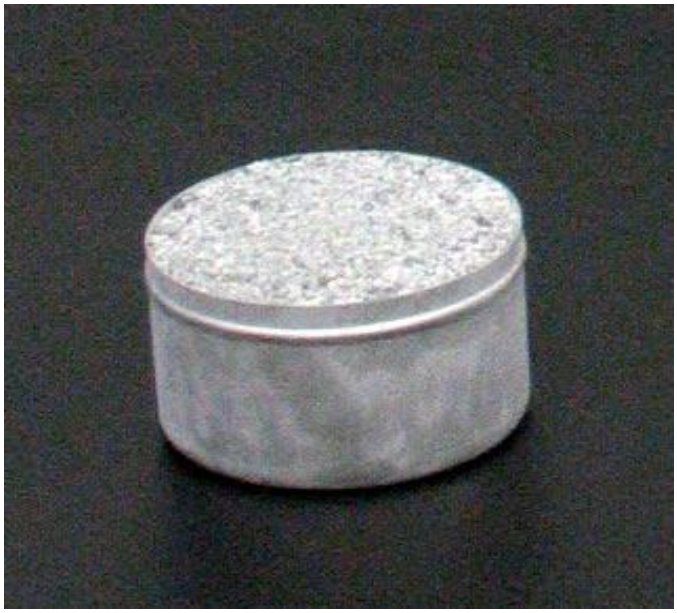


Fig. 3.9: Aggregate sample in 3 oz. (85 mL) tin.

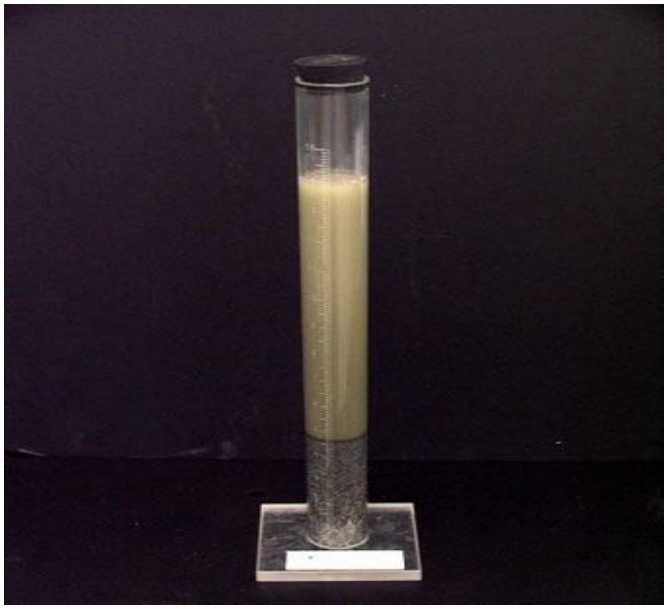


Fig.3.10: Sand equivalent test in progress

Procedure;

All fines attached to particles retained on the No. 4 (4.75 mm) sieve and include them in the sand equivalent sample was wash off. After which the sample split to obtain a little more than four 3 oz. (85 ml) tin measures (Figure 4) of material (about 12 oz. or 340 ml).

Extreme care was taken to obtain a representative sample in each tin. As the amount of material being split or quartered is decreased the accuracy of providing representative portions is reduced (AASHTO, 2000b).



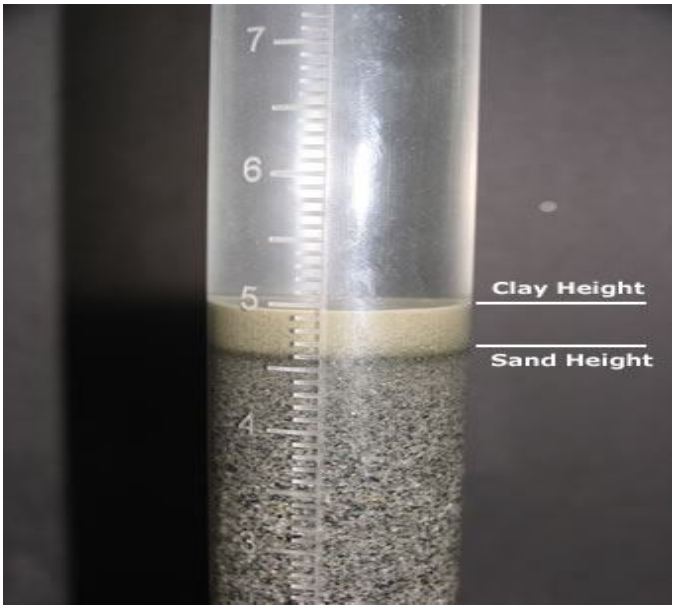


Fig. 3.11: Cylinder after shaking and irrigating - clay has not settled. **Fig. 3.12**: Close up of cylinder showing clay and sand height.

In the sand equivalent test, a sample of aggregate passing the No. 4 (4.75 mm) sieve and a small amount of flocculating solution were poured into a graduated cylinder and are agitated to loosen the clay-like coatings from the sand particles. The sample was then irrigated with additional flocculation solution forcing the clay-like material into suspension above the sand. After a prescribed sedimentation period, the height of flocculated clay and height of sand was determined and the sand equivalent was expressed as a ratio of the height of sand over that of clay. Higher sand equivalent values indicate "cleaner" (less fine dust or clay-like materials) aggregate.

- Value greater than 60 for Micro
- Value greater than 45 for Slurry

Sand equivalent was calculated using the following equation:

$$\text{SE} = \frac{Sand\ reading}{Emulsion\ reading} \text{ x } 100\% \quad -- \quad -3.5$$

3.4.10 Methylene blue Test ASTM (C 837- 09)

This test was performed in accordance with the provision in ASTM C837 - 09. The Methylene blue value of a specific fine aggregate fraction was reported in milligrams of MB per gram of fine aggregate. The MB value essentially expresses the quantity of MB required to cover the total surface of the clay fraction of the sample with a single-molecule layer of MB. Therefore, the MB value is proportional to the product of the clay content times the specific surface of the clay (Hosking, 1992). Higher MB values indicate more clay.

Significance of the test

Tests run on many types of clay generally indicate that a straight-line relationship exists between the methylene blue indexes (MBI) and such fundamental clay properties as cation exchange capacity, dry bond strength, and casting rate. Where the colloidal portion of the clay is kaolinite, there is also a direct correlation with specific surface (as determined by nitrogen adsorption). Where the colloidal portion contains significant amounts of illite or montmorillonite, the same close correlation does not exist. The MBI better correlates with the ceramic-forming properties than does the specific surface.



Figure 3.13: Methylene blue.



Figure 3.14: Methylene blue test Apparatus.

Procedure:

This test adds quantities of a standard aqueous solution of methylene blue (MB) dye (Figure 2) to a sample of dry fine aggregate passing the No. 200 (0.075 mm) sieve until adsorption of the dye ceases. The MB solution was then titrated step wise in 0.5 ml increments from the burrette into a continually stirred fine aggregate suspension. After each addition of MB solution and stirring for one minute, a small drop of the aggregate suspension was removed with a glass rod and placed on a filter paper. Initially, a well-defined circle of MB-stained dust was formed and was surrounded with an outer ring of clear water. Successive additions of MB solution are repeated until the end point was reached when the ring of clear water turns light blue.

3.4.11 Mixing/Setting Times ASTM (C403)

The mixing test is used to predict how long the material can be mixed in the machine before it begins to break. It is more for information to be used by the contractor than for the quality of the end product. It is, however, a good field test to check for consistent sources of material, both emulsified asphalt and aggregate. The process include the determination of emulsifier loading

level, after which the emulsions (high/low emulsifier loading) was Blended. The time needed was greater than 4 minute mixing time in lab and it was allowed to show clear water in 15-20 min under finger pressure.

3.4.12 Mix Consistency (SLURRY) ASTM (D6103)

The slurry seal possessed sufficient stability so that premature breaking of the material in the spreader box does not occur. The mixture was homogeneous during the mixing and spreading. It was free of excess water and emulsion and free of segregation of the emulsion and fine aggregate. Spraying of additional water into the spreader box will not be permitted.

3.4.13 Cohesion Test (ASTM D 3910)

Cohesion test was used to establish baseline formulations of emulsion, mineral filler, water (distilled) and aggregate suitable for testing. Selection of appropriate filler contents and water content was made based on results obtained after 30 and 60 minutes of curing at room temperature, 25^0 (77^0F) and 24hours curing in a 60^0 (140^0F) oven. The minimum values required are 12 Kilogram-centimeters for the 30 minutes test, 20 kg-cm for 60 minutes and 24 kg-cm for 24 hours cured cohesion.

The apparatus and materials used for this test are; Set of Cohesion tester, Specimen mounting pads, Specimen molds (6mm x 60mm) diameter, ASTM E-11 Sieve 4.75mm and 0.75mm, Plastic 0.6 liter (20 ounce) cup for mixing, Steel Spatula for mixing and for scraping off neoprene foot, A scale capable of weighing at least 600g to a hundredth of gram accuracy, Wash bottle with a very fine spout, Oven set at 60^0C (140^0F) and for Calibration;

a. 20-30 mesh standard ASTM C-190 Ottawa Sand,
b. 220 grit silicon carbide 3-M^{TM} brand sand paper,

c. 100 grit silicon carbide Carborundum^{TM} brand sand paper, and

d. Load cell to periodically check the cohesion meter pressure.

Sample Preparation.

Aggregate Grade II gradations were screened over a 4.75mm (No. 4) Sieve. Material not passing the 4.75 mm sieve was discarded. (3) Kilograms of aggregate were split and quartered using a riffle box. One hundred grams of aggregate was carefully measured into a plastic cup. The appropriate amount of cement or mineral filler used was carefully measured out. Whenever the mineral filler appeared slightly lumpy, it was sieved through a 0.075mm (No. 200) sieve prior to use. The mould was placed on the centre of felt pad, the corners of the pad having already been marked with the designated information, such as the amount of water, cement, and emulsion. Mineral filler was then added to the aggregate in the cup and thoroughly dry mixed for 10 seconds by stirring vigorously with a steel spatula. The aggregate and filler mixture was placed on the scale. After zeroing the scale, the desired amount of distilled water was added. The mixture was then thoroughly mixed for 10 seconds using steel spatula. Asphalt emulsion was added after the scale had been zeroed. Accepted scale tolerance was 0.01 gram. The mixture was stirred rapidly for 5 to 10 seconds until uniformly mixed. The mixture was then poured to one side of the mould. Using a steel spatula, immediately, the mixture was spread to cover the mould, in a minimum number of strokes leaving a flush surface. The mold was the gently lifted off in an upright manner with the fingers, so that the sample was not disturbed. A timer was used to measure the time for testing, either 30 minutes or 60 minutes. The 24-hours cured sample were placed in a 60^0C (140^0F) oven for 24 hours. Samples were cooled for two to five minutes and then tested.



Fig. 3.15: Cohesion test in Progress



Fig. 3.16: Sample after Cohesion test

Testing Procedure.

The sample was centered under the neoprene foot. The torque wrench was set to zero and placed on the top of the cylinder rod. The vertical load was applied for five seconds. Then the torque wrench was twisted in a smooth, firm, horizontal motion through a 90^0 arc within 0.5 to 0.7 seconds. The cohesion reading on the wrench was recorded as the cohesion of that mixture formulation at a specific time.

3.4.14 Wet Track Abrasion (ASTM D1044)

The test was performed in accordance with ASTM (D1044). The wet-track abrasion test is a field simulation test to establish the minimum asphalt emulsion content necessary to prevent excessive raveling. Two tests were conducted after curing the samples. The first test was performed after one hour of soaking in water and the second after six days of soaking to determine susceptibility to long-term moisture exposure.



Fig. 3.17: Wet Track Abrasion Test Apparatus



Fig. 3.18: Wet Track Abrasion Test Samples

The apparatus and materials used for this test are; A Hobart N-50 mixer, equipped with a 2.27kg abrasion head, quick clamp mounting plate and 300mm depth flat bottom metal pan fitted with a stable pan supporting, A scale capable of weighing 5,000 grams to within 0.1 gram, Fourteen kg (30 lb) roofing felt squares 300mm x 300mm, Twenty-five mm diameter and 450mm long, smooth, planed hardwood dowels, Rust resistant metal flat surface specified mold, depth 6.35mm and diameter 254mm. Forced draft oven set at 60^0C, Open air, rubber tanks and 127mm length reinforced rubber covered hose. (Parker 290 Ozex general purpose hose) with 19mm internal diameter and 6.25mm wall thickness.

Sample Preparation and Testing Procedure.

Sample preparation was essentially the same as that for cohesion testing except that 700 grams of dried aggregate were used in sample preparation. As such, the material quotation for each formulation which was based on 100 grams of aggregate was multiplied by seven. The sample was thoroughly mixed for not more than 10 seconds in round bottom steel using a long spoon.

The specimen mould was centered on the square roofing felt pad. The micro-surfacing slurry was then rapidly poured out onto the felt pad, over about half the space from one edge to cover. It is important that the mixture is squeezed in one direction only and worked over only once with a wooden dowel using a sawing motion. Segregation occurred if worked over more than once and emulsion bled from beneath the mould. The whole operation must be completed in less than 45 seconds. After the emulsion broke, the mould was removed. The molded sample was then placed in a 60^0C (140^0F) oven to dry to a constant weight. About fifteen hours was required to dry the sample to a constant weight.

The dried samples were removed from the oven and allowed to cool for ten minutes. After cutting off the edges of felt pad, the sample was weighed and the weight recorded. The sample was then immersed in a water bath at room temperature of 25^0C (77^0F) for 60 minutes or six days.

At the end of the soaking period, the sample was placed in the flat bottom pan of the abrasion tester and covered with five to six mm of distilled water at room temperature. The sample was then carefully clamped to the pan. If this was not done carefully, some aggregate was lost.

An unused side of the abrasion head (water hose) was brought into contact with the sample by lowering the head. The head at this stage was freely resting on sample surface. The timer was set for five minutes and fifteen seconds. The mixing speed was adjusted to position one and allowed to abrade the sample for the set time. For each rest, a fresh side of the hose was exposed. Each hose piece was used a maximum of four times.

The tested sample was removed from the pan, and the surface was flushed with slow-running room temperature distilled water. It was then dried to a constant weight in a 60^0C (140^0F) oven, and the new weight was recorded.

3.4.15 Loaded Wheel Tracks ASTM (D2240)

The test was carried out in conform to ASTM (D2240). The loaded wheel test is a field simulation test used to investigate resistance to flushing under heavy load. It serves as a means of determining the maximum amount of binder the mixture can withstand, by measuring how much fine sand adheres to a preconditioned sample.

The apparatus and materials used for this test are; A wheel testing machine designed to the specifications given in the ISSA technical bulletin No. 109 January 1991 (5), Specimen mold 9.5 mm thick x 75mm x 406mm (0.375 in x 3 in x 16 in) outside, and 50mm x 80 mm (2 in x 15 in) inside dimensions. Steel specimen mounting plates 0.6 mm (0.024 in) galvanized steel 75 mm x 406 mm (3 in x 16 in), 56.7 kg (125 Ib) weight. Steel sand frame, 5mm x 63.5 mm x 380 mm, (0.188 in x 2.5 in x 15 in) outside and 37.5 mm x 360 mm (1.5 in x 14 in) inside dimensions; one side of the frame should be completely lined with 12.5 mm x 12.5 mm (½ in x ½ in) adhesive backed foam rubber insulation and hold down clamps and Hard wooden dowel 150 mm (6 in) long and 25 mm (1 in) diameter.



Fig. 3.19: Loaded Wheel Tracks test Apparatus

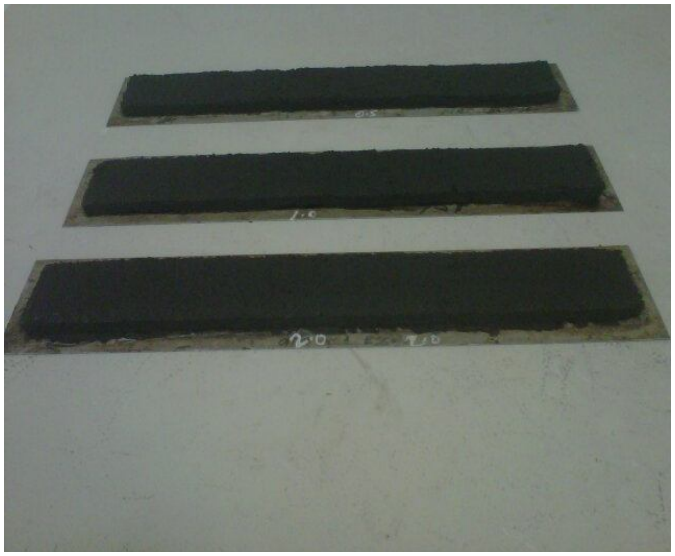


Fig. 3.20: Loaded Wheel Tracks Test Sample

Sample Preparation and Testing Procedure.

Samples were prepared in the same manner as for wet track abrasion, except that only 300 grams of aggregate was used. A short, wooden dowel was used to screed off excess material using a sawing motion. The sample frame was rigidly held in one hand while this was being done. The sample was cured to a constant weight for a minimum of fifteen hours in a 60^{o}C (140^{o}F) forced air oven before testing. After the sample had cured and cooled to room temperature, it was firmly clamped to the frame and exposed to the passage of 1000 cycles of the 56.7 kg (125 Ib) loaded wheel. A properly calibrated machine should achieve this in 22.5 minutes. The weight of this compacted sample was recorded. The sample was then firmly clamped together with the steel sand frame. Two hundred grams of fine Ottawa sand (ASTM Designation C-109 graded standard) heated to 82^{o}C (180^{o}F) was uniformly spread over the sample surface that appears within the frame. A preheated metal strip (heated for 20 minutes in the 82^{o}C (180^{o}F), oven) was placed over the sand covered sample surface. This metal strip has dimensions that allow it to fit

snugly into the sand frame. The wheel was immediately placed on the sample, 56.7 kg (125 Ib) loaded, and 100 cycles applied.

The sample together with the sand frame, closely held together, was then removed. Loose sand was poured out and the sand frame was released. Gently but firmly, the sample was then tapped uniformly from one end to the other and back in twenty light strokes. The sample weight was then recorded. The difference in weight is the adhered sand.

3.4.16 Test on Cement (OPC)

Some preliminary tests like setting time and soundness tests were carried out on cement in according with BS EN196, part 3 (1995). The results is as shown in the table 3.1

3.5. Material Mix Design

The mix design was done to give the values of each of the materials used, for comparison to the requirements given in the material specifications. Also before construction starts the mixing and lay-down machine must be calibrated, to ensure that each of the ingredients used in the mix are in the correct proportions. ISSA TB-A143 for Micro-Surfacing and TB-A105 for Slurry Seal are excellent guidelines and should be used as reference for the development of local standards and specifications. Quality control of the mixture is critical and initial trial runs were run to ensure compliance with the mix design.

3.5.1 Slurry Seal Mix Design Data

Quarry Screen Dust	**100** %
Portland Cement	**1.0** %
Added Water	**9.0** %
CQS-1H	**13.0** ± 1.0%

Table 3.1: ISSA Specification for Mix Design Limit. (ISSA A105 / ISSA T106)

COMPONENT MATERIALS	LIMITS
Residual Asphalt (Emulsion)	Type I: 10 – 16% Type II: 7.5 – 13.5% Type III: 6.5 – 12% (Based on dry weight of aggregate)
Mineral Filler (Cement)	0.5 – 2.0% (Based on dry weight of aggregate)
Additives (Crumb Rubber)	As needed
Water	As needed to achieve proper mix consistency (Total mix liquids should not exceed the loose aggregate voids.)

3.6 Mix Stability

The slurry seal shall possess sufficient stability so that premature breaking of the material in the spreader box does not occur. The mixture shall be homogeneous during and following mixing and spreading. It shall be free of excess water and emulsion and free of segregation of the emulsion and aggregate fines from the coarser aggregate. Spraying of additional water into the spreader box will not be permitted.

3.7 Determining the Type of Maintenance

The appropriate type of maintenance for cracked pavements often depends on the density and general condition of the cracks. If cracks are abundant and do not exhibit a high degree of edge deterioration, they may best be treated through chip seals, slurry seals, or the like. If cracks are low to moderate in density and have typically progressed to a point of high edge deterioration, then the crack repair strategies, such as partial-depth patching or spot patching, may be warranted. If cracks are moderate in density and show moderate to no deterioration at the edges,

then they may be treated effectively through sealing or filling operations. Table 3.2 summarizes these guidelines.

Table 3.2: FHWA Guidelines for determining the type of maintenance to be performed. (FHWA-RD-99-147).

Crack Density	**Average Level of Crack Edge Deterioration (Percentage of Crack length)**		
	Low (0 to 25)	Moderate (26 to 50)	High (51 to 100)
Low	Nothing	Nothing or Crack Treatment	Crack Repair
Moderate	Crack Treatment	Crack Treatment	Crack Repair
High	Surface Treatment	Surface Treatment	Rehabilitation

Source: (FHWA Manual)

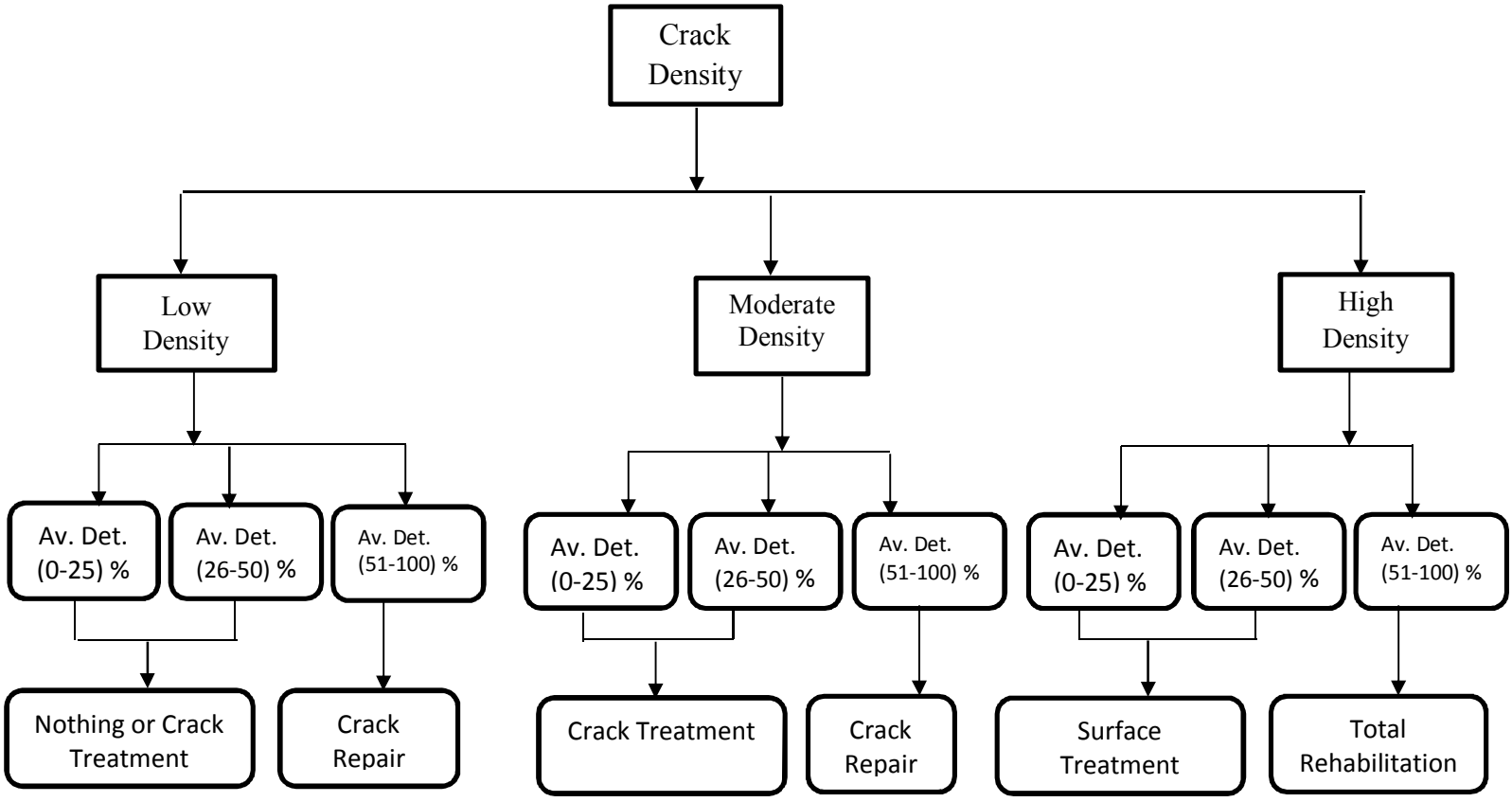


Fig. 3.21: Determination of the type of maintenance to be performed.

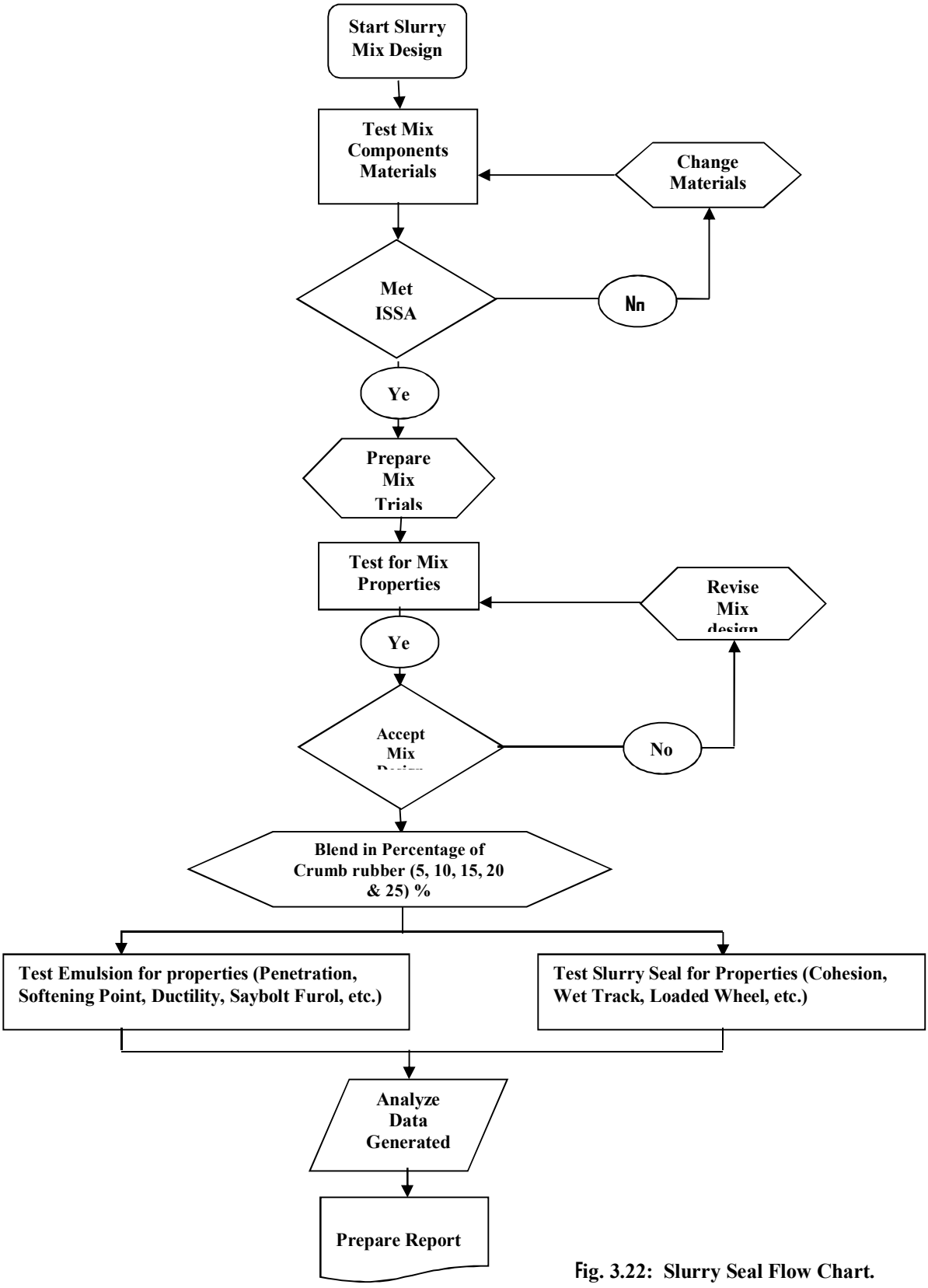


Fig. 3.22: Slurry Seal Flow Chart.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Asphalt (Bitumen) and Slurry Test result

The Results of various tests carried out on asphalt (bitumen) and slurry seal as described in chapter three is presented in this chapter. Results obtained were compared with the International Slurry Seal Association standards.

4.2 Test on Cement.

Cement used was tested for both initial and final setting times and soundness to determine its consistency. Results obtained was compared with the recommendations of BS EN196, Part 3 (1995) and shown in Table 4.1

Table 4.1: Result of Consistency Test on Cement.

TEST	Code Used	Average Value Obtained	Code Recommendation
Initial Setting Time	BS EN196, Part 3 (1995)	82minutes	>45 minutes
Final Setting Time	BS EN196, Part 3 (1995)	3hrs 35minute	< 10hours
Soundness	BS EN196, Part 3 (1995)	3.4mm	< 10mm

4.3.0 Specific Gravity of the materials

The Specific gravities of the materials used are as follows:

- Emulsion = 1.01
- Crumb Rubber = 1.15
- Fine Aggregate = 2.901

4.4.0 Aggregate Gradation and Data

The aggregate used in the test was found to be within the envelop range of International Slurry Seal Association (ISSA), with Sieve Nos. ranging from (0.075mm – 9.5mm). 100% of the aggregate passed through Sieve No. (9.5mm). The Sieve analysis of this aggregate also showed that 94.3% passed sieve No. (2.36mm) against ISSA range of (90 – 100) %, 68.6% passed sieve No. (1.18mm) against ISSA range of (65 – 90) %, 50.02 % of the aggregate passed Sieve No. (0.6mm) as ISSA range is (40 – 65) %. Also, it was found that 36.9% passed Sieve No. (0.3mm) against (25 – 42) % ISSA range, 25.8% passed Sieve No. (0.15mm) as ISSA range is (15 – 30) and 16.1% passed Sieve (0.075mm) ISSA range is (10 – 20) %. This was indicated on the graph with blue colour as the red colour indicated the lower and upper range of the ISSA.

Table 4.2 Aggregate Gradation

Aggregate: **Quarry Screen Dust**

Source: **MRT Quarry**

Sieve	% Passing	ISSA Type I	
		min	max
4.75 mm	**100.0**		
2.36 mm	**94.3**	100	100
1.18 mm	**68.6**	90	100
0.6 mm	**50.2**	65	90
0.3 mm	**36.9**	40	65
0.15 mm	**25.8**	25	42
0.075 mm	**16.1**	15	30
Sand Equivalent	81	10	20
Methyle Blue	1		

45

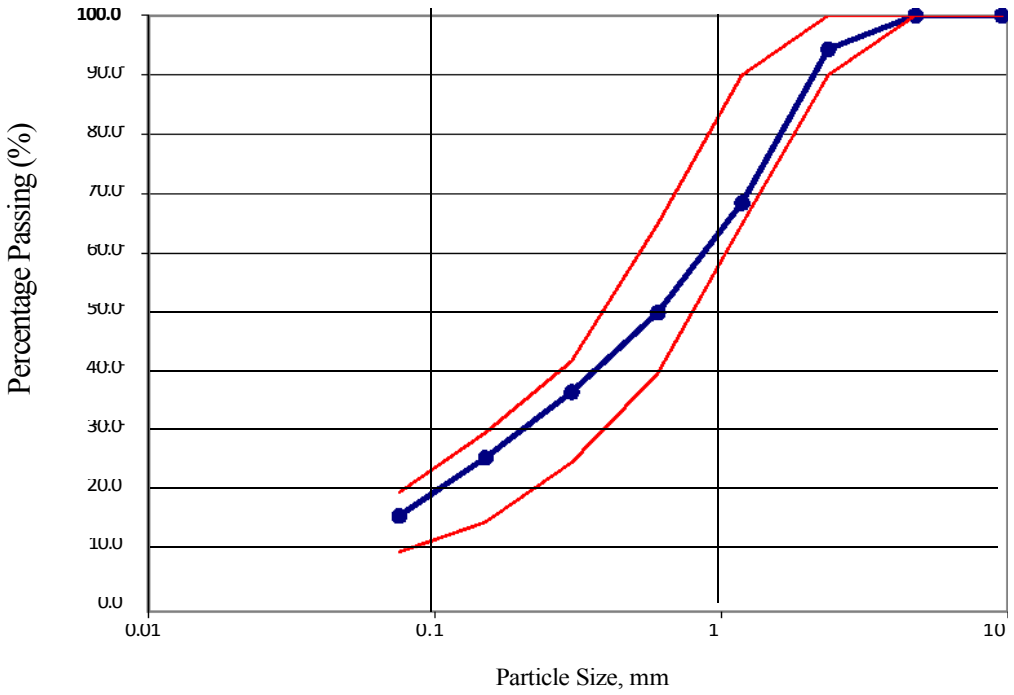


Fig. 4.1 Fine Aggregate grading curve.

Table 4.3: ISSA Specification on Aggregate Grading. (ISSA A105)

SIEVE SIZE	TYPE I % Passing	TYPE II % Passing	TYPE III % Passing	STOCKPILE TOLERANCE
3/8 (9.5mm)	100	100	100	
#4 (4.75mm)	100	90 – 100	70 – 90	±5%
#8 (2.36mm)	90 - 100	65 – 90	45 – 70	±5%
#16 (1.18mm)	65 - 90	45 – 90	28 – 50	±5%
#30 (600um)	40 – 65	30 – 50	19 – 34	±5%
#50 (330um)	25 – 42	18 – 30	12 – 25	±4%
#100 (150um)	15 – 30	10 – 21	7 – 18	±3%
#200 (75um)	10 – 20	5 – 15	5 - 15	±2%

Source: (ISSA A105 January, 2001).

4.5.0 Emulsion Test. (ISSA A143)

The various tests carried out on the Emulsion were in conforming to ISSA A143 specifications. The tests results showed the quality properties of the Asphalt cement (Bitumen) used in the production of emulsion. The result of the tests is as shown in Table 4.3. Graphs of the test like Saybolt-Furol Viscosity, Kinematic Viscosity, Residue by distillation, Penetration and Soft point against the Crumb rubber content is as shown in Figures (4.2 – 4.6) respectively.

Table 4.4: ISSA A143 EMULSION TEST DATA

Tests on Asphalt Emulsion	**CQS-1H Emulsion**						**ISSA A 143**
% Crumb Rubber	**0**	**5.0**	**10.0**	**15.0**	**20.0**	**25.0**	**Specification**
Saybolt-Furol Viscosity, 25°C, SFS	31.0	55.0	80.0	95.0	215.0	465.0	20 - 100
Sieve Test, % by mass	0.03	0.032	0.04	0.045	0.065	0.076	0.1 max
Particle Charge	Positive	Positive	Positive	Positive	Positive	Positive	Positive
Settlement, 5 days, %	1.2	1.5	1.8	1.9	2.0	2.5	5 maximum
Residue by Distillation, 260°C, % by mass	64.5	66.0	66.8	67.9	68.3	68.9	62 minimum
Oil Portion of Distillate, % vol./mass	0.5	0.5	0.5	0.5	0.5	0.5	5 maximum
Tests on Residue							
Penetration, 25°C, (mm)	73.4	64.2	63.2	60.5	58	55.3	40 - 90
Softening Point by R&B, °C	48.1	49.0	53.0	53.6	55.3	57.8	57 maximum
Kinematic Viscosity, 135°C, mm^2/s	1450.0	1235.0	1105.0	950.0	875.0	695.0	650 minimum

4.5.1 Saybot-Furol Viscosity

Saybolt-Furol Viscosity test graph in Figure 4.2 shows the effect of Crumb rubber on viscosity. Viscosity increased with Crumb rubber content from 31.0 at 0% Crumb rubber to 95 at 15% Crumb rubber content. These values are within the range specified by ISSA, but at 15% modification loading the viscosity value are greater than the maximum value of 100 specified by ISSA, an indication that it is not suitable to add more than 17.5 % Crumb rubber.

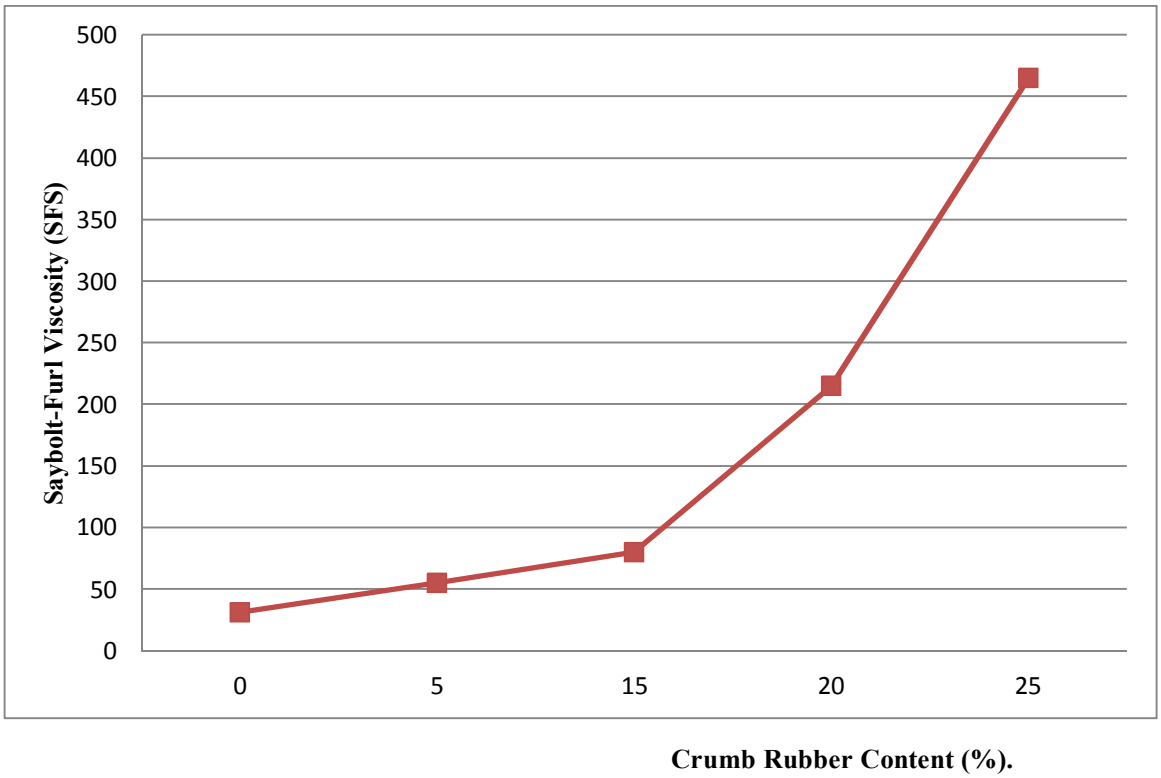


Fig. 4.2: Variation of Saybot-Furol Viscosity with Crumb Rubber Content (%).

4.5.2 Residue by Distillation

Figure 4.3 showed the variation of Residue by distillation with Crumb rubber content. This graph showed increment in Residue in an ascending order. The Minimum Residue recommended by the ISSA specification was 62g. However, 0%, 5%, 10%, 15%, 20% and 25% Crumb rubber content produced 64.5, 66, 66.8, 67.9, 68.3 and 68.9 respectively. The 17.5% Crumb rubber content produced 68g against 62g minimum specified by the ISSA.

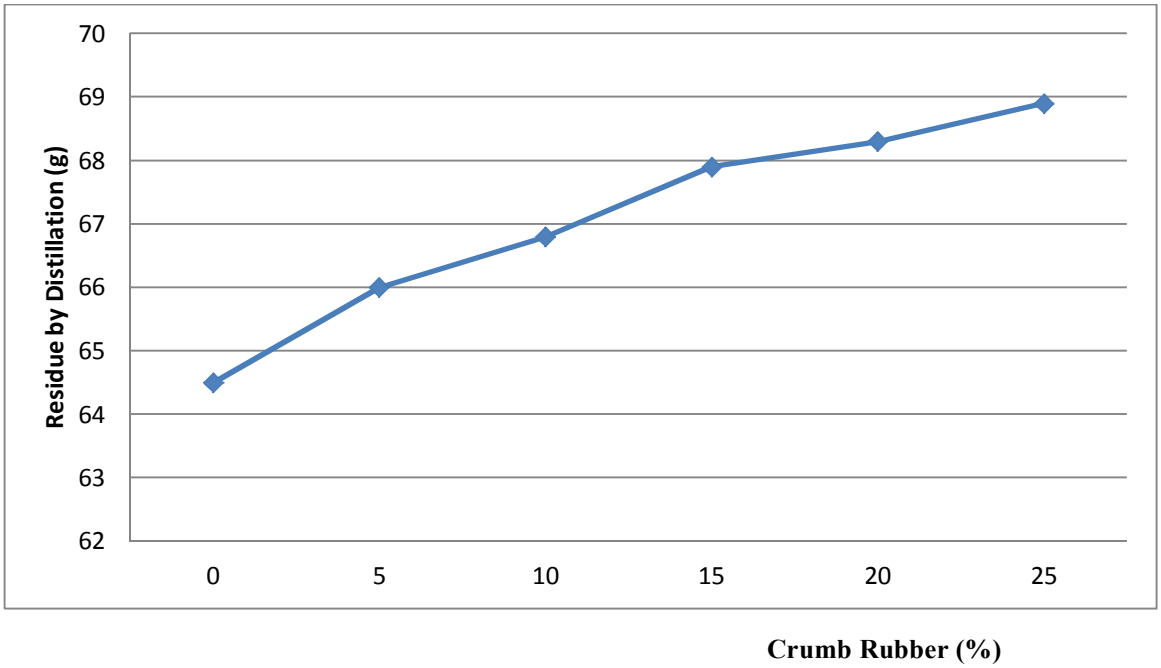


Fig. 4.3: Variation of Residue by Distillation (g) and Crumb Rubber (%)

4.5.3 Penetration Test

The International Slurry Seal Association specified that the penetration at 25^0C should lie between (40 – 90) mm. While at 0%, 5%, 10%, 15%, 20% and 25% the penetrations obtained were 73.4, 64.2, 63.4, 60.5, 58 and 55.3 respectively. Values obtained are within the limit specified by ISSA. The penetration was discovered to be reducing in a descending other as Crumb rubber content increases. Figure 4.4 showed variation of Penetration with Crumb rubber content.

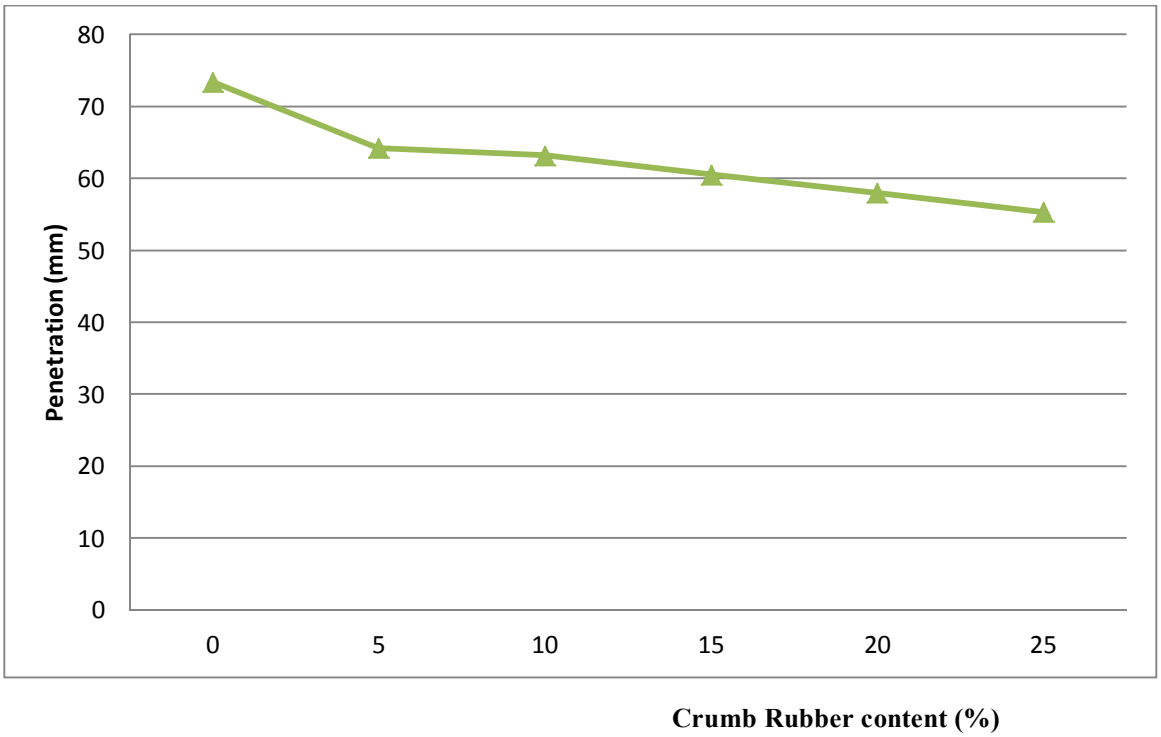


Fig. 4.4; Variation of Penetration (mm) with Crumb Rubber content (%)

4.5.4 Softening point Test

Softening point test carried out on the Emulsion showed that at only 25% Crumb rubber, Softening point value was57.8mm which was more than the maximum value specified by the ISSA. Results of tests at the remaining Crumb rubber content of 0%, 5%, 10%, 15% and 20% with values of 48.1, 49.0, 53.0, 53.6 and 55.3 respectively, are within the ISSA limit. Variation of Softening point test value with Crumb rubber content is as reflected in Figure 4.5.

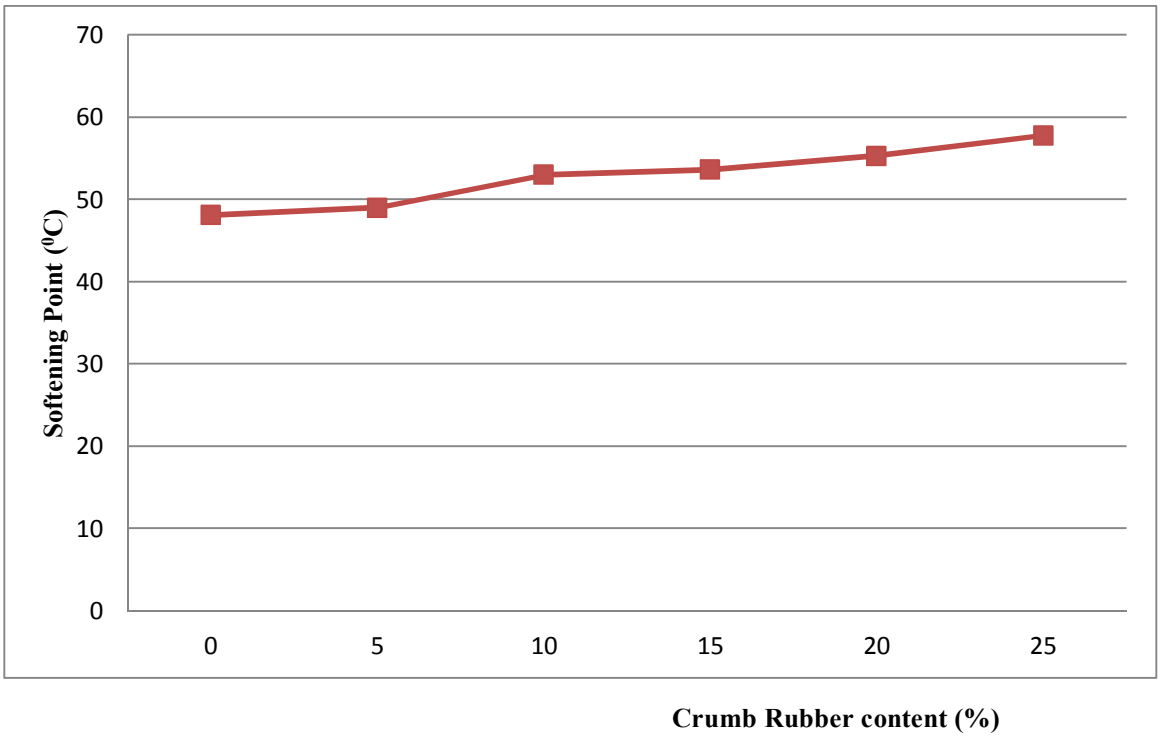


Fig. 4.5: Variation of softening point Value (^{0}C) with Crumb Rubber content (%)

4.5.5 Kinematic Viscosity Test

It was observed from the test, that Saybolt-Furol Viscosity increased in an ascending order with Crumb rubber content, while the Kinematic Viscosity test decreased with Crumb rubber contents. ISSA minimum value of 650mm^2/s at 135^{0}C was satisfied. However, at 0%, 5%, 10%, 15%, 20% and 25% values of 1450, 1235, 1105, 950, 875 and 695 were obtained respectively. This is shown in figure 4.6

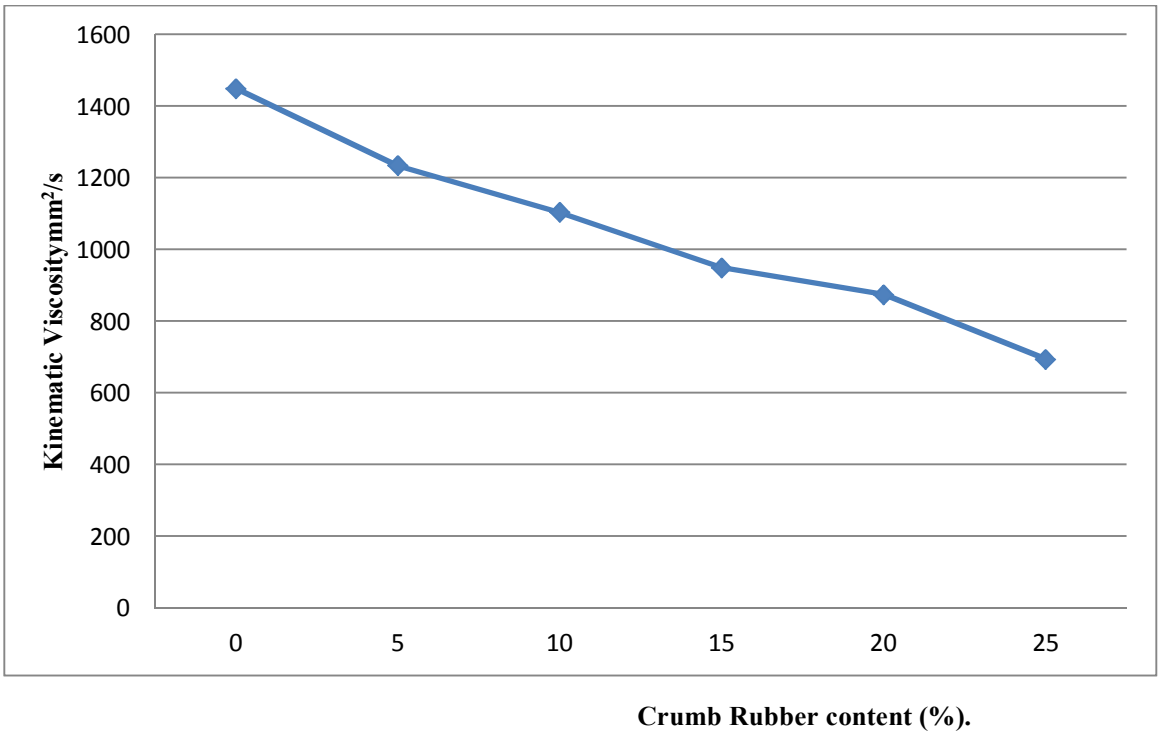


Fig. 4.6; Variation of Kinematic Viscosity with Crumb Rubber content (%).

4.6.0 Slurry Seal Trial Mix Design.

The trial mix design was done in 3 different categories, varying the emulsion content in oder to obtain most appropriate design mix to be used. In each of this design process, 100% of aggregate was used, 1 % of Portland cement was added, with water content varied from (10, 9 and 8) % respectively. The Emulsion content was also varied from (10, 13 and 16) % respectively.

The Slurry formed at 10% Emulsion and 10% water content was found to be Dry in appearance, Rough in texture and Mixing time of 120 seconds which is less than 180+ or > 180 seconds recommended by the ISSA. Although other parameters like Cohesion, WTA Loss, Wet Stripping, Lateral displacement and Excess Asphalt are within the range of ISSA Specification.

However, when 13% Emulsion and 9% water content was used, the appearance was Medium rich, the Texture was smooth and the Mixing time was 180+. All other parameters in this respect also conform to the ISSA Specification. As Cohesion was 19kg-cm at 30minute, 24kg-cm at 60minute against 12kg-cm minimum at 30minute and 20kg-cm at 60 minute minimum in ISSA standard. While WTA loss (g/m^2), Wet Stripping (%), Lateral Displacement (%) and Excess Asphalt (LWT) (g/m^2) were 254 (g/m^2), 97%, 4.5% and 280.2 (g/m^2) respectively against ISSA Specifications of 538 (g/m^2) Maximum, 90% Minimum, 90%Minimum, and 538(g/m^2) Maximum.

In using 16% of Emulsion and 8% water content, the appearance was found to be Rich, the Texture was Smooth and Parameters like cohesion, Wet Stripping were almost the same with the result when 13% Emulsion content was used. But parameters like WTA loss and Lateral displacement were found to be lower than the values obtained when using 13% Emulsion content. Although, they also conform to the ISSA specification. While Excess Asphalt (LWT) value was 334.1(g/m^2) against 538(g/m^2).

Therefore, based on the above results obtained 13% Emulsion content and 9% Water content found to be more desirable in Slurry Seal Mix Design was used. The mix design is as presented in Table 4.3 and Figure 4.2

Table 4.5 Slurry Seal Trial Mix Design Data

		SLURRY SEAL MIX			
Design Point		**1**	**2**	**3**	**ISSA A105**
% Quarry Screen Dust		100.0	100.0	100.0	
% Portland Cement		1.0	1.0	1.0	
% Added Water		10.0	9.0	8.0	
% CQS-1H		10.0	13.0	16.0	
Appearance		Dry	Medium	Rich	
Texture		Rough	Smooth	Smoot	
Mixing Time, sec.		120+	180+	180+	>180 sec
Cohesion @ 30 min, kg-cm		21	19	20	12.0 minimum
Cohesion @ 60 min, kg-cm		21	24	26	20.0 minimum
WTA Loss, g/m^2	1 Hr	270.2	254.0	227.1	538 g/m^2 maximum
Wet Stripping, %		97	97	97	90% minimum
Lateral Displacement*, %		4.58	4.5	4.25	5% maximum
Excess Asphalt by LWT, g/m^2		211.0	280.2	334.1	538 g/m^2 maximum

*Notes: * - only required for heavy traffic*

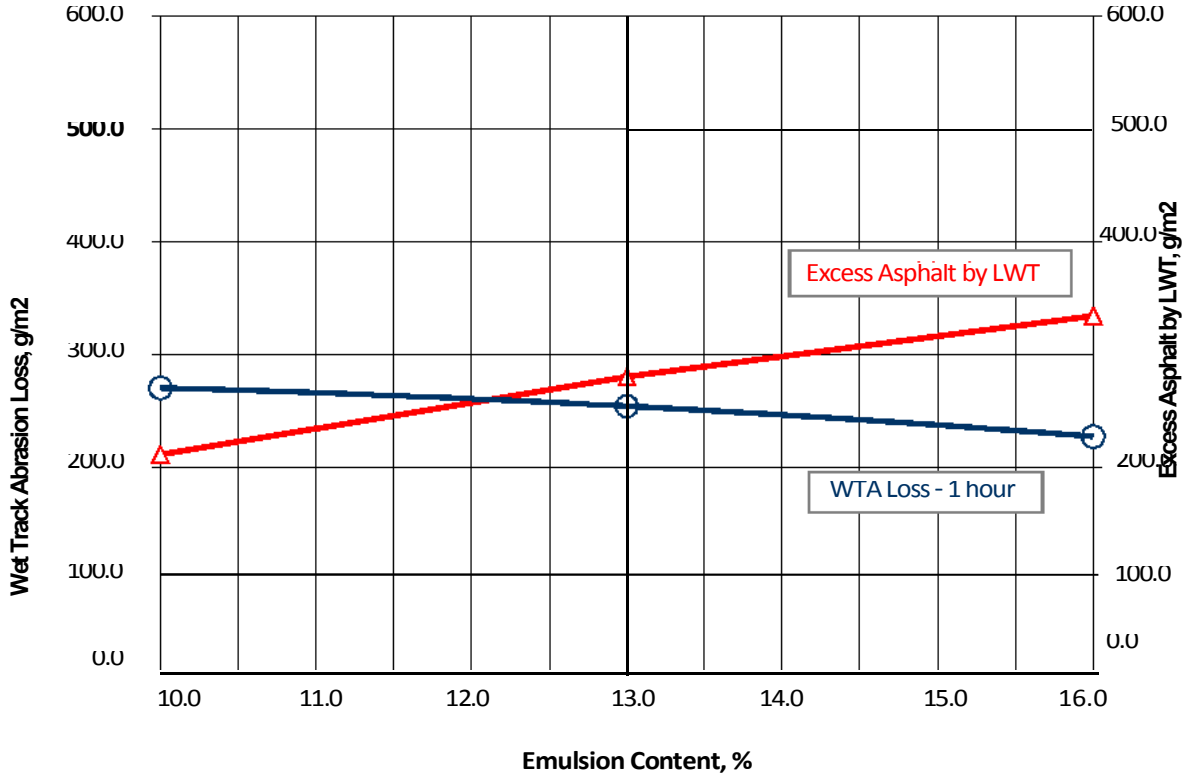


Fig. 4.7: WTL and LWT graph

4.7 Slurry seal Non Modified Mix Design.

The Non Modified Mix design was obtained from the trial mix design test. The Mix No.2 in the trial mix design conforms to the ISSA specification and also gave most effective and reliable mix ratio. Results of tests for mix 2 is as shown in Table 4.4 as Non Modified Mix Design.

Table 4.6: The mix design for Non Modified Slurry seal meets the following specification

Test	**Time / Days**	**Tests Values**	**ISSA Specifications**
Residue Asphalt (%)		**8.45**	
Wet Cohesion (Kg-cm)	- 30 min. - 60 min.	**19** **24**	12 kg-cm minimum 20 kg-cm minimum
Wet Track Abrasion (g/m^2)	- 1 hour - 6 days*	**204.5** **254.0**	538 g/m^2 maximum 807 g/m^2 maximum
Excess Asphalt Loaded Wheel (g/m^2)		**280.2**	538 g/m^2 maximum
Lateral Displacement (%)		**4.5**	5 % maximum
Wet Stripping (%)		**97.0**	90 % minimum
Consistency (mm)		**22.0**	20 - 30 mm
Mixing Time (Sec)		**Pass**	Controllable to >180 sec.

4.8.0 Slurry seal Modified Mix Design.

The values obtained from the Trial mix No.2 of non-modified design was used as the values for 0% Crumb rubber content. After which the Crumb Rubber was added in incremental order of 5% up to 25% and used to replace Bitumen content in the mix. While the variation of the Crumb Rubber in a given percentage, all other parameters like fine aggregate content and Portland cement and Emulsion content used were kept constant. This is as shown in Table 4.6

Table 4.7: SLURRY SEAL CRUMB RUBBER MODIFIED MIX DATA

SLURRY SEAL CRUMB RUBBER MODIFIED MIX DATA							
Crumb Rubber Dosage (%)	**0**	**5.0**	**10.0**	**15.0**	**20.0**	**25.0**	**ISSA A105**
% Quarry Screen Dust	100	100.0	100.0	100.0	100.0	100.0	
% Portland Cement	1.0	1.0	1.0	1.0	1.0	1.0	
% Added Water	9.0	10.0	9.0	9.0	9.0	8.0	
% CQS.1H	13.0	13.0	13.0	13.0	13.0	13.0	
Appearance	Medium Rich	Medium Rich	Medium Rich	Medium Rich	Medium Rich	Medium Rich	
Texture	Smooth	Smooth	Smooth	Smooth	Poofy.Rough	Poofy..Rough	
Mixing Time, sec.	180	165+	195+	200+	220+	240+	>180 sec
Cohesion @ 30 min, kg.cm	19	18	21	23	20	20	12.0 minimum
Cohesion @ 60 min, kg.cm	24	20	23	28	23	22	20.0 minimum
WTA Loss, g/m2	1 Hr	338.9	345.5	365.2	394.8	408.0	538 g/m^2 maximum
Wet Stripping, %	97	97	97	97	97	97	90% minimum
Lateral Displacement*, %	4.5	4.81	4.14	3.59	4.42	5.04	5% maximum
Excess Asphalt by LWT, g/m^2	211.0	118.8	248.0	310.0	315.2	299.7	538 g/m^2 maximum

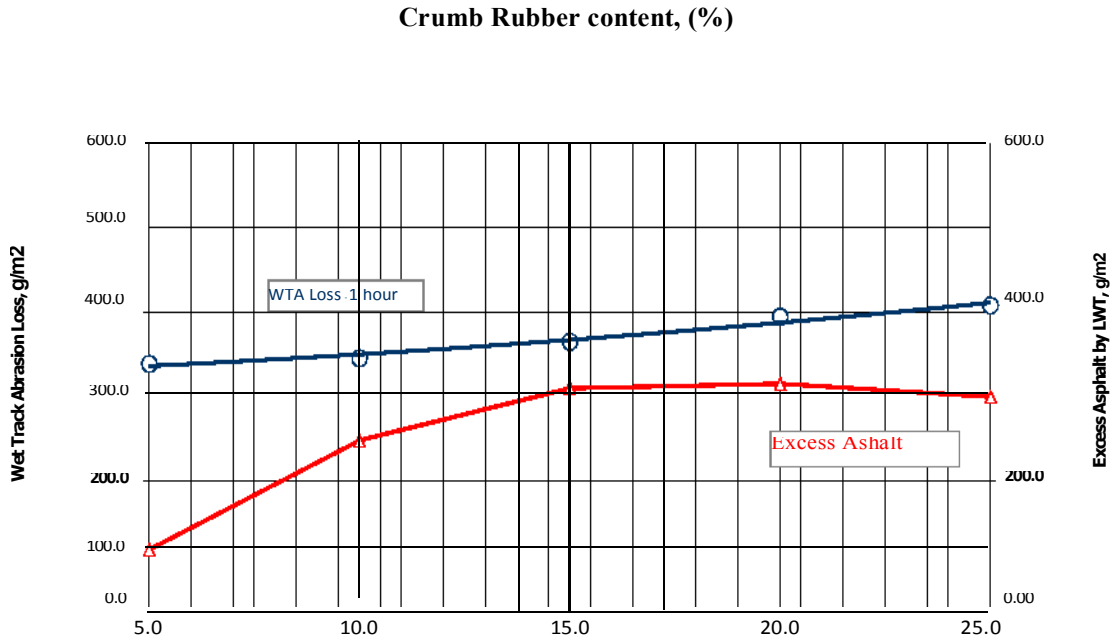


Fig. 4.8: Wet Track Abrasion, Excess Asphalt and Crumb Rubber graph.

Results of test reflected in Fig. 4.8 showed that increase in percentage of Crumb Rubber content resulted in increased in the values of Wet Tact Abrasion Loss test (WTA), and Excess Asphalt test result value. But it was observed that Lateral displacement was found to be lowest (3.59%) at 15% Crumb rubber content against value of (5.04%) at 25% Crumb rubber content and a little more than ISSA recommended value of 5%.

Cohesion was observed to be highest (28%) at 15% Crumb Rubber against 20%, 23%, 23% and 22% for 5%, 10%, 20% and 25% Crumb Rubber content respectively.

Based on the analysis of the results of Table 4.5 and Figure 4.3, 15% Crumb Rubber content was found to be most desirable. As such it was used as the most appropriate since it conformed to the ISSA recommendations. This is shown in Tables 4.6 and 4.7.

Table 4.8: Crumb Rubber Modified Slurry Seal Mix Data

Test Materials	**ISSA Specifications**
Quarry Screen Dust	**100** %
Portland Cement	**1.0** %
Added Water	**9.0** %
Optimum Crumb Rubber	**17.5** %
CQS-1H (Emulsion)	**13.0** ±1.0%

Table. 4.9: The modified slurry design at 17.5% crumb rubber content meets the following specification criteria:

Test	**Time / Days**	**Tests Values**	**ISSA Specifications**
Residue Asphalt		**8.45**	
Wet Cohesion	- 30 min. - 60 min.	**25** **28**	12 kg-cm minimum 20 kg-cm minimum
Wet Track Abrasion	- 1 hour - 6 days*	**365.2** **361.9**	538 g/m^2 maximum 807 g/m^2 maximum
Excess Asphalt Loaded Wheel		**310.0**	538 g/m^2 maximum
Lateral Displacement		**3.6**	5 % maximum
Wet Stripping		**97.0**	90 minimum
Consistency		**24.0**	20 - 30 mm
Mixing Time		**Pass**	Controllable to >180 sec.

4.9 Summary of the optimum test's values.

The Optimum Crumb rubber content of 17.5% and 13% Emulsion content was observed to be medially rich in appearance, Smooth in texture and passed > 180 Sec. mixing time specified by the ISSA. Hence its recommendation for use in emulsified asphalt for use as sealant. Table 4.9 showed the values obtained for the optimum value from the tests carried out.

Table 4.10: Summary of the Optimum values obtained from the Test.

TESTS	OBTAINED OPTIMUM VALUES	ISSA SPECIFICATION
Optimum Crumb Rubber Content	15%	
Emulsion Content	13%	
Appearance	Medium Rich	
Texture	Smooth	
Mixing Time, sec.	200	Controllable to >180 Sec.
Cohesion @ 30 min, kg-cm	23	12kg-cm Minimum
Cohesion @ 60 min, kg-cm	28	20kg-cm Minimum
WTA Loss, g/m^2 – 1 hour **- 6 days**	365.2 361.9	538g/m^2 maximum 807g/m^2 maximum
Wet Stripping, %	97	90 minimum
Lateral Displacement*, %	3.59	5% maximum
Excess Asphalt by LWT, g/m^2	310	538g/m^2 maximum
Consistency	24	20 - 30mm

4.10 RATE OF APPLICATION

The slurry seal mixture shall be of proper consistency at all times so as to provide the application rate required by the surface condition. The average application rate shall be in accordance with the following table below:

Table 4.11: Slurry seal Rate of Application.

AGGREGATE TYPE	LOCATION	SUGGESTED APPLICATION RATE
Type I	Parking Areas Urban and Residential Streets Airport Runways	8 - 12 lb/yd^2 (3.65 - 5.44 kg/m^2)
Type II	Urban and Residential Streets Airport Runways	12 - 20 lb/yd^2 (5.44 - 9.07 kg/m^2)
Type III	Primary and Interstate Routes	18 - 30 lb/yd2 (8.16 - 13.6 kg/m^2)

Source: (ISSA, 2005)

Application rates are affected by the unit weight of the aggregate, the gradation of the aggregate and the demand of the surface to which the slurry seal is being applied. ISSA Technical Bulletin 112 gives a method to determine expected application rates.

4.11 Cracks Treatment and Surface Preparation

It is advisable to pre-treat cracks in the pavement surface with an acceptable crack sealer prior to application of the slurry seal. Cracks should be thoroughly cleaned of any detritus and loose material, using compressed air, drying, and then sealing with slurry seal. On heavily trafficked roads or where opening has led to excessive stone loss, sweeping is essential. A suction broom is the best type of sweeper to use. Sweeping should be done just prior to opening to traffic and at periods determined by the level of stone loss. Manholes, valve boxes, drop inlets and other service entrances shall be protected from the slurry seal by a suitable method.

4.12 Sanding

Sanding may be used to reduce the time that cross streets or intersections are closed. Sanding is the application of a fine layer of dry, washed sand that is broadcast over the slurry surface to prevent pickup. Sanding may also be used on wet spots. Sanding should not be done until the slurry can withstand walking traffic.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Following the results obtained from the series of tests carried out on both the materials and the modified slurry seal, the following conclusions can be drawn from the study.

i) Optimum Crumb Rubber that produced the most appropriate result is 17.5%.

ii) The Modified Slurry Seal obtained at optimum Crumb rubber content of (17.5%), appears medium reach, the Texture was smooth, Mixing time was 200seconds against which is in coherence with the provision of the ISSA (>180 seconds),

iii) The Cohesion at Optimum Crumb rubber content for the 30 and 60 minutes was found to be 23 and 28 kg-cm respectively against the ISSA specification of 12 and 20 kg-cm minimum correspondingly.

iv) The Wet stripping was 97 against recommended (90) minimum and Lateral displacement was 3.59% against (5%) maximum, at the optimum Crumb rubber content of (17.5%).

v) The Wheel Track Abrasion loss WTA at 1 hour and 6 days was 365.2g/m^2, 361.9g/m^2 against the maximum value of 538g/m^2 and 807g/m^2 respectively optimum Crumb rubber content of (15%).

vi) The result of the Excess asphalt test optimum Crumb rubber content of (17.5%), was 310g/m^2 compared with ISSA specified maximum of 538g/m^2 and the Consistency was 24mm as the specification a range of 20 – 30mm.

5.2 RECOMMENDATIONS

- In view of the encouraging of the Crumb rubber modification for Slurry seal and in order to achieve an excellent product, Crumb rubber content should be in the range of 13% - 17.5%.
- The application of Crumb rubber modified Slurry seal should be investigated.
- The possibility of adapting Slurry seal in Federal Roads Maintenance Agency as one of the means of preventive maintenance method should be investigated.
- The economic evaluation of the Modified Slurry seal should be investigated.

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