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**Assessment on the Utilization of Recycled
Hollow Block as Asphalt Mastic Material**

A Thesis in Road and Transport

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Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

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UNDERTAKING

I certify that research work titled “Assessment on the utilization of Recycled Hollow Block as Asphalt Mastic Material” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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ABSTRACT

In road construction, different kinds of filler materials are used. Among them the very common are stone dust, cement, lime, crushed concrete, flay ash and crushed glass fines. These materials have their own drawbacks such as high cost and availability

Therefore, the theme of this thesis is to assess the rheological property of recycled hollow block to use it as mastic asphalt (blends of binder and recycled hollow block), as it is easily available from the wastes of building construction and also from hollow block manufacturing companies.

The objective of this research is hence to identify the availability of Hollow Block waste material from construction sites and manufacturing companies, to study the basic engineering properties of recycled Hollow Block before blending (as filler material) and to characterize the rheological property of mastic. i.e. Linear Visco Elastic (LVE) range, master curve and Multiple stress creep recovery (MSCR) of mastics.

To meet the objectives, to know the availability of waste Hollow Blocks questionnaires were distributed to different real estate companies, construction companies and Hollow Block manufacturing companies. A chemical composition test was performed to check on the chemical properties. For the Hollow block as a filler material specific gravity test, sieve analysis and plasticity index test were done. After having performed the filler tests, recycled hollow block was blended with the bitumen at 15%, 25% and 35% of the binder. After doing so, different tests for the binder and the mastic were performed to check on penetration, ductility, softening point, loss on heating.

The rheological properties of both the binder and mastic were checked by different tests such as amplitude sweep test, Frequency sweep test, Performance grade determination and MSCR were performed by Dynamic Shear Rheometer (DSR).

Prior to performing Frequency Sweeps Test (FST), Amplitude Sweep Tests (AST) was performed to establish the linear viscoelastic range of the mastics performed at different temperatures at 10 rad/s. After completing the AST based on LVE range, frequency sweeps for a range of temperatures and frequencies were performed on all the samples. Frequency sweeps are used to measure the complex shear modulus (G^*) and the phase

angle δ at different temperatures by applying a defined strain and a sweep of frequencies allowing construction of the master curves for the binder under consideration.

While adding recycled hollow block in the binder will make the asphalt material stiff, the LVE Range decrease with increasing the content of recycled hollow block and increase with increasing temperature. The FST results show that, in the low frequency region (high temperatures) and high frequency region (Low temperatures), the rheological behavior of the unaged and Aged mastics differs from the neat binder and increase the stiffness which is directly related to the durability. Furthermore, Based on the MSCR test as the content of recycled hollow block increased the non-recoverable compliance decrease at 0.1 kPa and 3.2 kPa shear stress levels, this notify as the rutting resistance is good .

The research concludes that adding recycled hollow block in Asphalt materials improves the performance of mixtures and increases the life of pavement. Furthermore, the fact that waste is being utilized meets advantage in reducing usage of virgin material and environmental pollution.

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LIST OF ABBREVIATIONS

AASHTO - American Association of State Highway and Transportation Officials

ANOVA-Analysis of Variance

AST-Amplitude Sweep Test

DSR - Dynamic Shear Rheometer

FST-Frequency Sweep Test

HCB-Hollow Concrete Block

HMA - Hot Mix Asphalt

LVE-Linear Visco Elastic Range

MSCR-Multiple Stress Creep and Recovery

RHB- Recycled Hollow Block

RTFO- Rolling Thin Film Oven

SHRP - Strategic Highway Research Program

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CHAPTER 1 INTRODUCTION

1.1 General Background

Recently the construction industry has shown a tremendous change in Ethiopia. The number of engineering facilities such as buildings for schools hospitals factories and shopping centers, highways and hydro-electric power stations has risen in short years.

Road construction is the major sub sector which takes the lion's share of construction expenditure on the construction industry. The share of road sector expenditure in the total government construction expenditure was 49.5percent, 44.5 percent and 48.4 percent in 2003/04, 2004/05 and 2005/06, respectively, overall accounting for nearly half of the expenditure of government expenditure on construction. This was due to the high priority accorded to road construction in the country (Table 1).

Table1.Federal and regional government expenditure on construction in million birr

No	Description	2003/2004	2004/05	2005/06
1	Government construction expenditure	4726.2	7004.4	8451.4
2		2339.5	3114.1	4088.00
Share of road construction (in %)				
3	Construction expenditure	49.5	44.5	48.4

Source: Data obtained from MoFED. Data for total government expenditure on construction obtained from national accounts

It is Observable that the leading urban development strategy in the country currently is the urban renewal approach by which the majority of the existing structures are demolished and newly reconstructed.

According to Solid waste management proclamation No 513/2007 /12.1 Urban administration may themselves undertake or enter into agreement with construction enterprise to refill solid waste disposal sites or Quarry pits with pebbles or gravels from demolished building or with excavated earth. But from what can be seen the implementation is almost null (solid waste management, 2007).

Different materials such as concrete, stone masonry, Hollow Block, mortar, brick, ceramics, metals, wood, asphalt concrete etc. are among the waste materials generated by the construction and demolition of highways and buildings. .

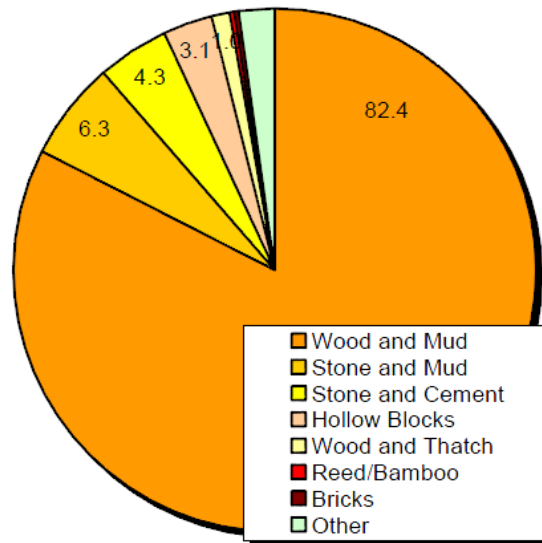


Figure1. Comparison of Urban Upgrading Projects on Development Cooperation in Ethiopia (UliWesslingTolon, 2008)

As shown in figure 1 among the different construction and demolished waste in Ethiopia Hollow block consists 3.1%.



(a)



(b)



(c)



(d)

Figure2. Demolished construction waste in the city of Addis Ababa ;(a) Gift Real-estate, (b) Kera, (c) Mexico and (d) Stadium

Currently demolition from construction activities is among the main causes of environmental pollution in Ethiopia. On the other hand, construction of highway pavement layers requires a large volume of quality materials, which their production is costly and environmentally disturbing, as they are taken from natural resources and used after processing. In addition, in some projects, Suitable Materials to be used for pavement construction, cannot be found near the project sites and need to be transported from long distances.

Therefore to recycle demolished materials from construction is a two sided advantage in which both, environmental pollution from waste materials of construction and shortages of suitable highway materials could be solved.

1.1.1 Recycled Hollow Block

Hollow Blocks will have a light grey concrete color, and on close inspection may show a granular texture depending on the type of aggregate used. They are made with a richer mix, and offer a number of advantages, such as lighter weight, easier handling and facility for conducting or reinforcement through the hollows.

The basic raw material is cement, fine aggregate and coarse aggregate. Very little water is used. This is possible only with mechanized compaction and vibration and gives the block high quality in spite of the lean mix, which uses very little cement. Depending on the constituents and dimension of the box it can be classified as Class A, U-shaped, Class B .Ribbed and Class C.

The machine also compacts and consolidates the mix so that the blocks are uniform in size and attain desired physical properties. The blocks are cured for a minimum period of 14 days, before they are ready to use.

HCB have an excellent thermal property, sound insulation and fire resistant. They are applicable in load bearing structures, in frame structures, as ground laying units and Specific Usage areas.

The main causes of block waste were: Manufacturing defects, such as deviations in the dimension of block and cracks, lack of halves and quarters of blocks, cutting blocks due to the lack of modular coordination in design and damage during unloading and transportation Operation.

Although their applicability in the building sector is vast their contribution for construction waste is not recognized. Since they are composed of the basic materials which constitute hot mix asphalt mix, they could be made to replace pavement materials in highways. The possible use of Recycled hollow block should be developed for construction of roads in different parts of Ethiopia. The necessary specifications should be formulated and attempts are to be made to maximize the use of solid wastes in different layers of the road pavement.



Figure3.Demolished Hollow block

1.1.2 Bitumen

Bitumen is basically composed of hydrocarbon molecules, along with small percentages of sulphur, nitrogen and oxygen. The last three elements are called hetero-atoms and may have considerable effect on bitumen properties. In addition to heteroatoms, some heavy metals such as nickel and vanadium may exist in very small amounts.

Bitumen is widely used as a binder in the construction of pavements in Ethiopia and throughout the world. Bitumen is a viscoelastic material, meaning that its response under a given condition of stress or strain depends not only upon the current state of stress or strain, but also upon its loading history. In more practical terms, this also means that the mechanical response of viscoelastic materials is both time and temperature dependent. Therefore bitumen performance must be characterized with test methods and analytical techniques that account for time (or rate) of loading and temperature.

1.1.2.1 The Viscoelastic Nature of Bitumens

Bitumen's are viscoelastic materials. Behavior of these materials therefore combines two parts: elastic behavior and viscous behavior. Materials with elastic behavior return to their initial state after removal of the applied loads, whereas permanent deformations remain under applied loads under viscous behavior. Several factors affect the behavior of viscoelastic materials in terms of their elastic and viscous behavior. Temperature is the most critical of these parameters. Viscoelastic materials have more elastic Behavior at low temperatures, whereas they behave more viscously at high temperatures. The second parameter, which has an effect on viscoelastic materials, is loading time or rate of loading. Bitumen behaves like an elastic solid at high rates of loading, whereas it behaves as a viscous liquid at long times of loading.

Therefore, to conclude, at a fixed temperature, long times of loading correspond to high temperature behavior (more viscous) and at short loading times the response shifts to low temperature behavior (more elastic). Bitumen, therefore, exhibits high stiffness and brittleness at short times of loading, whereas it is linked with high ductility and exhibits low stiffness at long loading time.

1.1.3 Mastic Asphalt

Hot mix asphalt (HMA) is generally composed of aggregates, asphalt binders and air voids. Among these components, aggregates comprise the highest share amounting 90-96 % by weight and provide the skeleton for the mix. In a way, most of the traffic load is carried by this skeleton of aggregate structures. It is also wise to note that asphalt binders amount 4-10 % by weight the total mix.

Asphalt binders together with fillers constitute “mastic asphalt”. Typically Fillers are fine minerals passing the no. 200 sieve. They are fine material and are usually considered as modifiers and are not considered in the gradation of aggregates (Anggraini et al. 2012).

Two main functional theories of filler are:

- Filler is that portion of the mineral aggregate generally passing the number 200 sieve (0.075 mm) which occupies void space between the coarser aggregate particles in order to reduce the size of these voids and increase the density and stability of the mass. The filler is a part of the aggregate-curve and works as a part of the aggregate.
- The filler is a part of the binder, and the filler-bitumen mix acts as a binder for the aggregate.

There are a number of filler types used in the pavement industry which include fly ash, hydrated lime, rock flour, volcanic ash, silt, Portland cement and mineral sludge and others. In this research we use Recycled hollow block as a filler material. These fillers differ in surface texture, shape, surface area, void content, mineral composition and other petrochemical properties (Bahia et al 2011). These components provide the adhesive property in the total mix helping in their action as visco-elastic material.

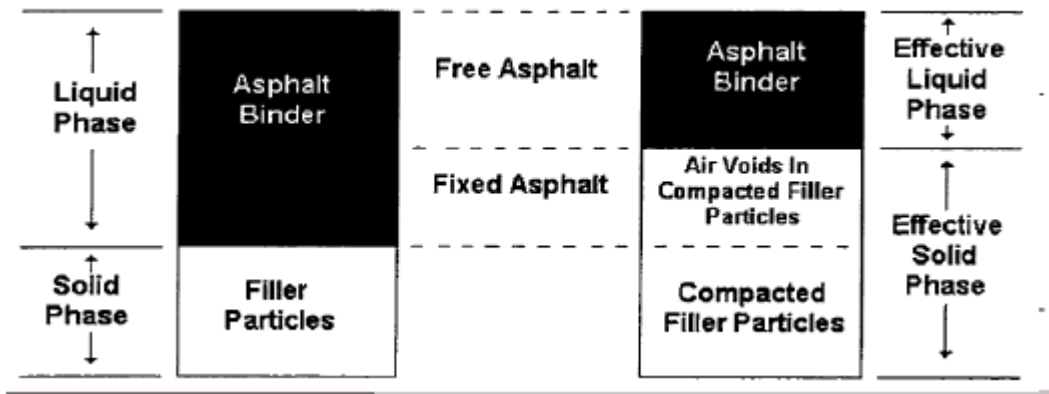


Figure4.Mastic Asphalt (Bahia 2011)

Fillers in HMA have a lot of advantages. In addition to filling the voids, they reduce moisture susceptibility (hydrated lime filler), increase bond between aggregate and asphalt, reduce the optimum asphalt content and increase the stiffness by adding of rigid materials in less rigid matrix (Buttlaret al. 1999). The physiochemical interaction between these fillers and binders has an effect on the eventual performance of the HMA. Hence their influence on the performance of asphalt concrete mixtures also differs accordingly.

Performance of asphalt mixtures in terms of linear visco-elastic behavior can be predicted using stress-strain behavior which can be defined by complex shear modulus and Phase Angle.

The viscoelastic properties can be evaluated by constructing a Master Curve (MC) of the stiffness modulus and the phase angle obtained from the test data over a range of temperatures and frequencies providing a fundamental characterization of asphalt concrete in which the time and temperature dependencies are fully described .The MC enables the prediction of the moduli at any loading frequency or temperature.

This paper do assessment on utilization of recycled Hollow block as mastic Asphalt and try to discuss the results of an experimental research on Rheological properties of Bitumen and the mastic. Finally we try to find out the performance of the mastic.

1.2 Statement of the Problem

Recently in Ethiopia specifically in Addis Ababa, the ever increasing volume of solid waste materials has become a major environmental problem. One of the industries,

which have the major contribution into the generation of waste materials and consumption of energy and natural resources, is the construction industry.

The large quantities of construction and demolition wastes (CDW) has been generated from increasing construction, maintenance and demolition activities, and infrastructure development projects.

From site visits among construction wastes due to unskilled workmanship or quality aspect hollow block is highly vulnerable to wastage. On the other hand natural aggregate and bitumen are taken from natural resources and their processing, production and transportation consumes energy, Using Recycled hollow block will minimize the cost of construction with respect to virgin materials, it may overcome environmental pollution due to the dumping of demolished construction waste and will have economical advantage due to binder replacement.

1.3 Objective

1.3.1 General objective

Introduce the benefit of reusing recycled hollow block wastes as asphalt modifier in the advantage of using modifiers with minimum cost, to encourage the road sector and to overcome environmental pollution caused by demolished construction wastes.

1.3.2 Specific objective

- To identify the availability of Hollow Block waste material from construction sites and manufacturing companies.
- To evaluate the basic engineering properties of recycled Hollow Block before blending (as filler material).
- To characterize the rheological property of mastic (blends of binder and Recycled hollow block)

1.4 Scope

The research reported herein was focused on mastic asphalt material characteristics such as the rheological property and creep. The materials selected for this study were collected from different sources, i.e. Bitumen from Addis Ababa institute of technology highway Laboratory and Recycled hollow block obtained from construction sites. Further, the research also includes the preparation of specimens for filler and mastic.

All the samples were tested in the laboratory and evaluated. The Recycled hollow block (all pass 0.075mm sieve) were separated. The mastics were prepared using RHB with different amount. The results produced in this research were based on DSR procedures.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Recently there is a significant expansion in the availability of recycled materials for use in road construction. As pavement materials predominantly consists of crushed rock and aggregate there is a significant opportunity to utilize alternative materials in pavement construction.

The need for well performing asphalt pavements together with the rising prices of liquid asphalt and the scarcity of quality aggregates have placed additional pressure on agencies and owners to create effective economic solutions worldwide.

Currently Construction and demolition of waste materials are among the main causes of environmental pollution in our country. On the other hand, construction of highway pavement layers requires a large volume of quality materials, which their production is costly and environmentally disturbing, as they are taken from natural resources and used after processing. In addition, in some projects, appropriate materials to be used for pavement construction, cannot be found near the project site, and need to be transported from long distances. Therefore, finding an application for the construction and demolition of waste materials in highway pavements would be an economically and environmentally effective measure.

A study held by ACID (Africa Infrastructure Country Diagnostic) on the burden of Maintenance: Road In sub-Saharan Africa shows the following Periodic maintenance spending per Km for main network and rural network.

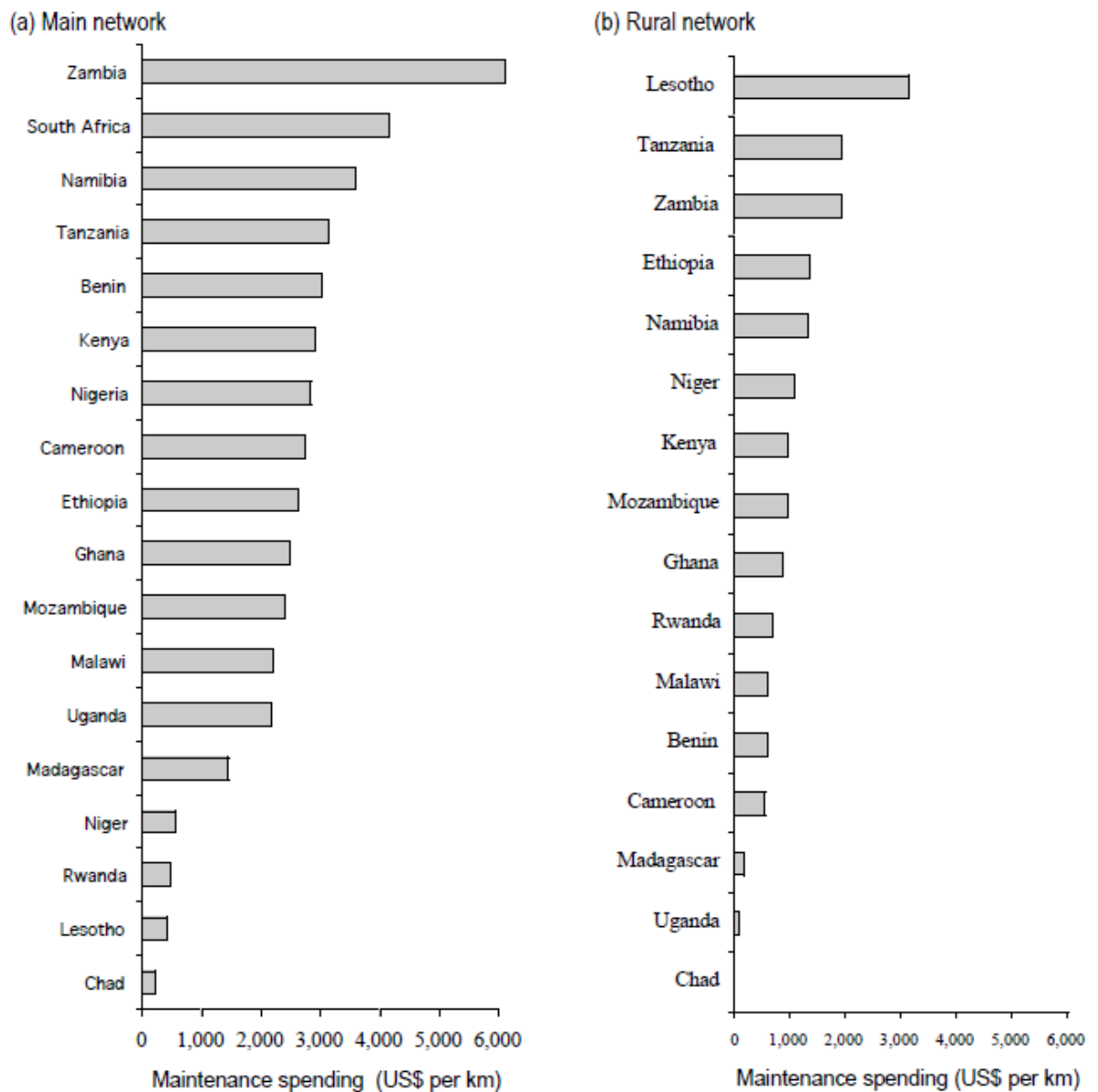


Figure 5. Average maintenance spending across different parts of the network, AICD Fiscal Costs Study (ACID2008).

The above monograph clearly shows our country Spend a lot of money for maintenance

The cost of Road construction and maintenance materials can be reduced by replacing the new (virgin) asphalt cement and mineral aggregates with recycled products derived from construction waste such as concretes, Hollow blocks, Stone masonry or byproducts that may contain asphalt mix components. Using recycled products saves not only on the cost of asphalt and aggregates materials, but also on the amount of construction waste since it is not being placed in landfills.

Recycling Alternative products into asphalt pavement also means less energy is needed to produce the pavement, making it a more sustainable product that minimizes its impact on the environment. Furthermore, properly designed asphalt mixes that contain recycled products can exhibit no performance differences or even improved performance for certain applications compared to typical mixes (Al-Qadi et al, 2007).

The continuing rapid growth in traffic demand, along with the increase in allowable axle loads, necessitates the improvement of the highway paving materials. The goal of highway authorities is to provide safe, economical, durable, and smooth pavements that are capable of carrying the anticipated loads. To achieve this goal, many experts, engineers, and researchers are eager and devoted to selecting paving materials that can minimize pavement distresses and improve the performance of asphalt pavements. Filler, as one of the components in an asphalt mixture, plays a major role in determining the properties and behavior of the mixture, especially its binding and aggregate interlocking effects.

2.2 Effect of Fillers on HMA

Fines or mineral fillers are those materials which are passing 75 μm sieves in a mix. The two most important properties of mineral filler are geometry and composition. Filler geometry can be defined by size, shape, angularity and texture. Asphalt filler interaction is affected by a number of chemical compounds. The two main properties of these interactions are the reactivity (calcium compound and water solubility) and the harmful fines (active clay content and organic content) (Bahia et al 2011).

Mineral fillers which are used in the pavement industry can be divided into two groups namely, the natural fillers and imported fillers. The natural fillers include andesite, basalt, caliche, dolomite, granite and limestone while the imported fillers include fly ash, slag, and hydrated lime. Fillers cannot be regarded as aggregates, however, their interaction with bitumen results in the formation of mastics.

The effect of fillers on the properties of hot mix asphalt has been studied by a lot of researchers since the beginning of the 19th century. Richardson pointed out that the larger surface area exhibited by mineral fillers contributes to a larger surface energy associated with it and permits the use of more bitumen which in turn contributes to more

cementing power (Richardson1915). The presence of filler in another case is associated with reduced optimum asphalt content (Brown et al 1989).

The concept of free volume in the characterization of fillers was first developed by P.J Rigden (Rigden 1947). He postulated that the free asphalt which is the asphalt in excess of the fixed asphalt used to fill the void in a dry compacted bed is the main factor which affects the flow properties of the mastic. Rigden voids' content describes the volume percentage of voids in a dry compacted filler sample. Higher Rigden voids leads to higher stiffening of binder.

Fillers tend to increase the resilient modulus of asphalt mixes (Anderson1987) .However, most of the strength of HMA is attributed to the surface contact between the aggregate particles.

The most important effect of filler is its stiffening effect. Mineral fillers are also important in changing the viscosity of the binder. They tend to make the binder less viscous at elevated temperatures in such a way they can be regarded as modifiers. Having a high content of filler, however, will result in undesirable stiffness which can affect the workability of the mix. The stiffening effect of fillers tends to decrease at lower temperatures instead the mineral fillers tend to improve the fracture properties of the asphalt binder(Lee et al 1995).

Different agencies have different recommendation of the dust to filler ratio. The SHRP volumetric mix design criteria recommends, for example , a dust to filler ratio between 0,6 to 1,2 percent by volume (SHRP).There is a need for further research to determine what optimum amount of filler content.

In this literature review trial will be made to discuss some of filler materials used in the road sector more specifically recycled Hollow block.

2.2.1 Crushed Concrete (Aggregates for bituminous mixes)

Crushed concrete by definition is composed of rock fragments coated with cement, with or without fillers, produced to comply with tolerances for grading and minimum foreign material content

Recyclable concrete often, becomes available from demolition works and other construction activities. During processing of recyclable concrete, steel and other

contaminates are removed as necessary and crushing and screening produces a graded road-making material. In recent years, recycled crushed concrete has been produced and supplied to wide range of road applications, including the stabilized sub base of various sections of the western roads.



Figure6.Crushed Concrete

A study held in Bangladesh compared Waste concrete dust and the common filler materials like cement, lime stone, granite powder. The Marshall method of mix design was used for the comparison. The study indicates the possibility of using waste concrete dust and brick dust as filler in bituminous mix.(DipuSutradhar, 2015)

Although it is the primary choice to use concrete as an alternative material since it contains aggregate in high proportion, when we come to Ethiopia its availability is doubtful because it is widely used in the building sector.

2.2.2 Crushed Glass Fines

Glass material is non-metallic and organic, it can neither be incinerated nor decomposed and can be recycled without loss of product quality .Glass Aggregate is a product of recycled mixed glass from manufacturing and post –consumer waste.

When glass is properly crushed, this material exhibits a coefficient of permeability similar to coarse sand .Also the high angularity of this material compared to rounded sand, may enhance the stability of asphalt mixes .

Pereira *et al.* (2010)studied the use of waste flat glass as a filler in asphalt mixtures and it concluded that the effect of, waste glass on the asphalt mixture does not differ from those made with conventional materials and may be used effectively in asphalt paving. Jonyet *al.* (2011)compared the effect of using different fillers with different contents, glass

powder is proposed as an alternative to traditional lime stone powder and ordinary Portland cement fillers in hot asphalt mixtures. The results indicate that there is a satisfactory stability, where using glass powder filler improve the Stability values for all mixtures comparing to Portland cement or Limestone powder fillers. (Khalil Nabil Dalloul,2013)

While it is rewarding to introduce new materials to the sector, it is questionable when we come to its practicability and availability to use as a construction material specially in our country.

2.2.3 Hydrated Lime

Lime is used in hot-mix asphalt as an anti-stripping additive and as mineral filler. Numerous state transportation departments have found that incorporating hydrated lime into hot-mix asphalt adds years to the life of a highway, thus making the addition cost effective. The addition of hydrated lime can reduce stripping, rutting, cracking and aging. Hydrated lime substantially improves each of these properties when used alone, and also works well in conjunction with polymer additives, helping to create pavement systems that will perform to the highest expectations for many years.

Vanelstraete and Verhasselt (1998) compared the effects of hydrated lime with limestone of identical size and gradation. Rheological measurements were made prior to and following aging of the mastic. Their conclusions are in close agreement with Lesueur, Little, and Epps(1998) that hydrated lime reduces temperature susceptibility of the mastic, that mastics with hydrated lime are significantly stiffer at higher temperatures than the limestone-filled mastics(whereas little stiffness difference exists at low temperatures), and that lime's active filler effect is graduated until it becomes highly effective at high temperatures. They document an increase in stiffness modulus of about 50 percent at 60°C. Their study also shows that the increase in stiffness modulus subsequent to construction aging is considerably smaller for the mastics with hydrated lime than for those with the identically-sized limestone filler. The effects of hydrated lime are especially important for wearing courses and porous asphalt mixtures where deterioration by aging is one of the main causes of road deterioration.

2.2.4 Fly Ash

Fly ash is one of the residues formed in combustion and consists of the fine particles that rise with the flue gases. It is a waste material and is dumped on the land. In India, 95 million ton of fly ash is generated every year which has occupied approximately 65,000 acres of land. Coal requirement and generation of fly ash estimated for the year 2031-2032 is around 1,800 million ton and 600 million ton respectively (MOST-2010). From the above figures, it is clear that there is huge amount of unused fly ash which has to be disposed of each year. Highway industry is capable of using waste material in large quantities if their effect on pavement performance proves to be technically, economically and environmentally satisfactory. Fly ash has successfully been used as filler for bitumen mixes for a long time and has the advantage of increasing the resistance of bitumen mixes to moisture damage. In addition to filling voids, fly ash was reported to have the ability to work as a bitumen modifier. (Tayebali, A.A., Malpass, G. A., and Khosla, N.P ,1998).

Fly ash can be used as cost-effective mineral filler in hot mix asphalt (HMA) paving applications. Where available locally, fly ash may cost less than other mineral fillers. Also, due to the lower specific gravity of fly ash, similar performance is obtained using less material by weight, further reducing the material cost of HMA.

2.2.5 Recycled Hollow block

Hollow block is composed of cement, Fine aggregates/Sand, and Red ash, Coarse aggregate /Gravel and Water. According to the proportion of the constituents and dimension of the box it can be classified as Class A, U-shaped, Class B .Ribbed and Class C. Since aggregate is from the main constitute of HB, using it as a mastic asphalt will be a valuable approach to the road sector.

Now days in Ethiopia especially in Addis Ababa many infrastructures are constructed, since the Urban development program encourage renovation of buildings, many buildings are demolished. Among the demolished construction waste hollow block significantly contribute waste for the environment.

Hollow block materials can be recycled to produce fine aggregate. This may be accomplished on-site with mobile equipment, or rubble can be hauled to a permanent recycling facility. On-site recycling can provide these materials at a reduced net cost.

The main sources for recycled hollow block in Ethiopia are Hollow block manufacturers, Real-estates, housing developments and other construction companies.

Comparing to other filler materials discussed in this research using recycled hollow block has advantage of requiring minimum cost beyond its performance as a filler material.

Recycling Hollow block is a "win-win" scenario. The consumer wins with lower construction and rehabilitation costs without compromising quality, and allowing more roads to be kept in better driving condition than if all virgin asphalt is used. The public also wins by a reduction in the volume of construction rubble in landfills and dumping sites.

2.3 Summary

There is no doubt that bitumen is one of the main influences on pavement behavior and selecting a suitable bitumen for specific conditions such as climate, traffic and pavement structure is one of the aims of a pavement engineer. However, when bitumen does not meet the requirements, modification of the bitumen with an additive can be an effective engineering solution. A large number of bitumen modifiers are used in paving applications. These materials have been classified into different groups by different researchers or institutes. For example, SHRP has classified modifiers in eight categories: thermoplastics, anti tripping agents, mineral fillers, antioxidants, fibers, extenders, recycling agents and oxidants (Rahimzadeh, 2012).

Most of the concept of the literature describes the different filler materials used in Hot Mix Asphalt. Basically this research evaluates the performance of Recycled hollow block as fillers on HMA by preparing laboratory samples with different filler contents.

Although it is rewarding to introduce or utilize all the mineral filler materials used in the literature, we have to be careful in selecting specially for developing country like us.

To conclude, Based on the literature review we get the required information to gather the material preparation and the methodology to conduct laboratory tests.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

Since this research focuses on Utilization of recycled Hollow block as mastic asphalt, Information was sought in order to know the availability of Recycled hollow block in construction and demolished wastes. The information was gathered by distributing questioners to Hollow block manufacturers, Real-estates, housing developments and other construction companies. The questioner gathered According to Addis Ababa Housing Development Project Office Construction & Supervision Department: Quality Control Guide Line At Hollow Concrete Block (HCB) Production. It consists of important and valuable questions that will be helpful to know the quality of the recycled hollow block and its abundance in order to utilize it as mastic asphalt.

The aim of this research is to determine the rheological property and performance of asphalt modified with filler i.e recycled hollow block. The effectiveness of the mastic evaluated by comparing test results conducted on virgin specimens. The test used in this study to compare their performance was Dynamic Shear Rheometer (AASHTO TP5) and Multiple Stress Creep and Recovery (MSCR) test method (AASHTO TP 70). Accordingly basic filler tests were conducted on Recycled hollow block. Tests on Filler, asphalt binder and mastic were conducted according to AASHTO testing standard.

3.2 Experimental design

In this research, the effects of recycled hollow block in bitumen were evaluated in the laboratory. The research evaluated recycled hollow block and binders using DSR test method and MSCR with conditioning procedures.

The experimental work undertaken in this research has been divided into three main parts: filler test, bitumen testing and asphalt mixture testing.

Four different proportion of recycled hollow block were used with asphalt binder with penetration grade of 80 – 100. One of the four mixes was a controlled experiment and did not utilize recycled hollow block.

The bitumen was tested in both their unaged and short term aged conditions. As oxidative ageing and loss of volatiles occurs during asphalt mixture preparation to simulate short-term ageing, the binders were aged using the Rolling Thin Film Oven Test.

3.3 Materials

Since both recycled hollow block and bitumen were required for producing mastic specimens, it was important to evaluate both filler and binder sources.

The sources of the hollow block are Real-estates housing developments and other construction companies.

The asphalt binder used for testing was obtained from Addis Ababa institute of technology highway Laboratory .Since the filler material will make the binder stiff it is better to use 80-100 binder.

The recycled hollow block was used to produce 9 specimens for filler and over 217 mastic specimens in this study.

3.4 Filler Tests and Preparation of Samples

Fillers are generally added to mixture to improve the stiffness and load carrying capabilities of the material .They are normally inert but their physical properties can influence the performance of the asphalt mixture. They can be defined as that portion of the aggregate passing the 0.075-mm sieve.

Important properties tests were conducted when selecting hollow block for the Mastic. First specific gravity, silt content and plasticity were conducted for the filler. The basic tests conducted for the filler are discussed below.

3.4.1 Crushing and Screening



(a)



(b)

Figure7.Crushing and screening ;(a) Crusher machine, (b) Crushed RHB

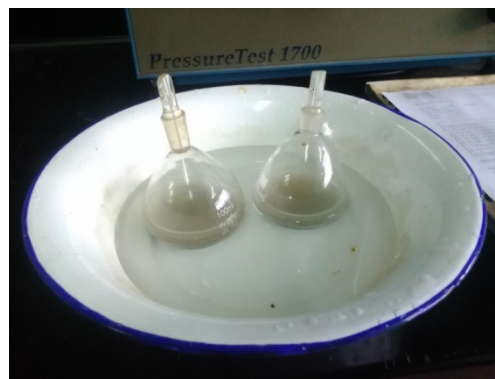
3.4.2 Specific gravity

It is the ratio of the mass in air of a given volume of material at a stated temperature to the mass in air of the same volume of gas free distilled water at a stated temperature.

The particle is used in almost every equation expressing the phase relationship of air, water and solid in a given volume of material.



(a)



(b)

Figure8.Specific gravity test;(a) Boiling the sample,(b) Socking the sample to cool

3.4.3 Hydrometer test

It is used to determine particle size distribution of the recycled hollow block passing no 200 sieve size and the silt content of the filler

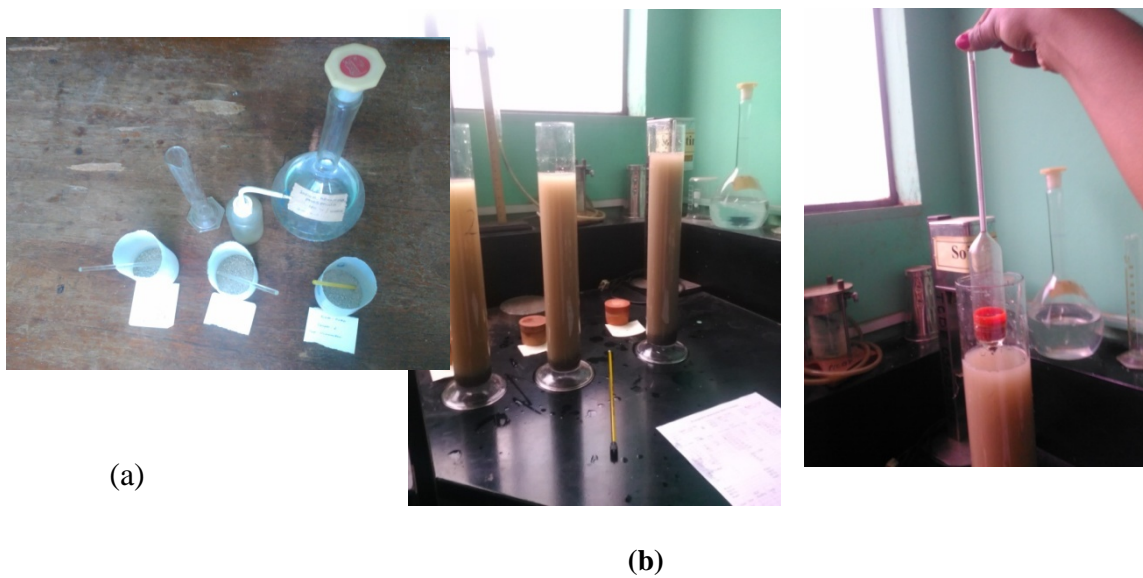


Figure9.HydrometerTest; (a) Sample preparation,(b) Hydrometer Jar

3.4.4 Plastic Index

The plastic limit of the particle is the lowest water content determined at which the soil remains plastic. The plasticity index of a soil is the range in water content, expressed as a percentage of the mass oven dried particle, with in which the material is in plastic state. It is the numerical difference between the liquid limit and plastic limit of the particle.

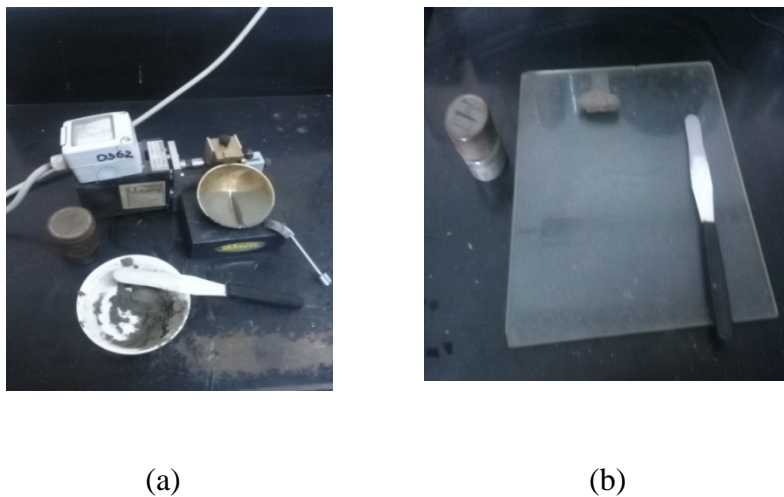


Figure10.PlasticIndex ;(a)Liquid limit test, (b) plastic limit test

3.5 Binder Tests and Preparation

The penetration grading system was developed in the early 1900s to characterize the consistency of semi-solid asphalts. Penetration grading quantifies the following asphalt concrete characteristics: Penetration depth of a 100 g needle 25°C (77°F), Flash point temperature, Ductility at 25°C (77°F), Solubility in trichloroethylene, Thin film oven test (accounts for the effects of short-term aging that occurs during mixing with hot aggregate).

3.5.1 Penetration test

Penetration expressed as the distance in tenths of millimeter that a standard needle vertically penetrates a sample of the material under known conditions of loading, time, and temperature. The penetration test is used as a measure of consistency; higher values of penetration indicate softer consistency.



(a)



(b)

Figure 11. Penetration Test; (a) sample's in water bath, (b) Penetrometer

3.5.2 Ductility

Ductility is evaluated by measuring the distance in centimeters that a standard briquette of asphalt binder will stretch before breaking. The test is performed at a standard temperature of 25°C (77°F) in a water bath by separating the two ends at a rate of 50mm/min until rupture.



Figure12.Ductility test

3.5.3 Softening point

It measures a temperature at which the bitumen phase changes from semi-solid to liquid. At the softening point temperature, the bitumen sample placed in a brass ring can no longer support the weight of a steel ball, and consequently flows. Basically it determines temperature at which a standard amount of deformation occurs.

The softening point is useful in the classification of bitumen's, as one element in establishing the uniformity sources of supply, and is indicative of the tendency of the material to flow at elevated temperatures encountered in service life



(a)



(b)

Figure13.Softening point test ;(a) Sample trimming,(b)Ring and ball apparatus

3.5.4 The Rolling Thin Film Oven Test (RTFOT)

It is the determination of the loss in mass (exclusive of water) of air and asphaltic compound when heated. It clearly determines the short term aging effect. Short term aging occurs during road construction, i.e. mixing and paving, where the stiffness of bitumen increases because of rapid oxidation and volatilization as a result of high temperatures used during construction.

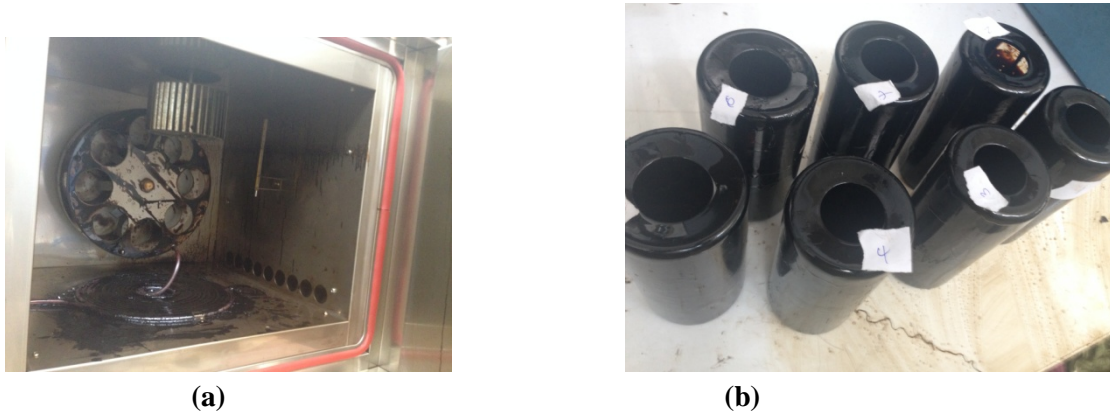


Figure14.RTFO test ;(a)Oven,(b) sample bottle

The procedure is Fifty grams of material, spread out in a dish 5 mm in diameter, is heated in moving air for 5 h at 325°F (163°C) and the percent loss of mass determined along with a comparison, before and after, of any other desired characteristics. This test method provides only a relative measurement of the volatility of a material under test conditions.

The following blending sequence was used for the filler-asphalt samples:

- Asphalt cement was heated in an oven to a temperature of at least 160°C.
- The stainless steel beaker used for mixing was cleaned and kept in the oven at a temperature of at least 160°C.
- The required amount of asphalt was weighed in the beaker and then the amount of filler required to yield the desired filler-to-asphalt ratio was weighed.
- The beaker was placed on a hot plate to maintain a mixing temperature of at least 160°C for a mini- Filler gradually was added to the beaker while stir- ring. The speed of the mixer was increased to 500 rpm.

- Mixing was continued for at least 30 minutes, until an homogenous asphalt-filler mastic was obtained.
- The mastic was continuously stirred as it cooled to prevent settling.
- At the end of mixing, the mastic was used to pre- pare specimens for the penetration, softening point, and Ductility tests

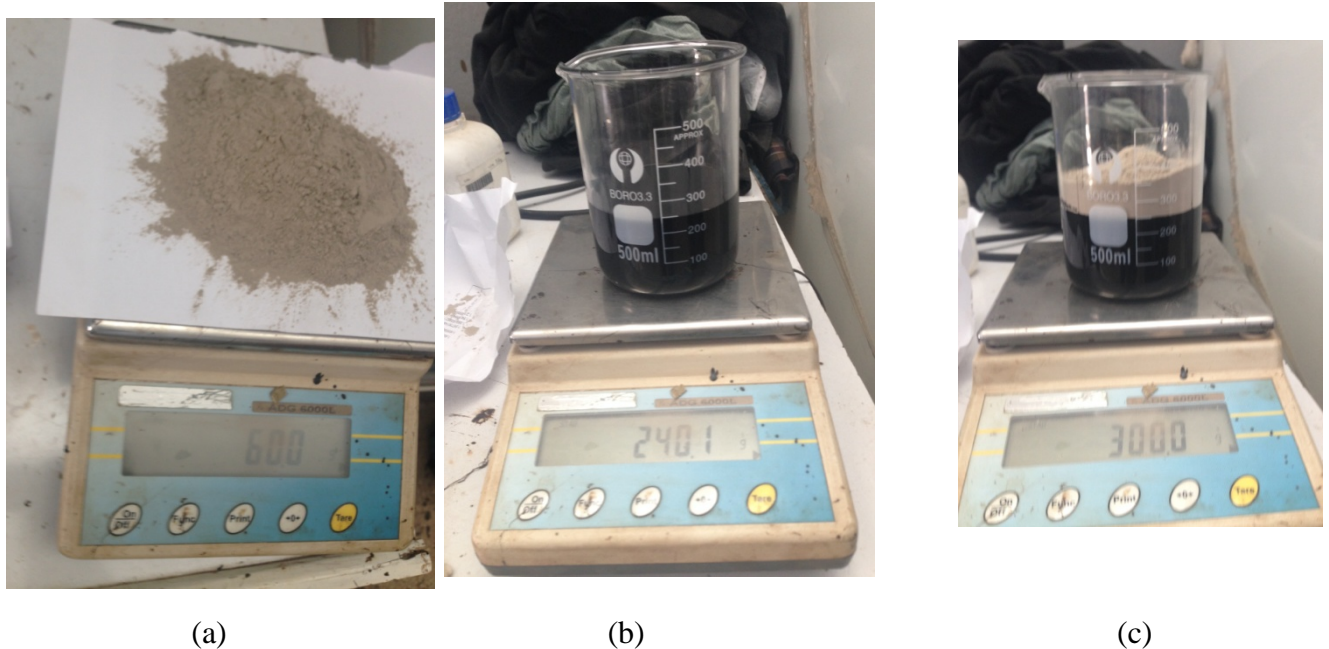


Figure15.Preparation of the mastics ;(a)RHB,(b)Binder, and (c) Mastics

3.6 Mastic Asphalt

Rheology is a science which deals about deformation and flow of matter.HMA pavement deformation is closely related to asphalt binder rheology. Deformation and flow of the asphalt binder in HMA is important in determining HMA pavement performance. HMA pavements that deform and flow too much may be susceptible to rutting and bleeding, while those that are too stiff may be susceptible to fatigue or thermal cracking.

Permanent deformation of flexible pavements is a result of accumulated plastic deformation, which is caused by repeated application of loads. Rutting occurs primarily at intermediate and high temperatures, where bitumen behavior is more viscous resulting

in non-recoverable deformation. Although, the aggregate properties have an important role in rutting resistance, the contribution of the bituminous binder cannot be ignored.

Rutting can be investigated by considering the energy dissipated as plastic deformation occurs during each cycle of loading under stress-controlled conditions. Therefore, the energy dissipated should be minimized for minimum rutting.

The two fundamental methods used for determining viscoelastic properties are: Dynamic shear rheometer and Creep test.

3.6.1 Dynamic Shear Rheometer(AASHTO TP5).

This test is used to measure the linear viscoelastic moduli of asphalt binders in a sinusoidal loading mode. Measurements may be obtained at different temperatures, strain and stress levels, and test frequencies. The Dynamic Shear Rheometer (DSR) operation is simple; asphalt binder is sandwiched between two parallel plates, one that is fixed and one that oscillates. As the plate oscillates, the sample is subjected to a defined strain or stress that is resisted by the material through its complex shear modulus (G^*).

The complex shear modulus (G^*) is a measure of the total resistance of a material to deformation when exposed to repeated pulses of shear stress (Asphalt Institute, 1997). Two components make the complex shear modulus, these are the storage modulus (G') and the loss modulus (G''); the first modulus is related to the elastic properties of the material, whereas, the second modulus relates to the viscous properties of the material. The phase angle (δ) is then the angle between the storage modulus (G') and the resultant complex shear modulus (G^*), the higher the phase angle the more viscous-like the material will behave; likewise the lower the phase angle the more elastic-like the material will behave. Figure 18 illustrates the theory of operation of the DSR.

ω = Angular frequency
 θ = Deflection angle
 T = Torque

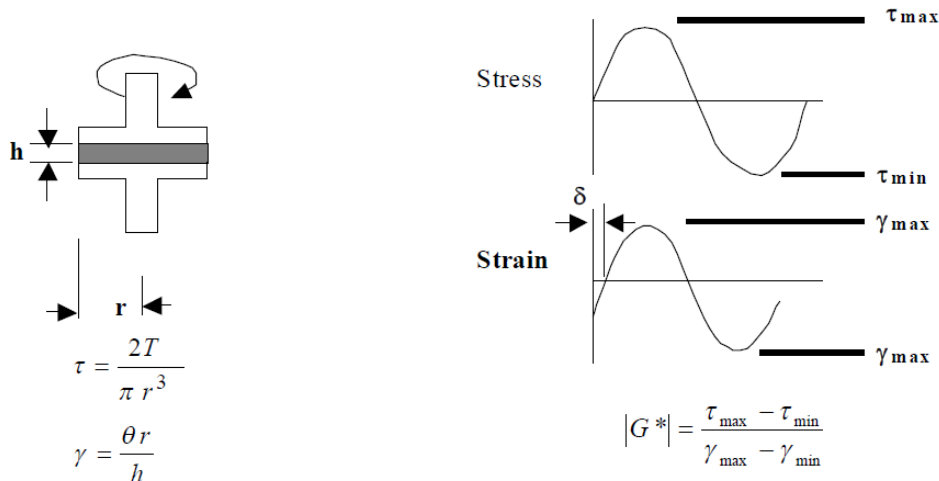


Figure16. Complex shear measurements using parallel plate geometry (Rahimzadeh, 2002)

Dynamic shear test may be conducted in two ways: controlled-stress and controlled strain. A controlled-stress test applies a sinusoidally varying stress and measures the magnitude and phase of the resulting strain. A controlled-strain test applies a sinusoidally varying strain to the sample and measures the magnitude and phase of the resulting stress. For this specific research controlled stress is used.

A DSR system consists of three major parts: the rheometer, the controller, and the computer.



Figure 17.DSR Equipment

Two types of test are performed during this study for the dynamic shear testing: strain sweeps, frequency sweeps, prior to performing frequency sweeps, strain sweep tests were performed to establish the linear viscoelastic range of bitumen at different temperatures and frequencies.

Amplitude sweep test are mostly carried out for the sole purpose of determining the limit of the LVE Range. the sample is often tested at an angular frequency of $\omega=10\text{rad/sec}$. In this case, the stress level is gradually increased until significant non-linearity is detected in the response. As long as the γ amplitude remain below the limiting value γ_L , the G^* curve show a constantly high plateau i.e is the structure of the sample is stable under this low deformation condition. The index “L” stands for limiting value .At amplitudes higher than γ_L , the limit of the LVE range is exceeded .The structure of the sample has already been irreversibly changed or even completely destroyed. The γ_L is mostly taken at $0.95 G^*$.

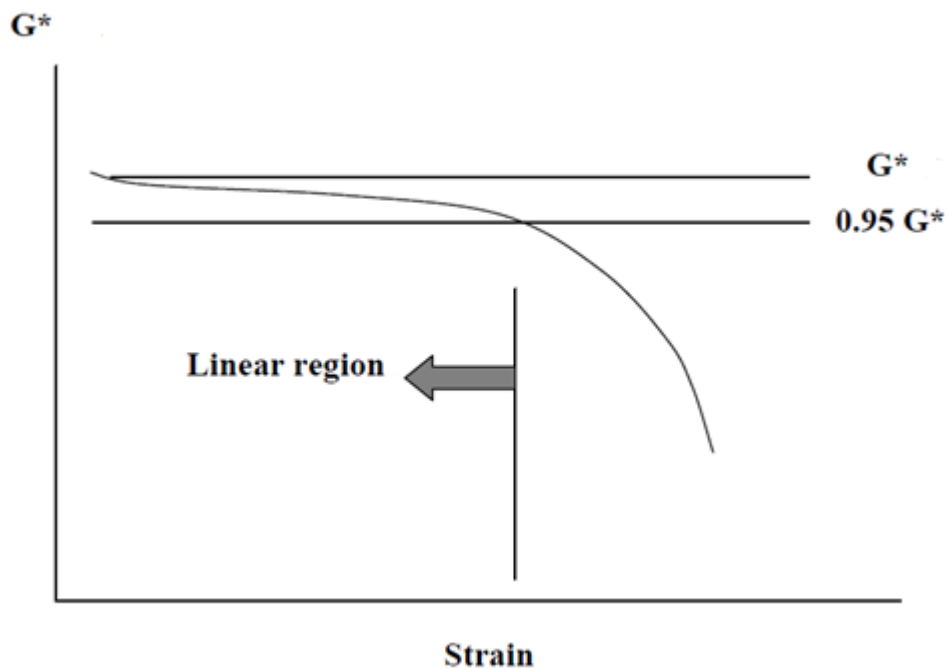


Figure 18. Limit of Visco -elastic Range (Rahimzadeh, 2002)

Frequency sweeps are used to measure the complex shear modulus (G^*) and the phase angle δ at different temperatures by applying a defined strain and a sweep of frequencies allowing construction of the master curves for the binder under consideration.

For this specific research Based on dynamic modulus test temperatures 21.1°C , 37.8°C and 54.4°C are used.

3.6.1.1. Procedure of Dynamic Shear Rheometer Test

The samples are prepared by pouring the modified asphalt into silicone molds with the appropriate geometry for the type of material to be tested. For AST and FST The geometry of the samples of the unaged and RTFO aged materials is 8mm in diameter. The gap established by the standard to be used in the rheometer for sample testing is 2 mm for the Unaged and RTFO aged materials. For performance grade and MSCR 25mm plate with 1mm gap was used.

The performance-graded asphalt binder specification uses the values of G^* and δ to determine the performance grade of the binders. The unaged and RTFO materials are related to the performance of the binders at their maximum design temperature for

rutting. Loading time of 0.1 seconds was chosen to represent the loading time with in the pavement, which can be attributed to truck tyre travelling at 80Km/hr..Using DMA this 0.1 second loading time is equivalent to sinusoidal loading at 10rad/sec.

The results from the frequency sweep tests in the form of complex modulus and phase angle parameters have been presented as isothermal plots, isochronal plots, black diagrams and master curves for each type of bitumen. Because of the large amount of data generated in these tests, these plots were very useful in presenting and interpreting the results. Master curves allow the rheological data to be presented over a wide range of frequencies and temperatures in one plot. Therefore, to avoid presenting a large number of graphs, the results are mainly presented and analyzed as master curves.

3.6.1.1.1 Isothermal Plots and Master Curves

An isothermal plot is simply a plot of some viscoelastic function, such as complex modulus or phase angle, versus loading time or frequency in this plot, viscoelastic data, at a given temperature, is plotted over a range of frequencies or loading times. Therefore, this plot can be used to compare different viscoelastic functions at different loading times at a constant temperature. In addition, it can be used to study the time dependency of materials

Master curves allow the representation of rheological measurements such as complex modulus or phase angle at frequencies or temperatures, which cannot be attained by the test instrument. Master curves therefore reflect the time dependency of bitumen over a wide range of loading times, e.g. values of complex modulus or phase angle at a few thousandths of a second or several years of loading time. Time temperature superposition is used over a range of temperatures and frequencies in the construction of a master curve. At first, a reference temperature is selected and then the data at all other temperatures is shifted horizontally with respect to time to produce a single smooth curve. The shifting is done by using the shift factor, $a(T)$, which varies for each test temperature.

3.6.1.1.2 Mathematical Models for Shift Factors

The temperature dependency of the viscoelastic behavior of bitumen can be Indicated by shift factors,, $a(T)$.Different types of Mathematical models developed by different researcher's ,A research developed at the university of Maryland showed the master curve can be represented by sigmoidal function (2002 design guide ,2004),shown by the following equation.

$$\text{Log}(G^*) = \sigma - \frac{\alpha}{1 + e^{(\beta + \gamma \log(fr))}}$$

$$\phi = -90 * \sigma \alpha - \frac{\exp(\beta + \sigma \log(fr))}{(1 + e^{(\beta + \sigma \log(fr))})^2}$$

$$\log(aT) = \frac{-c_1(T - T_{ref})}{c_2 + (T - T_{ref})}$$

Where

G^* =Dynamic modulus

fr =Loading frequency at the reference temperature (reduced frequency)

σ =Minimum modulus Value

$\sigma + \alpha$ =Maximum modulus value

β, γ =parameters describing the shape of sigmoidal function

ϕ =Phase angle

a_T =Shift factor

T =Temperature

T_{ref} =Reference temperature

C_1 and C_2 are model constants

In order to minimize the error between predicted G^* from master curve and lab measured G^* , an error minimization technique was used. This technique was accomplished by using the Solver module in Microsoft's Excel to find out all the regression coefficients.

3.6.1.1.3 Black Diagrams

A black diagram is simply a plot of complex modulus versus phase angle obtained from a dynamic test. Therefore, viscoelastic data is plotted over wide range of temperatures

and frequencies using the black diagram. This plot is therefore very useful for presenting the effect of ageing or modification of bitumen's.

3.6.2 Multiple Stress Creep and Recovery (MSCR)

Creep can be explained by a sudden stress being applied to bitumen. Creep after sudden stress is the opposite of stress relaxation after sudden strain. In a stress relaxation test, stress decreases for constant strain, whereas in creep, strain increases at constant stress.

Recently, a new Multiple Stress Creep and Recovery (MSCR) test method (AASHTO TP 70) along with the specification (AASHTO MP 19) have been proposed to address the shortcomings of the M 320 specification (D'Angelo, 2009a). The MSCR test method allows better characterization of the high temperature performance-related properties of unmodified and modified binders by eliminating the need for various "PG Plus" tests (D'Angelo, 2009a). The test utilizes the conventional Dynamic Shear Rheometer (DSR) device with 25 mm parallel plate and 1 mm gap setting. The test is conducted at the specific project location pavement design temperature.

The creep load is applied for one second followed by nine seconds of recovery. Ten creep and recovery cycles with no rest periods are included at each stress level. The TP 70 test method requires measurements using two stress levels (100 Pa and 3200 Pa) and results in MSCR test parameters that include non-recoverable creep compliance and percent recovery. The average non-recoverable creep compliance and average percent recovery of ten cycles at shear stress levels of 0.1 and 3.2 kPa can be computed using the following Equations.

$$J_{nr}(0.1) = \frac{\sum_{n=0}^{10} J_{nr}(0.1, N)}{10}$$

$$J_{nr}(3.2) = \frac{\sum_{n=0}^{10} J_{nr}(3.2, N)}{10}$$

$$R(0.1) = \frac{\sum_{n=0}^{10} \epsilon_r(0.1, N)}{10}$$

$$R(3.2) = \frac{\sum_{n=0}^{10} \epsilon_r(3.2, N)}{10}$$

Where

$$J_{nr(0.1,)} = \varepsilon_{10}/0.1$$

$$J_{nr(3.2,)} = \varepsilon_{10}/3.2$$

ε_{10} = the strain value at the end of recovery portion

$J_{nr(0.1)}$ = average non-recoverable creep compliance at 0.1 kPa

$J_{nr(3.2)}$ = average non-recoverable creep compliance at 3.2 kPa

$J_{nr(0.1,N)}$ = non-recoverable creep compliance at 0.1 kPa

$J_{nr(3.2,N)}$ = non-recoverable creep compliance at 3.2 kPa

$\varepsilon_r(0.1,N)$ = percent recovery at 0.1 kPa

$\varepsilon_r(3.2,N)$ = percent recovery at 3.2 kPa

N = number of cycles

3.7 Summary

The experimental work undertaken in this research has been divided into three main parts: ,filler test, bitumen testing and asphalt mixture testing.

Four proportion of recycled hollow block was prepared to use it with asphalt binder with penetration grade of 80–100.

First in order to know the basic property of the filler and the bitumen fundamental test was discussed,

The mastics was Prepared in both their unaged and short term aged conditions. To simulate short-term ageing, the Rolling Thin Film Oven Test (RTFOT) was utilized

After that the two fundamental methods used for determining viscoelastic properties Dynamic shear rheometer and Creep test methods was discussed. Following that the basic Procedure for the AST, FST and the MSCR test was presented.

CHAPTER 4 RESULT AND ANALYSIS

This chapter will present and discuss the results obtained from the testing that were carried out according to the experimental plans presented in Chapter 3. The following sections will report first questionnaire result (refer Appendix A) then the filler test for recycled hollow block, which include chemical composition hydrometer test and plasticity index. For the binder testing results, first engineering property tests were done which include, Ductility, penetration, softening point and RTFO. The Mastics Rheological results will be reported later in this chapter, which incorporate LVE, master curves, black diagram and MSCR.

4.1. Results for RHB

The analysis based on the aim of the research will be discussed below.

Before production begin, for fine aggregates laboratory test at least for organic impurity, clay content and gradation for a given source of fine aggregate should be done. But based on the Analysis only 22.2% of manufacturers check laboratory tests. In relation to that most of them focus on after production test i.e. Quality approval test, based on the study 70% of them make the approval test the rest do not perform neither of the tests.

From the site visit Construction works particularly HCB wall, steel and ceramic tiles are relatively the most vulnerable to wastage. It is understandable these relative weights may vary from the nature and management efficiency of the project. Although there are different reasons for the hollow block to be a waste, according to site and production area visit the main causes are from quality aspect and unskilled workmanship, based on the study 85% believe both the after mentioned reasons are the cause of wastages, 10% workmanship problem and the remaining 5 % believe it is from quality aspect.

Since the aim of this paper is to utilize Recycled hollow block as Mastic asphalt, we have to know like other construction waste recycled hollow block significantly included in demolished construction waste. The result is 95% of them believe it significantly included in DCM the rest not significantly but in a least amount.

The results of the questioner guided as due to workmanship or quality problem there is a high chance that Hollow block can be included in the construction waste.

After doing so, basic test conducted for the recycled hollow block was Specific gravity, hydrometer analysis & sieve analysis and plasticity index.

The specific gravity of the sample is around 2.4 and it is classified as Non plastic material .Result for Chemical composition and hydrometer analysis is discussed below.

4.1.1 Chemical Composition of Recycled hollow block

Since recycled hollow block is a composite material, we have to know the chemical composition .sieve number 200 pass sample is used for determination of major and minor oxides. The analytical method used was LIBO2 fusion use as a reagent, Hydrofluoric attack which can easily attack silicates, Gravimetric which determines the carbon content, Colorimetric used for determination of fluoride content and Automated flow injection Analysis used for major element determination. From the result it contains Silicon and calcium by high proportion.

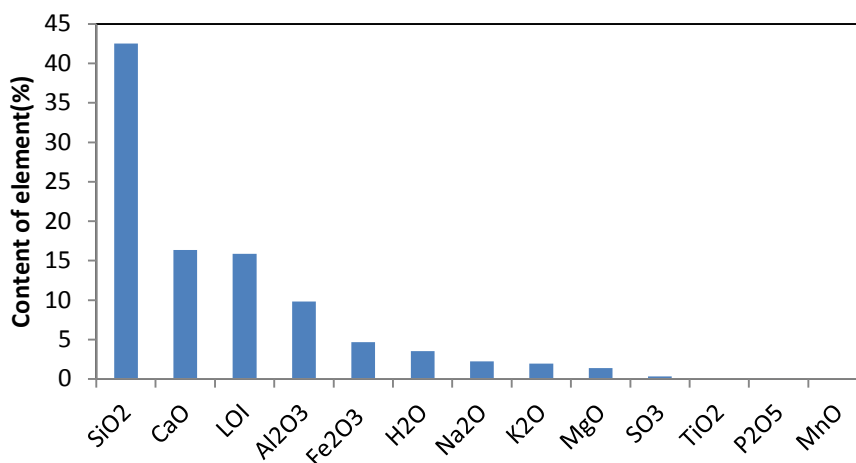


Figure19.Chemical composition of recycled hollow block

In bitumen the presence of heteroatoms can make the molecule polar and thus more likely to react with other molecules. sulphur plays an important role in the ageing of bitumen because it is more chemically reactive than hydrogen or carbon, and can oxidise more easily than the hydrocarbons. When bitumen oxidase, two main products are formed, sulfoxide (S=O) and carbonyl (C=O).On the chemical composition of recycled hollow block the sulphur amount is less there has less effect on the aging process. Metals play an important role in the ageing process. The Recycled hollow block also consist

metallic elements like Iron, potassium and sodium. As shown in figure19 the content of metallic elements is less. Overall adding recycled hollow block has a less effect on the aging.

4.1.2 Hydrometer Analysis & Sieve Analysis (AASHTO T-88)

It is used to determine particle size distribution of the recycled hollow block passing no 200 sieve size and the silt content of the filler.

Table 2. Particle size distribution of the recycled hollow block

	Sieve Size(mm)	% Passing
Sieve Analysis	50	100.00
	37.5	100.00
	25	100.00
	19	100.00
	12.5	100.00
	4.75	100.00
	2	100.00
	1.18	86.00
	0.425	62.00
	0.3	52.00
Hydrometer Analysis	0.075	36.00
	0.0391	33.67
	0.0253	25.12
	0.0148	20.84
	0.0105	18.71
	0.0075	14.43
	0.0037	10.15
0.0016	8.02	

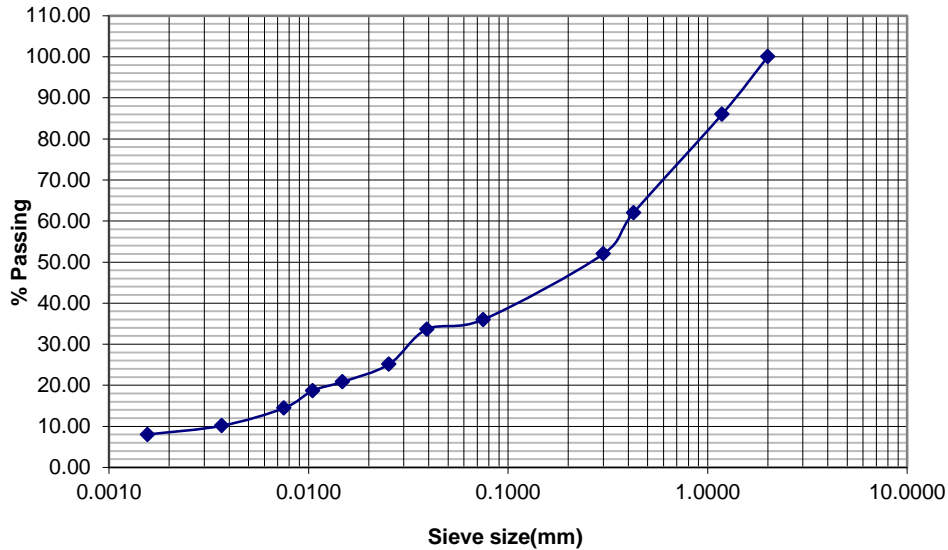


Figure 20. Sieve Analysis and Hydrometer analysis

Based on the analysis the following result is obtained

- Particles larger than 2mm = 0%
- Coarse Sand 2mm - 0.425mm = 38%
- Fine Sand 0.425mm - 0.075mm = 26%
- Silt 0.075-0.002mm = 27%
- Clay smaller than 0.002mm = 9%

Filler material with particle size less than the binder film thickness (i.e. the nominal thickness of non-absorbed bitumen coating the aggregate particles), act as a suspension with the binder, and thereby becomes part of the binder. Filler material with particle size larger than the binder film thickness will act as a part of the aggregate.

Higher filler content increase the aggregate surface area and thus reduce the asphalt film thickness Mineral filler characterize vary with the gradation of the filler, if the size of the mineral filler particles smaller than about 10 microns, the filler act as an extender of the asphalt cement because the thickness of most asphalt films HMA is less than 10microns.

Based on the hydrometer analysis more than 18.7 % of the material is less than 10microns, so we can conclude the recycled hollow block can be part of the binder, so it may modify the binder.

4.2 Binder Tests

Table3.AASHTO M20-70 and ASTM D946/D946M 80-100

Type of Test	Test method	Unit	Min	Max	Controlled binder
Penetration	ASTM D5	mm	80	100	82
Softening point	ASTM D36	°c	42	52	42
Ductility	ASTM D113	cm	100	-	100
Performance After RTFO					
Retained penetration (% of original)	ASTM D5	%	50		35
Increase in Softening point	ASTM D36	°c		<8	47
Softening point after Hardening	ASTM D36	°c	45		47

4.2.1 Ductility Test

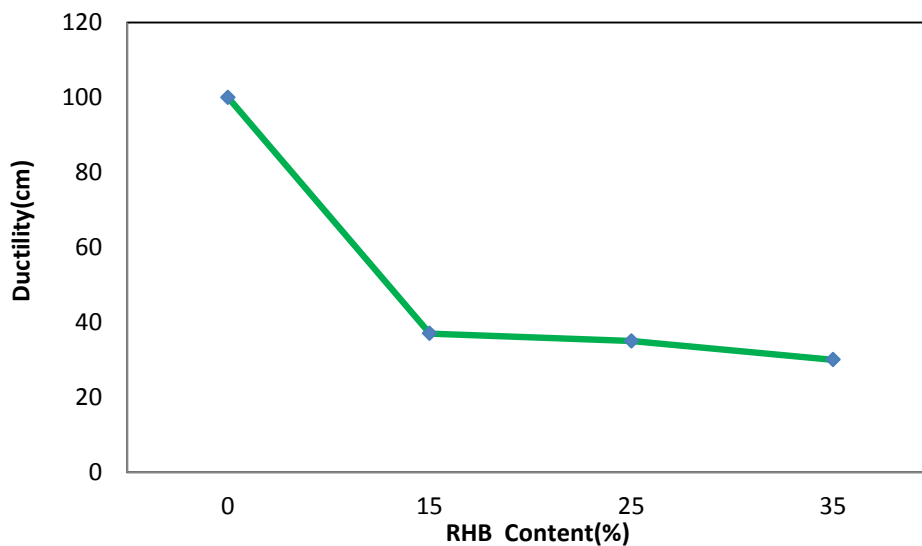


Figure 21.Ductility test Result

From the graph we can see that the ductility decrease with increasing the content of recycled hollow block.

4.2.2 Penetration Test

From Figure 22 we conclude that the penetration will decrease due to adding Recycled hollow block and Ageing. It also passes the retained penetration at 25°c.

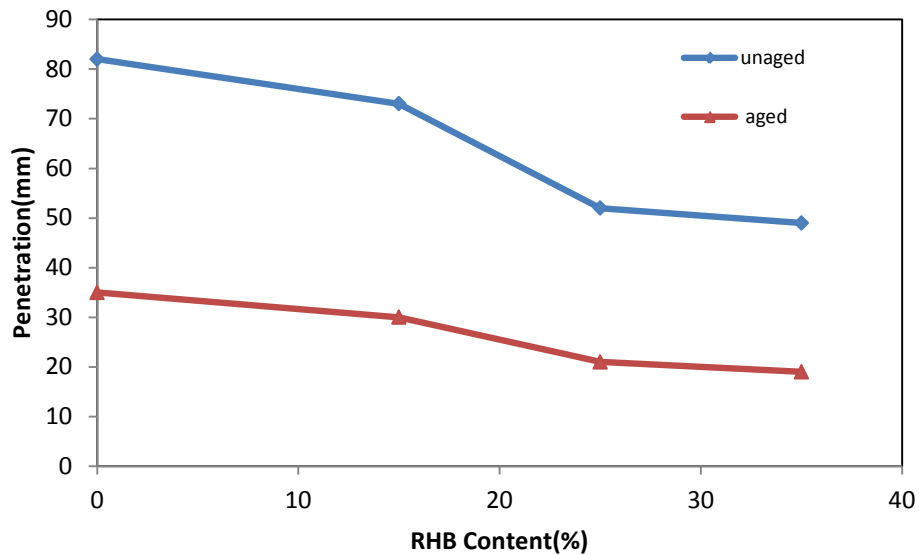


Figure 22. Penetration test result for Unaged and Aged mastics

A penetration ageing index, which is the ratio of the penetration at 25°C after ageing to that of the original bitumen, can also be used for comparison purposes. The penetration ageing index was done (Refer Appendix B), from the result the aging index has a slight reduction with increasing the content of recycled hollow block. This shows adding recycled hollow block may reduce the aging process but it is not significant.

4.2.3 Softening Point Test

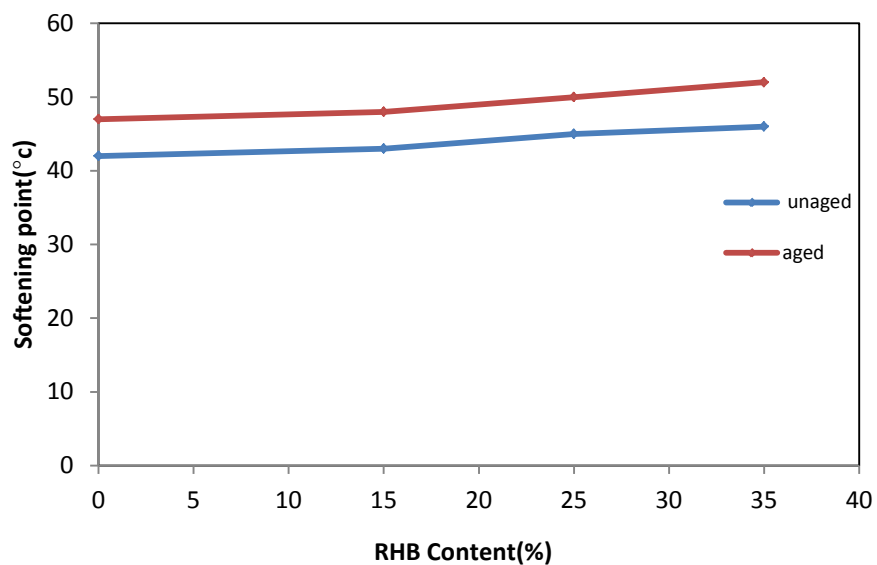


Figure 23. Softening point Result for RTFO Aged and Unaged mastics

Figure 23 shows the softening point will increase due to adding Recycled hollow block and Ageing. Based on the result since it increase the elevated temperature encountered in service life adding recycled hollow block will be advantageous.

4.2.4 Amplitude Sweep Test

Amplitude sweep test (Ast) is done to know the Linear visco elastic range of the binder and the mastics, In this research the linear visco elastic properties of can be characterized by applying a stress Range with 100-90,000 Pascal under different temperatures. It is tested at an angular frequency of $\omega=10\text{rad/sec}$.

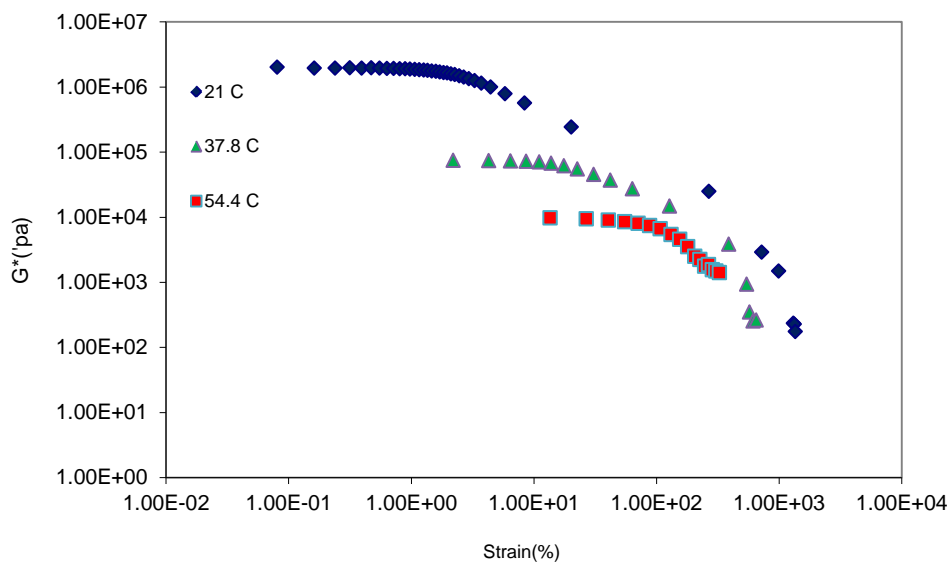


Figure 24. AST results For 25%RHB At Different Temperatures

For different proportion of Recycled hollow block for range of temperature the Linear visco elastic range is done.

Table 4.LVE Range foraged and unaged Samples

Binder Condition	Temperature(°C)	LVE Range (%)	
		unaged	aged
Controlled binder	21.1	2.65	2.2
	37.8	21.4	25.3
	54.4	86.4	67.6
15% RHB	21.1	1.81	1.67
	37.8	18.2	17
	54.4	72	59.1
25%RHB	21.1	1.26	0.98
	37.8	18.2	16.8
	54.4	65.4	57
35%RHB	21.1	0.61	0.3
	37.8	8.09	6.36
	54.4	46.3	23.5

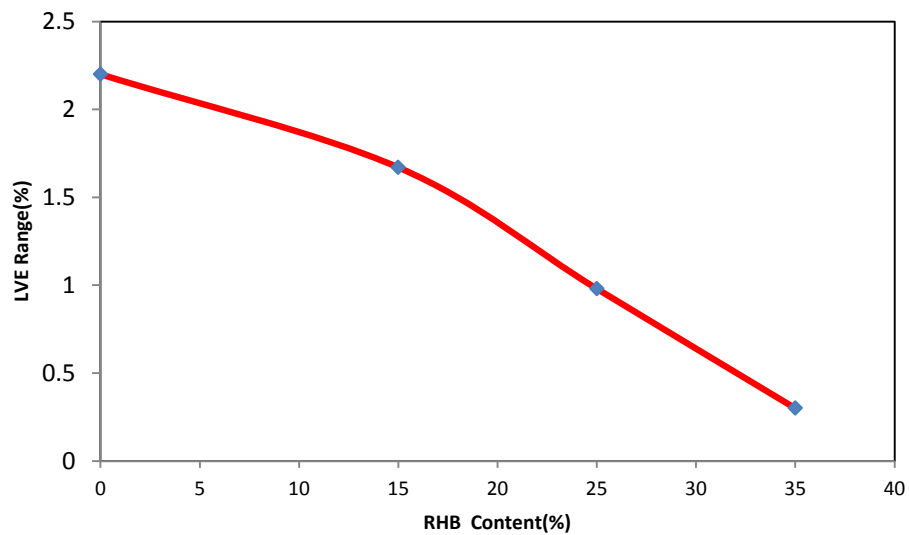


Figure 25. LVE Range of the mastics at 21.1^oc

From the results we can see that for a given temperature the viscoelastic range of the mastics decrease with increasing the content of the recycled hollow block and increase with increasing the temperature.

Based on the linear visco elastic range 1% Strain for 0%RHB, 15%RHB and 25%RHB and 0.1% strain for 35% RHB frequency sweep test for a range of temperature and frequencies were performed.

4.2.5 Frequency Sweep Test

In this Thesis, frequency sweep tests were conducted to characterize the visco elastic properties of the asphalt binder and the mastics. The frequency sweep tests were conducted using three temperatures (21.1, 37.8, and 54.4 °C) over frequency ranges (0.1 to 157 rad/s). The 8 mm diameter plate configuration with 2 mm gap setting was used for testing. The asphalt binder samples were conditioned using the Rolling Thin Film Oven (RTFO).

For all test temperatures, the shear modulus increases (phase angle decreases) with increasing test frequency. This implies that the asphalt binder stiffness decreases with viscoelastic-liquid behavior when tested at higher temperature and lower frequency ranges (Figures 26).

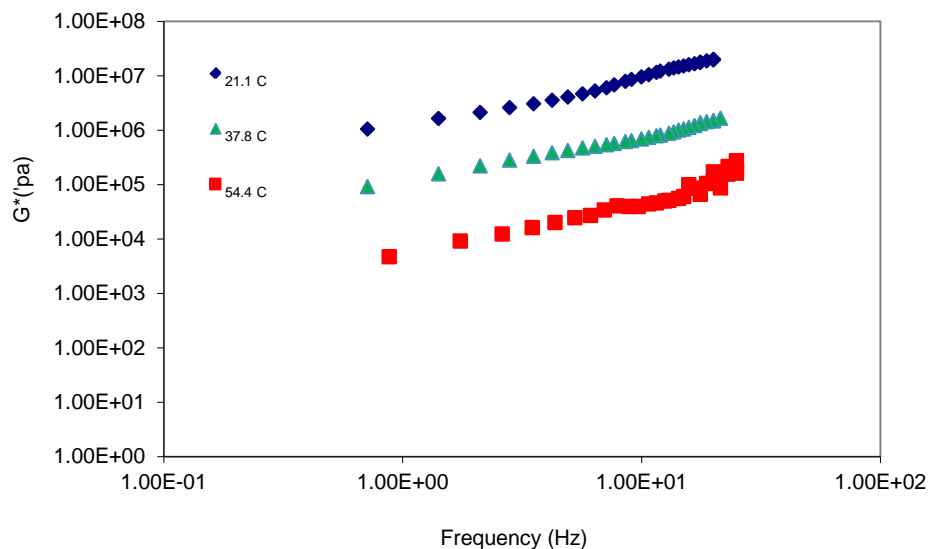


Figure 26. FST result for 25% RHB aged at different temperature

The black space diagram is a simple rheological plot of shear modulus and phase angle in semi-log space (Figure 27). The binder and mastics resulted in smooth black diagram, which exhibits viscoelastic-liquid properties. As described next, the isotherms shown in these figures can be shifted horizontally to form a single master curve, which is identified by a reference temperature of choice.

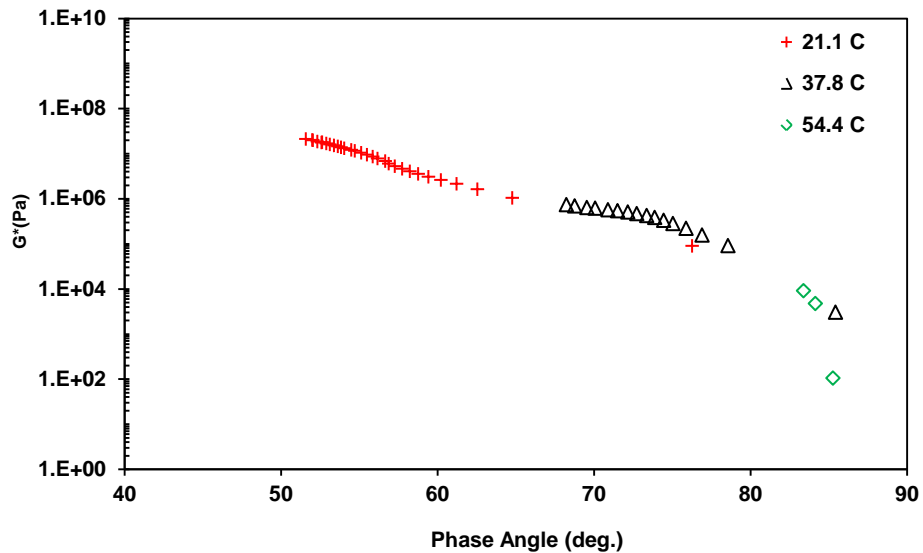


Figure 27. Black Space Diagram for 25% RHB aged at different temperature

4.2.5.1 Master Curve

The master curve for each binder mix at a reference temperature of 21.1 °C is shown in Figure 28 and 29. The individual isotherm curves were shifted horizontally along the frequency axis to form a master curve at the reference temperature. The shifting is done by using the shift factor, $a(T)$, which varies for each test temperature. The fitting parameters calculated are listed in Table 5. β and γ gamma illustrates the shape of the sigmoidal function. α and δ will show the maximum and minimum modulus value respectively.

Table 5. Fitting parameter for MC

Condition	Fitting parameter	RHB(%)			
		0	15	25	35
Unaged	alpha	60.34	9.90	52.96	53.47
	delta	-54.06	-1.54	-35.91	-42.94
	beta	-4.01	-1.19	-1.35	-2.44
	gamma	0.43	0.43	0.10	0.17
	a21.1	0.00	0.00	0.00	0.00
	a37.8	-1.21	-1.78	-1.35	-1.90
	a54.4	-1.56	-2.70	-2.70	-3.03
Aged	alpha	51.14	51.06	52.96	53.85
	delta	-40.66	-40.73	-35.91	-42.53
	beta	-2.35	-2.42	-1.35	-2.36
	gamma	0.17	0.17	0.10	0.15
	a21.1	0.00	0.00	0.00	0.00
	a37.8	-1.603	-1.70	-1.35	-1.89
	a54.4	-2.753	-2.95	-2.70	-3.35

It can be seen from figure 28 and figure 29. as the reduced frequency decreases, the shear modulus decreases continuously which reflects the decrease in the resistance to shear deformation; which in turn results in a decrease in elasticity or ability to store energy. At lower temperature and higher reduced frequency, the binder exhibited higher viscoelastic properties (higher stiffness and lower phase angle).

For a better comparison figure 28&29 presents the four master curves together for unaged and RTFO Aged condition, from this figure it can be seen that the behavior of neat and 15% RHB mixtures are very similar at low, intermediate and high temperatures, however it seems that for high temperatures 35% RHB mixture performs a little bit better than 0%, 15% and 25% RHB mastics. To see if there is any statistically significant difference a statistical analysis was performed at 21.1 reference temperature for a certain frequency.

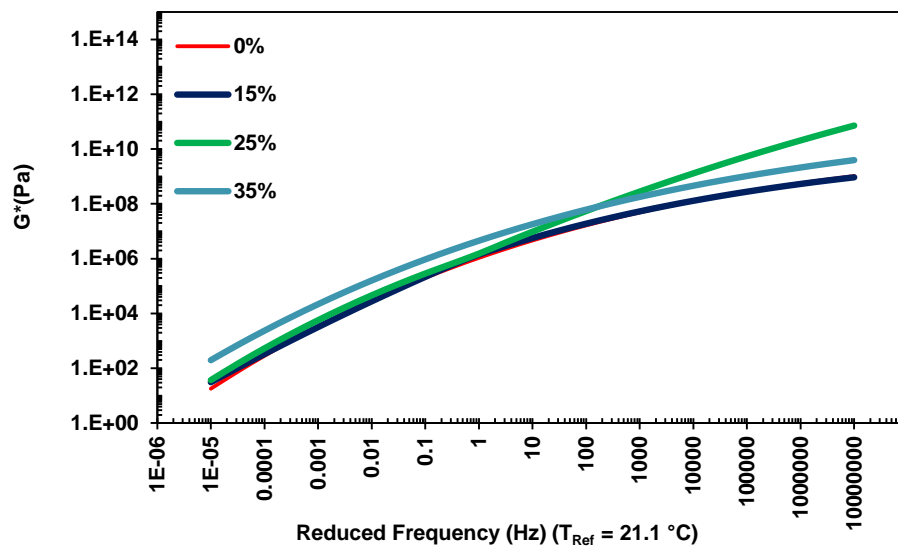


Figure 28. Comparison of Master curve for RTFO Aged Mastics

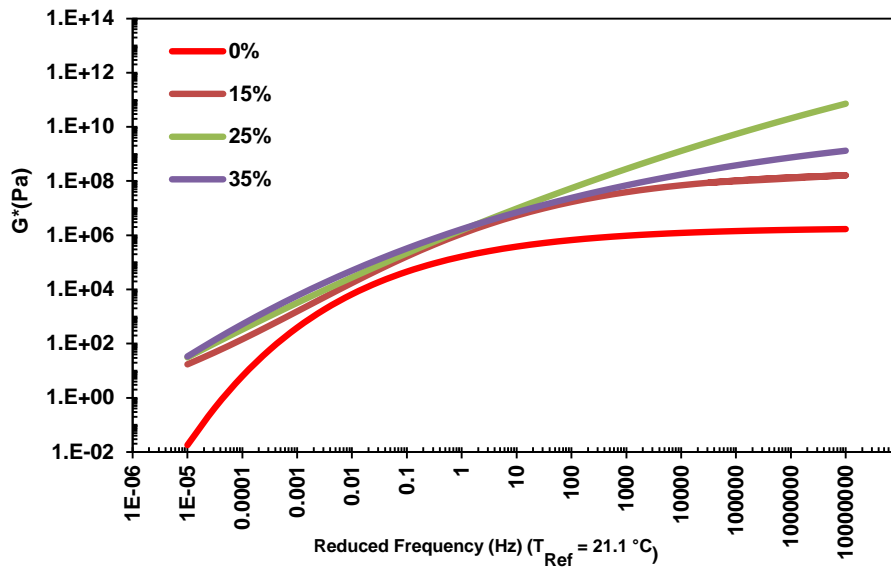


Figure29.Comparison of Master curve for UN Aged mastics

From the master curve, it can be conclude that for Unaged and RTFO Aged Conditioned the shear modulus increase with increment of RHB for high temperature areas with low frequency. Furthermore for 35% RHB mastic since it has a grade bumping (refer Appendix B) and have increased stiffness, comparing to other mastics is suitable for Addis Ababa and near cities, based on that the research recommend it to use it as mastic asphalt. Alternatively for Low temperature areas with high frequency 25% RHB mastic suitable than the others.

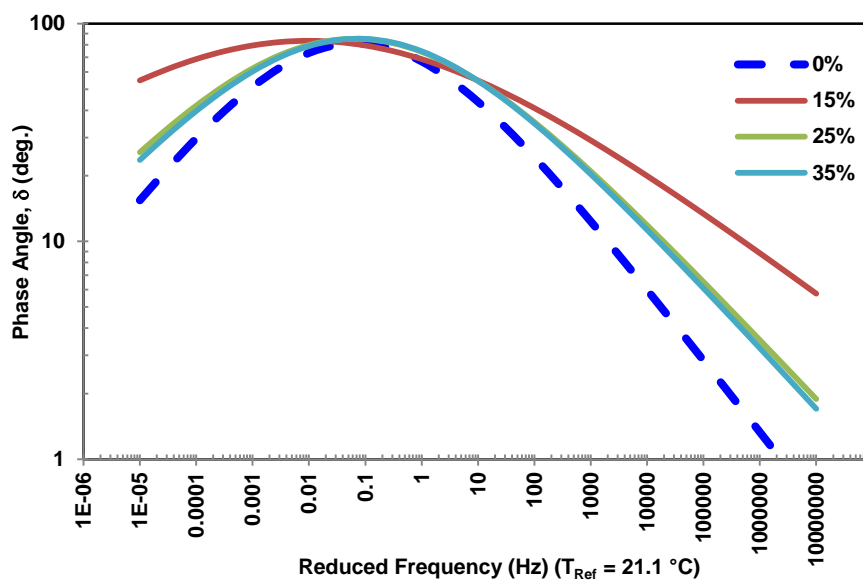


Figure30.Comparison of Master curve for Aged

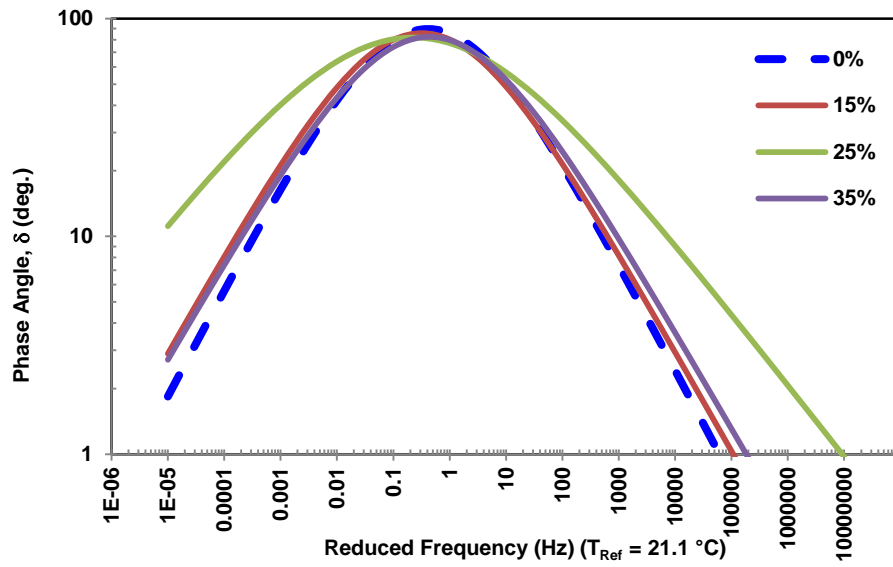


Figure31.Comparison of Master curve for UnAged

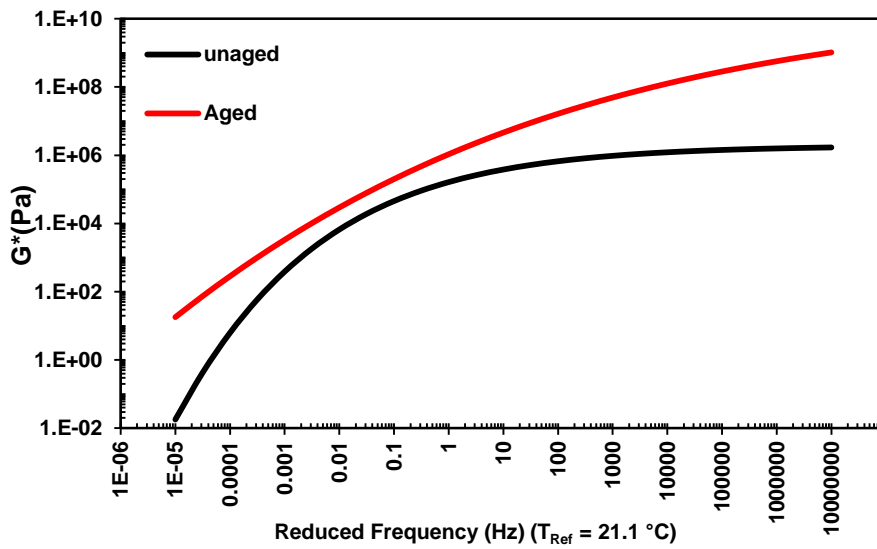


Figure32.master curve of neat binder before and after aging

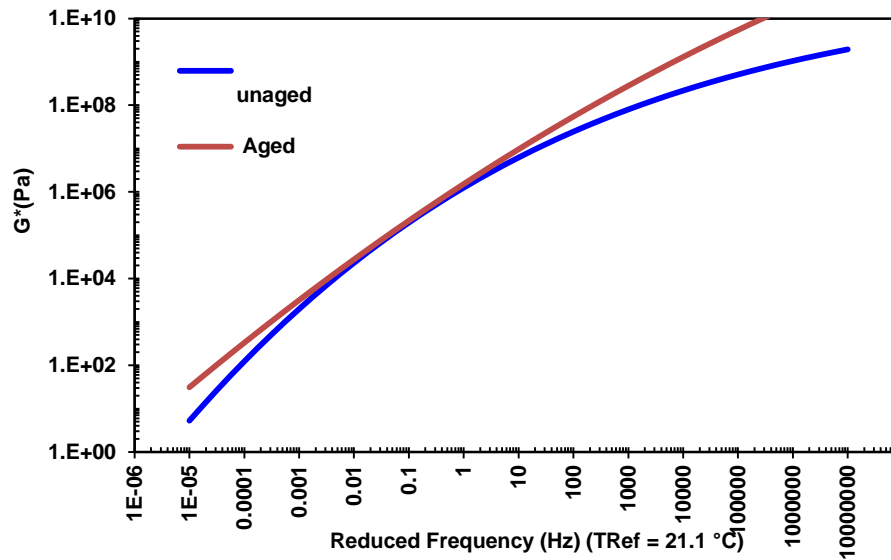


Figure 33. master curve of 25% RHB before and after aging

As discussed earlier to know the aging effect before aging FST is done. Figure 32 and figure 33 shows comparing to the mastics the neat binder stiffness increases due to aging. These shows adding Recycled hollow block reduce the aging, but it has no significant effect on the aging process. The aging index is Presented Appendix B.

Since the stiffness is related to durability, therefore modifying bitumen with RHB will be valuable approach.

4.2.6 MSCR Test

The MSCR tests were conducted using the 25 mm diameter plate (1 mm gap). For each of the binders, two aged replicates were tested. Ten creep and recovery cycles (creep for 1 s and recovery for 9 s) with no rest periods were performed for each of the shear stress levels.

The Selection of temperatures is consistent with the standard pg high temperature ,The PG for 0% ,15% and 25% of RHB is 58 and for 35% RHB the PG bumped by one i.e 64. Temperatures 52°C, 58°C, 64°C, and 70 °c were included in the MSCR test. The performance grade results are listed in Appendix B.

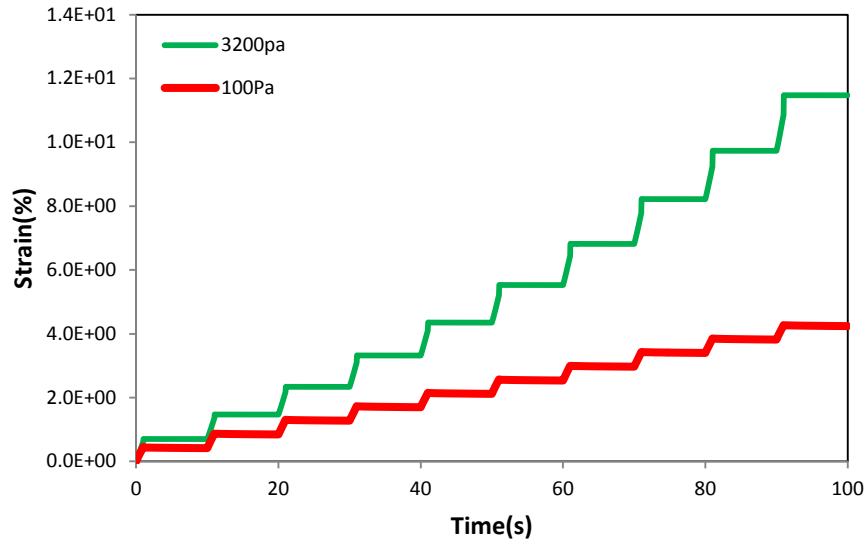


Figure34.The effect of stress on 25% RHB At 64°c

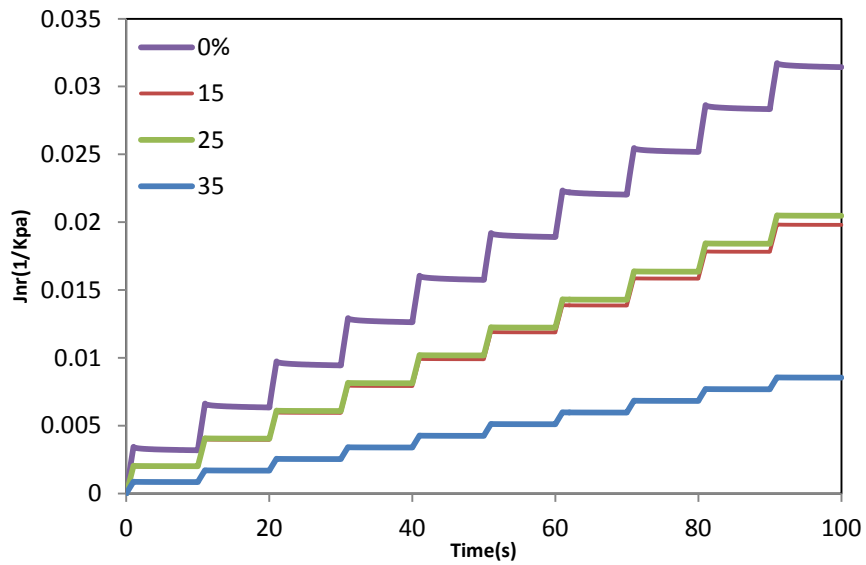


Figure 35.Comparison of Jnr at different % of RHB at 58°

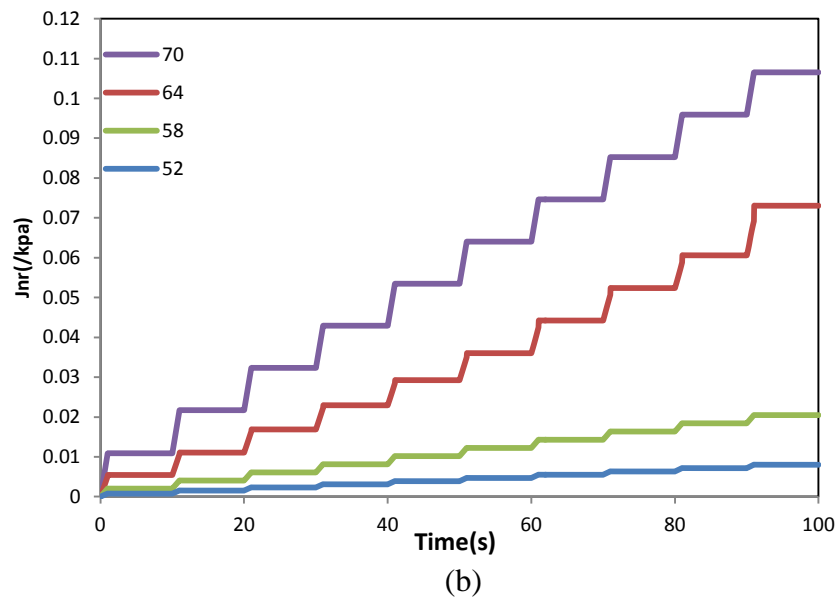
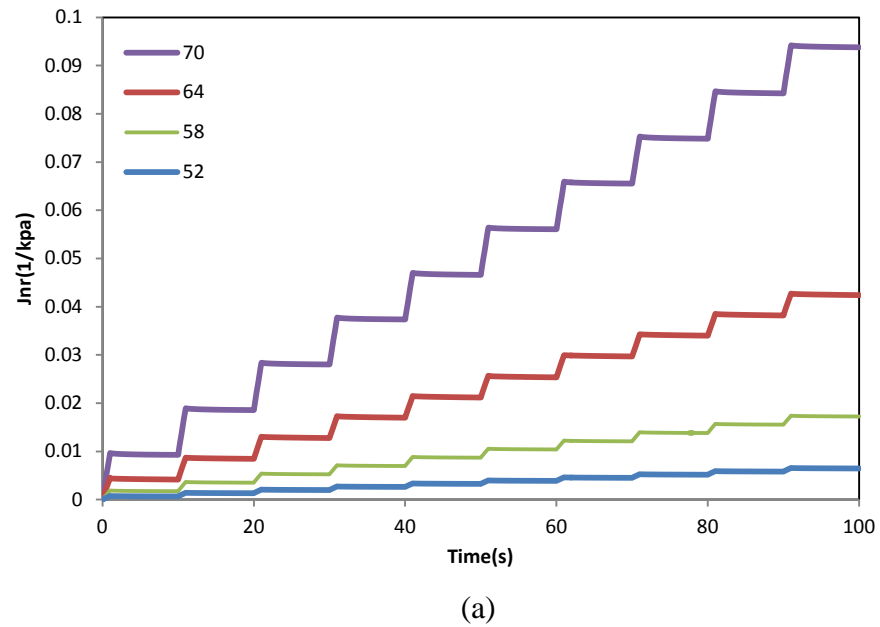


Figure36.For 25% RHBComparison of Jnr at different temperature;(a) 100Pa,(b)3200Pa

Figure 35 and Figure 36 illustrate for 25% RHB the non-recovery compliance increase with temperature increment at 0.1Kpa and 3.2Kpa Stress level. And also at the same temperature when percent of RHB increase the non-recovery compliance decrease. The same holds for 0%RHB,15%RHB and 35 %RHB(Refer Appendix B).

Figure 37 clarifies typical MSCR test results of 25% RHB mastic tested using multiple stress levels at a temperature of 64°C. This figure shows ten creep and recovery cycles using a shear stress of 100 Pa and the resulting shear strain response. The load was applied for one second and released for nine seconds. A total of ten loading (shear stress = 100 Pa) and unloading (shear stress = 0 Pa) cycles over 1000 seconds are shown in this figure. A progressive increase in strain is observed during the ten creep recovery cycles. The inset computation in this figure presents an example how to calculate the creep compliance and percent recovery using the applied 100 Pa shear stress and the adjusted strains.

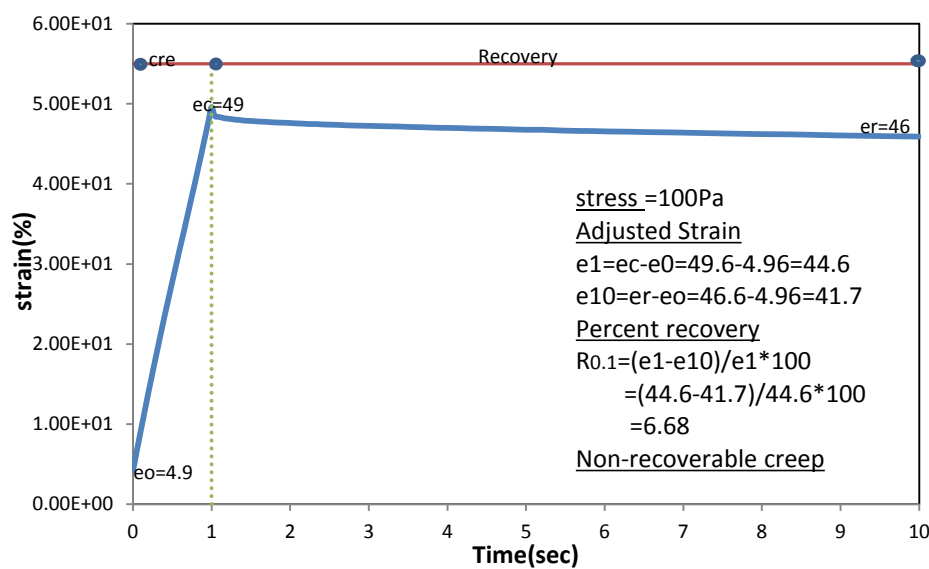


Figure 37. Example of MSCR Analysis using one creep and recovery cycle

Table 6. Jnr and PR results at different temperature

RHB Content (%)	Temperature(°c)	Jnr (1/kPa)		PR(%)	
		0.1 kPa	3.2 kPa	0.1 kPa	3.2 kPa
0%	64	4.5	11.2	5.5	0
	58	3.1	3.9	7.1	0
	52	1	1.3	11.6	1.5
15	64	4.2	6.9	8.9	0
	58	1.7	2	8.1	0
	52	0.6	0.8	14.4	4.4
25	64	4.2	6.8	5.5	0
	58	1.7	2.1	7.4	0
	52	0.6	0.8	11.7	2.6
35	70	3.3	5.2	12.4	0
	64	1.7	2	9	1.7
	58	0.7	0.9	11.7	1.2

Figure 38 shows the relationships between Jnr and temperature tested at 0.1 kPa and 3.2 kPa shear stress levels for 35% RHB. Asphalt binder with higher Jnr value typically measure lower stiffness. It is shown in this figure that the increase in temperature reduced the stiffness properties of the asphalt binder. For a given test temperatures, slightly higher Jnr(3.2) value was obtained compared to the Jnr(0.1). Overall, the stress-temperature dependency and the elastic recovery properties of the asphalt binders were sufficiently characterized using the MSCR test.

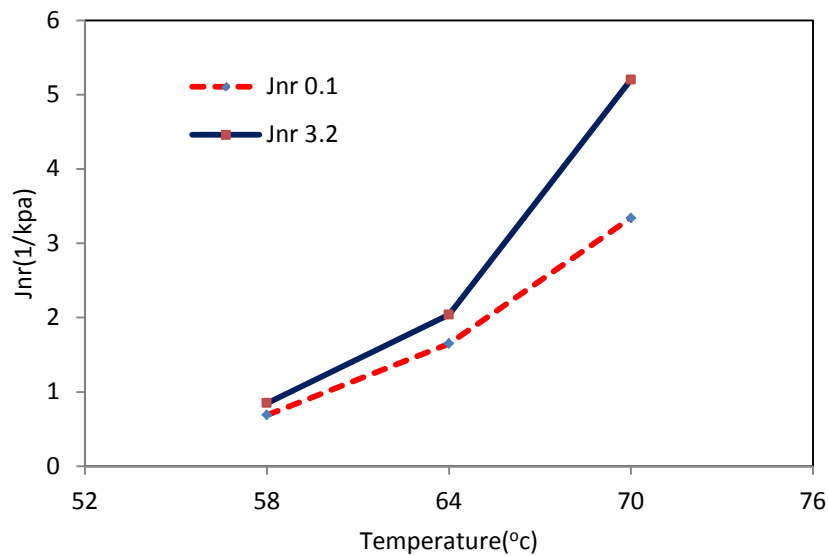


Figure 38. MSCR Test results; Jnr

The results of Jnr values is summarized by figure 39 below, the figure illustrate at 0.1 Kpa as the temperature increase for a given mastic the non recoverable compliance increase. However at a specific temperature as the content of the recycled hollow block increase the jnr value decrease, which tell us adding recycled hollow block will have a good resistance against rutting. Accordingly the results for 3.2 Kpa presented in Appendix B.

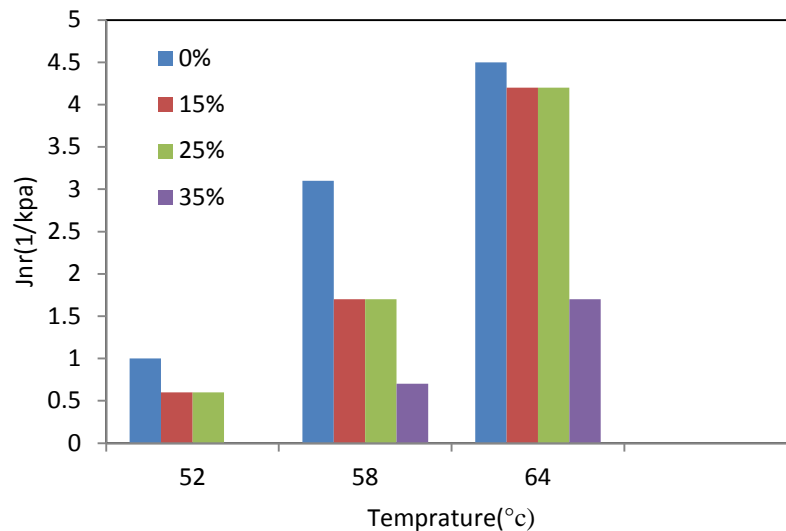


Figure 39. Comparison of Jnr values of the mastics at different temperature at 0.1kpa.

Since Jnr directly imply the rutting, as shown on Table 6 adding Recycled Hollow block will increase the rutting resistance. Based on the result 35% RHB mastics has good result to rutting resistance comparing to the other mastics

In General from the MSCR test we can conclude that due to increasing temperature thenon-recoverable compliance decrease for each mastic at 0.1 kPa and 3.2 kPa shear stress levels. For the other mastics it is presented on Appendix B.

4.3 Statical Analysis of Complex Modulus Using ANOVA

Following the laboratory procedures and data collection, to evaluate the significance of Recycled Hollow block, a statistical analysis was performed for Complex Modulus results performed using an Analysis of Variance (ANOVA).

Anova: Single Factor (A one-way ANOVA) This tool performs a simple analysis of variance on data for two or more samples. The analysis provides a test of the hypothesis that each sample is drawn from the same underlying probability distribution against the alternative hypothesis that underlying probability distributions are not the same for all samples.

In an experiment involving many treatments, a common objective is to test whether or not the treatments differ in terms of their effects on the response variable. Two hypotheses are possible – null hypothesis and alternative hypothesis. Null hypothesis

(H_0) exists if the treatment effects are all equal; alternative hypothesis (H_A) exists if the treatment effects differ (at least two of the treatment effects differ).

For this specific research, if Complex modulus of different mixes is compared, null hypothesis will exist if Complex modulus of the mixes does not vary (i.e., $G_{mix1} = G_{mix2} = \dots = G_{mix4}$). If Complex modulus of all or at the least two of the mixes differs then alternative hypothesis exists (i.e., $G_{mix1} \neq G_{mix2} \dots \neq G_{mix3}$). H_0 is either accepted or rejected depending upon p -value. If the computed p -value is less than the significance level (α) H_0 is rejected i.e., reject H_0 if $p < \alpha$.

The Four groups of independent variables are 0% RHB, 15%RHB, 25%RHB and 35%RHB and the dependent variable will be complex modulus for three selected frequency listed in Table 8 below. The frequency is selected in order to emphasize short time and long times of loading. The ANOVA is done for aged and unaged condition. The full analysis is presented in Appendix C.

Table 7. Complex modulus for aged and un aged condition for selected frequency.

Aging condition	Frequency(Hz)	Complex modulus(G^*)Kpa			
		0% RHB	15%RHB	25%RHB	35%RHB
UNAGED	0.1	45.32	164.82	216.81	326.21
		44.80	163.69	196.84	318.25
	1	163.10	1135.53	1524.08	1681.06
		163.35	1142.19	1255.01	1665.24
	10	394.15	5299.99	6211.85	7011.30
		380.77	5295.86	9629.60	6986.78
AGED	0.1	199.82	286.60	216.81	940.67
		205.58	259.22	202.13	780.45
	1	1069.92	1417.78	1524.08	4529.10
		1066.10	1331.98	1466.54	3670.80
	10	4614	5683.44	9629.60	18142.52
		4585.46	5738.98	9690.61	14351.76

The decision to accept or reject the null hypothesis (H_0) is made by comparing the test statistics (computed F ratio) with critical value from the table. If the computed F ratio is exceeds the critical value, the hypothesis is rejected; if not, the hypothesis is not rejected.

Table 8. Complex modulus ANOVA Table

Aging condition	Frequency(Hz)	F - Value	F critical	P value	Error(α)	Null Hypothesis (if $p < \alpha$) reject
Unaged	0.1	452.16	6.59	0.0000	0.05	Reject
	1	94.72		0.0004		Reject
	10	15.43		0.0115		Reject
Aged	0.1	60.54		0.0009		Reject
	1	42.27		0.0017		Reject
	10	30.84		0.0032		Reject

The ANOVA result of Complex modules collected in laboratory on unaged and RTFO aged indicates that, on all cases the observed value of the test statistics, the F ratio exceeds the critical value at 0.05 level of significance, and therefore the null hypothesis is rejected.

Table 8 presents the results obtained from the ANOVA analysis, which showed that significant difference was observed between the mastic types at the determined frequency and at that specific testing temperature. Thus, it can be concluded that the four mastics Asphalt mixtures will have a different performance at low, intermediate and high frequencies. Hence this research accepted that Using recycled hollow block has an effect on the Complex modulus of HMA.

4.4 Summary

Prior to performing the rheological tests, basic filler test for the recycled hollow block and Engineering property test for the bitumen and the mastics was done. Based on the result all the mastics pass the requirements.

The rheological tests were performed using a Bohlin DSR in order to study the linear and non-linear viscoelastic behavior of four different modified bitumen. Amplitude sweep test, frequency sweep tests and multiple stress recovery tests were performed during this study as part of the dynamic shear testing.

AST were used to determine the linear viscoelastic limit while FST in the linear viscoelastic range of response were used to determine the LVE rheological characteristics of the binders. The effect of stress level, at different temperatures and frequencies, was evaluated by plotting complex modulus and phase angle versus strain.

In analyzing the amplitude sweep data, the SHRP method was used to determine the linear region. In this method, the linear strain limit is somewhat arbitrarily established as the stress or strain at which the complex modulus decreases to 95 percent of its initial value. The data from these tests, i.e. the linear stress or strain limits were plotted against temperature. These graphs showed that the LVE strain limit generally increases with increasing temperature for each mastic.

Upon completing the AST and establishing the target strains, frequency sweeps were performed on all samples. All of the frequency sweep tests were conducted at strain below the linear limit. Prior to the construction of each master curve, multiple graphs of the absolute value of complex modulus versus frequency (isothermal plots) were developed. After preparing the isothermal plots, complex modulus and phase angle master curves were constructed using a reference temperature of 21.1 °C for the mastics.

The results showed that, in the low frequency region (high temperatures), 35% RHB has showed better performance than other mastics. 25% RHB showed a predominant elastic behavior at high frequency and low temperature.

Before performing the MSCR test performance grade was determined, the result showed adding RHB will bump the grade when 35% of the bitumen is added. The MSCR result shows adding recycled hollow block will decrease resistance to rutting compared to neat bitumen.

Finally based on the ANOVA analysis adding recycled hollow block has a significant effect on Asphalt material.

CHAPTER 5 CONCLUSIONS AND RECCOMENDATIONS

This Research focused on evaluating the use of recycled hollow block to improve the durability of HMA as well as its performance against rutting.

Using standardized testing procedures, the recycled hollow block was tested for the basic filler tests including specific gravity, plasticity index, and hydrometer test. Correspondingly important quality tests of bitumen were conducted and all the results were pass the necessary specifications.

To characterize the rheological property of mastic .i.e. Linear visco elastic range, master curve and Multiple stress creep recovery of mastics was Performed.

Based on the laboratory result and analysis the following conclusion and recommendation was done.

5.1 Conclusion

- The Durability of Mastics was evaluated using Frequency sweep test. Based on the results, for high temperature areas with low frequency the Complex modulus of the mastics increases as the Recycled hollow block content increases i.e 35% RHB shows higher stiffness than the others.
- For the case of Low temperature areas with high frequency a higher Complex modulus values are observed for 25% RHB sample.
- The MSCR result shows adding recycle hollow block will increase resistance to rutting compared to neat bitumen. This result supports the earlier findings in that 35 % RHB sample are more resistant to rutting than neat. The higher stiffness exhibited by 35% compared to the other mastics might give a good explanation to its better resistance against rutting.
- Finally, since recycled hollow block improve the long-term performance and durability of pavements, the researcher believes that using recycled hollow block will increase pavement life.

5.2 Recommendation

- Based on my inspection most of manufacturing companies and also users real estate's ,contractors don't made Quality test for the hollow blocks .Since it a basic thing awareness should be Created and Addis Ababa Housing Development Project Office Construction & Supervision Department should work on the quality control.
- Nongovernmental or governmental service companies which focus on Jobsite Sorting, Collection and Hauling, Tipping, Picking and Sorting, Containerization and Transport and Diversion or Disposal on should be formed in order to use the waste effectively.
- The researcher believes that using recycled hollow block will increase pavement life. However, it is not used in our country. Therefore highway engineers and contractors all other concerned bodies should consider the role of recycled hollow block in improving the long-term performance and durability of pavements.

5.3 Future Study

- Since Hollow block is a composite material further Studies needed to be determined in order to characterize the chemistry of binder modified with RHB.
- Further investigations need to be done in order to know the optimum RHB content.
- The advantage of RHB conducted on this research evaluates the mastic on the Unaged and short term condition. Further study should be done to evaluate it in long term condition in order to know the life time performance.
- The Rheological propriety is done using controlled stress method; further study could be done using controlled strain.
- Further study could be performed to know the effectiveness of Recycled hollow block in asphalt mixtures in relation to other filer materials
- Life cycle cost analysis should be conducted to know the effect of RHB on Asphalt material as a modifier in comparison to unmodified Binder.

REFERENCES

- A novel Approach to improve road quality by utilizing plastic waste in road construction, may 2011
- AASHTO.(2010). Designation T 315 Standard Method of Test for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR). Standard Specifications for Transportation
- AnggrainiZulkati; Wong YiikDiew; and Darren Sun Delai . “Effects of Fillers on Properties of Asphalt-Concrete Mixture.”, July 2012.
- BehzadRahimzadeh, Bsc, Msc, Miat, Miht., "Linear And Non-Linear Viscoelastic behavior Of Binders And Asphalts", March 2002.
- Bjorn OveLerfald., "Ageing and Degradation of Asphalt Pavements on Low Volume Roads" February 2000.
- Buttlar, W. G., Bozkurt, D., Al-Kateeb, G. G., and Waldhoff, A. S., “Understanding Asphalt Mastic Behavior through Micromechanics,” , 1999.
- DebashishKar, Mahabir Panda and JyotiPrakashGiri, "Influence Of Fly-Ash As A Filler In Bituminous Mixes", June 2014.
- DipuSutradhar "Effect of Using Waste Material as Filler in Bituminous Mix Design". 2015.
- ERA .2013. Ethiopia flexible pavement design manual.
- H. Zelelew¹, C. Paugh², M. Corrigan³, and S. Bel'agutti⁴. , "Evaluation of Multiple Stress Creep and Recovery (MSCR) Test Data Reporting Methods", 2012
- H.M. Zelelewa and A.T. Papagiannakis^b., "Interpreting asphalt concrete creep behavior through non-Newtonian Mastic rheology", 2012.
- HasanTsherkaBehanamAmani., "Utilization Of The using Of Cement stabilized Recycled concrete and brick in pavement layers", 2014.
- Hussain U. Bahia, "Test Methods and Specification Criteria for Mineral Filler Used in HMA", February , 2011.
- Ken Gwilliam, Vivien Foster, Rodrigo Archondo-Callao, Cecilia Briceño-Garmendia, Alberto Nogales, and Kavita Sethi, "The Burden of Maintenance: Roads in Sub-Saharan Africa", June 2008
- Khalil Nabil Dalloul, "Study of the Effect of Crushed Waste Glass as Coarse Sand and Filler in the Asphalt Binder Course", 2013.
- Margaret Mary O'Mahony., "Recycling of Materials in Civil Engineering", 1990.

Solid Waste Management Manual: With Respect to Urban Plans, Sanitary Landfill Sites and Solid Waste Management Planning, April 2012.

Solid waste management proclamation ,Federal democratic republic of Ethiopia 12th february, 2007

Tayebali, A.A., Malpass, G. A., and Khosla, N.P “Effect of mineral filler type and amount on design and performance of asphalt concrete mixtures.”, 1998.

UliWesslingTolon, “Comparison of Urban Upgrading Projects on Development Cooperation in Ethiopia.”, 2008.

Use of Recycled materials for road construction, September 2011.

Using Recycled Industrial Materials in Road ways, July 2009.

YohannesGebremeskelkiflat., "The Effect of Filler Type and Shape on HMA Energy Dissipation Performance", 2013.

APPENDIX A

Questioner



**Addis Ababa Institute of Technology,
School of Civil and Environmental Engineering
Road & Transport Engineering Stream**

**Thesis Title: Assessment on the Utilization of Recycled Hollow block as
Asphalt Mastic Material**

Production area and facilities

1. Availability of sufficient clean, dry and ventilated cement store
a/yes b/No
2. Availability of sufficient area under shade for production, curing and storage
of HCB

a/yes

b/No

Do they make HCB Quality approval test?

a/ yes

b/No

Feed back

Do they collect feedback from customers

a/ yes

b/No

If your answer is yes for the above question, could you let us know if you face problem from quality Aspect? or other

Like other construction waste, do you believe demolished HCB significantly included in DCM?

a/ yes

b/No

Could you tell us your opinion about Demolished HCB waste from construction site occur from quality aspect or workmanship problem

Please reason out your answer for question Iv.3.

Based on your judgment how many percent of HCB included in DCM ?

Appendix B

Table B.1. Chemical composition of recycled hollow block

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MnO	P ₂ O ₅	TiO ₂	H ₂ O	LOI	SO ₃
42.50	9.81	4.68	16.34	1.40	2.22	1.96	<0.01	0.03	0.10	3.53	15.88	0.34

Table B.2. Penetration Aging Index

RHB(%)	Unaged	Aged	Penetration Aging index
0	82	35	0.43
15	73	30	0.41
25	52	21	0.40
35	49	19	0.39

DSR TEST RESULTS

AST RESULTS

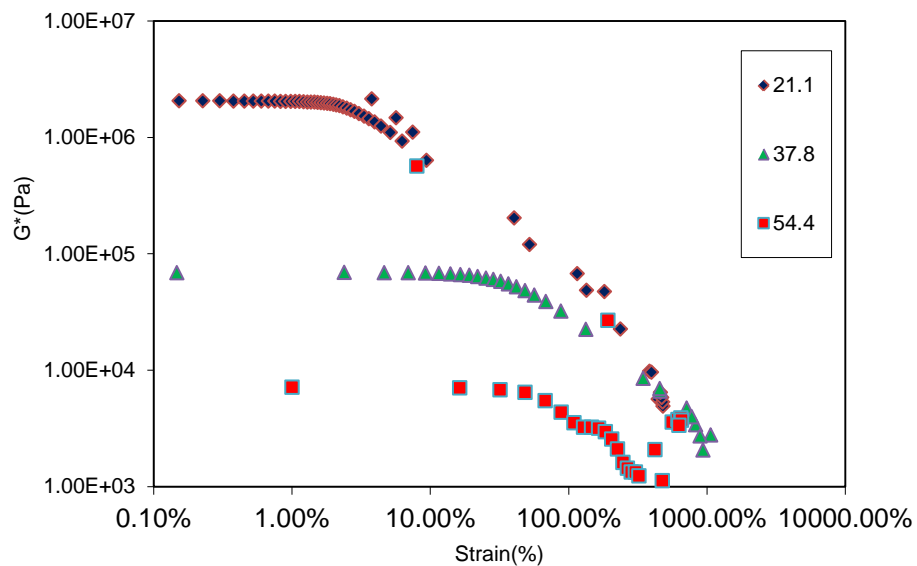


Figure.B.1.Ast for Aged Controlled binder at Different Temperatures

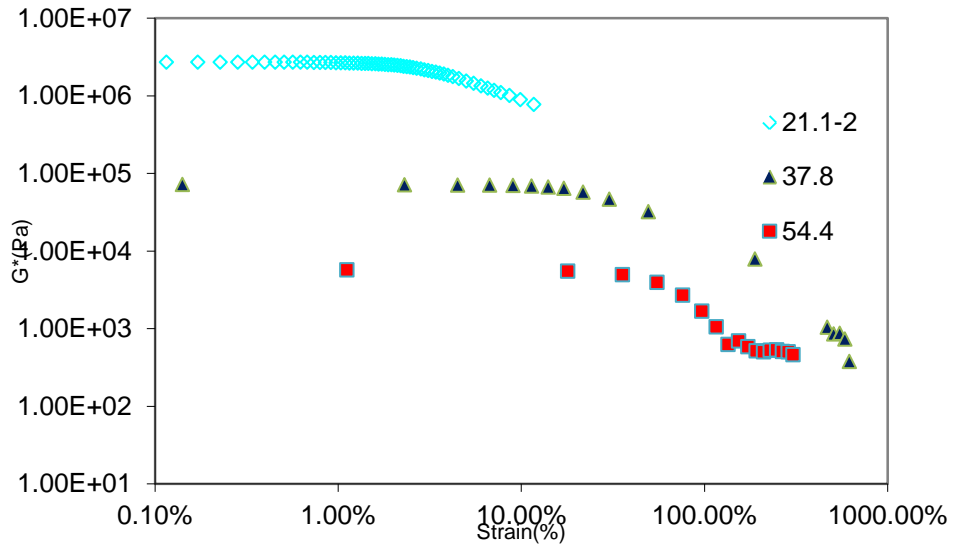


Figure.B.2.Ast result for 15% RHB Aged at Different Temperatures

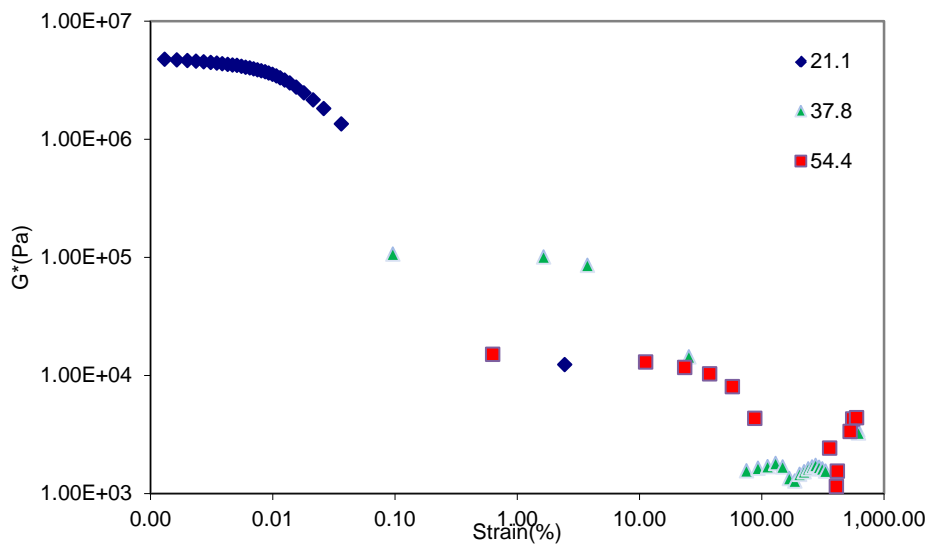


Figure.B.3.Ast result for 15% RHB Aged at Different Temperatures

FST RESULTS

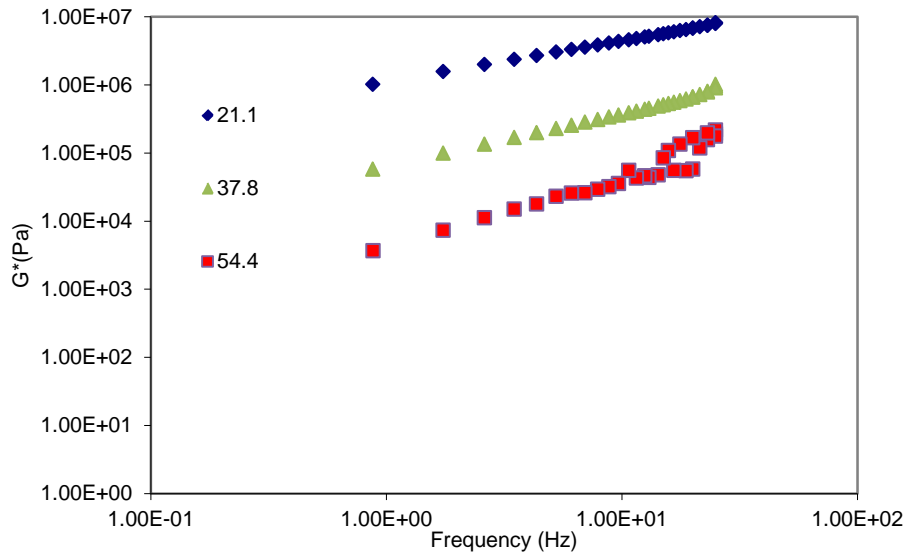


Figure.B.4.FST result for Controlled binder at Different Temperatures

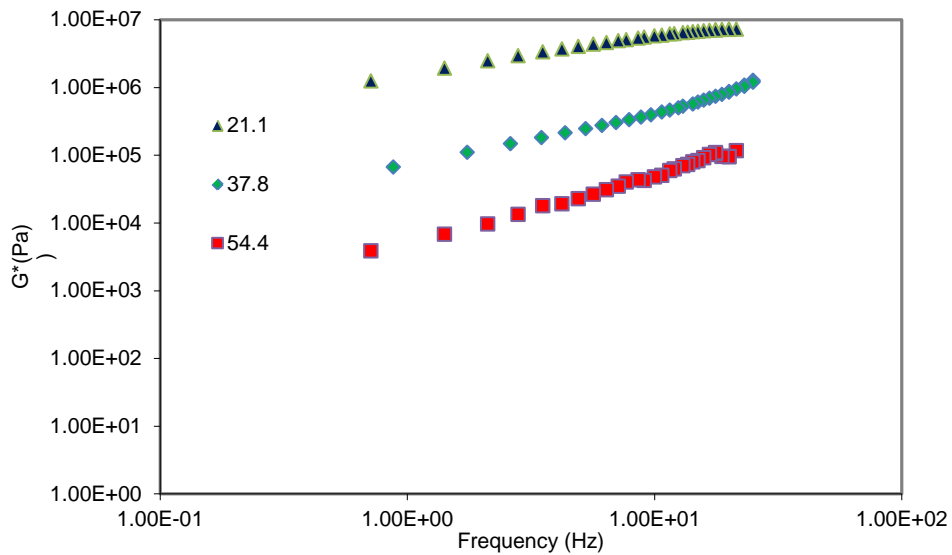


Figure.B.5.FST For 15% RHBAged At Different Temperatures

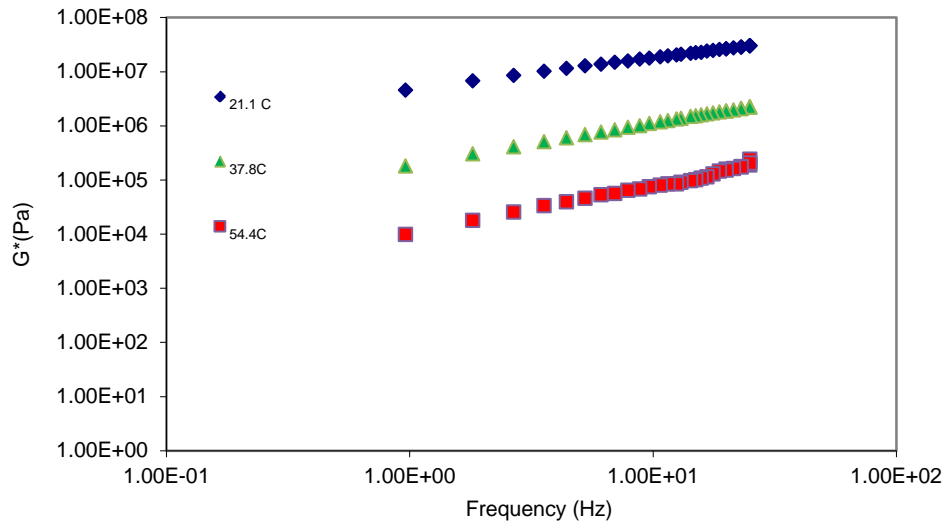


Figure.B.6.FST For 35% RHBAged At Different Temperatures

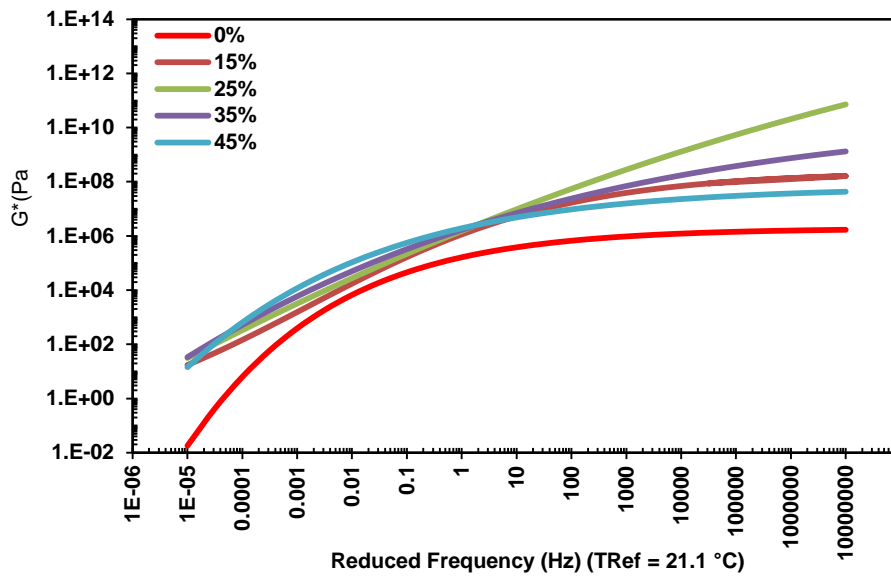


Figure.B.7.Master curve for Unaged Mastics including 45% RHB

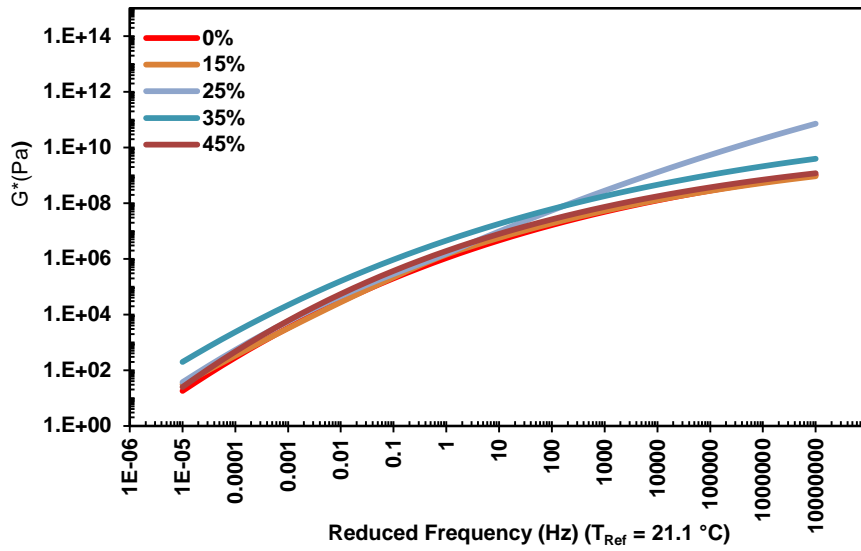


Figure.B.8.Master curve For RTFO aged Mastics including 45%RHB

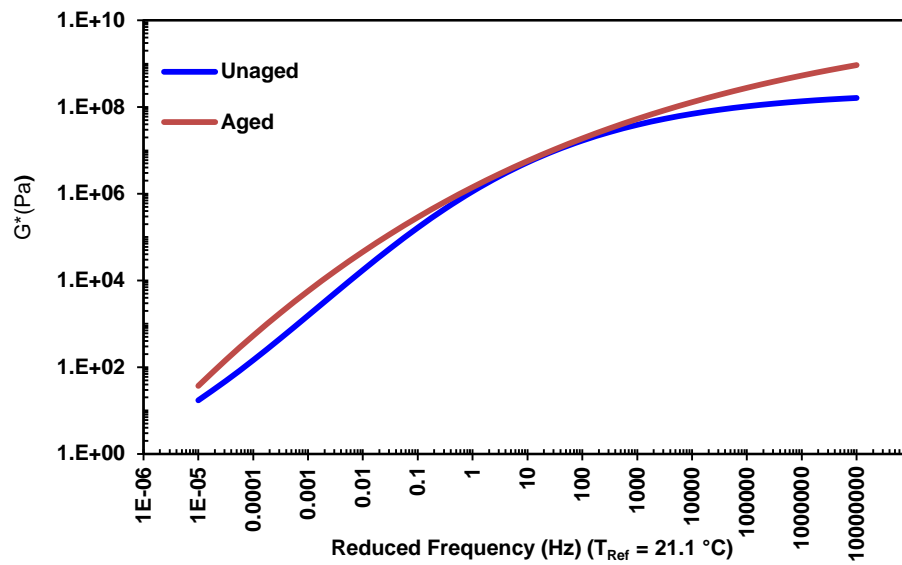


Figure.B.9.Master curve of 15% RHB before and after ageing

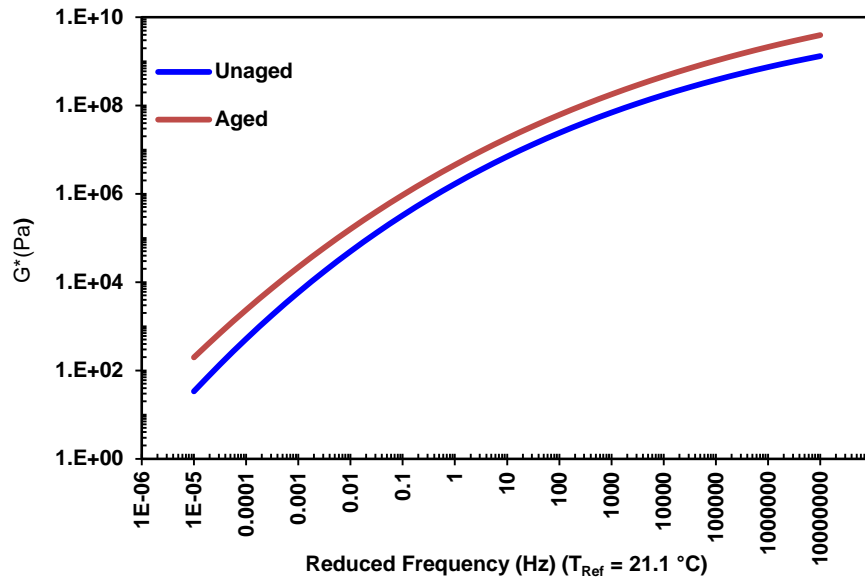


Figure.B.10.Master curve of 35% RHB before and after ageing

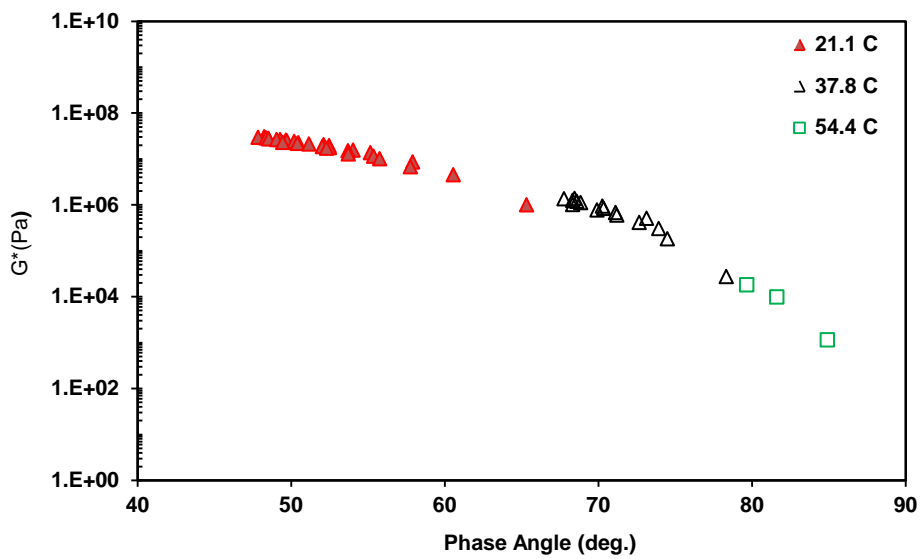


Figure.B.11.Black diagram of 35% RHB aged

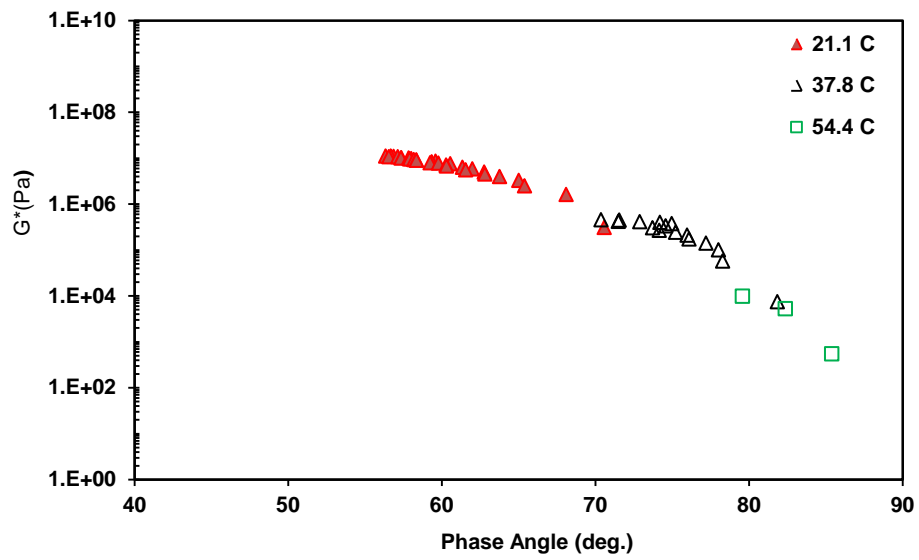


Figure.B.12.Black diagram of 35% RHBUnaged

PERFORMANCE GRADE DETERMINATION FOR RTFO AGED MASTICS

Table B.3. Performance determination for RTFO Aged mastics

RHB(%)	Temperature	Frequency	Phase Angle	Complex Modulus	Elastic Modulus	Viscous Modulus	Complex Viscosity	Shear Stress	Strain
	(°C)	(Hz)	(°)	(Pa)	(Pa)	(Pa)	(Pas)	(Pa)	(%)
0	51.99	1.60E+00	82.16	8.18E+03	1.12E+03	8.10E+03	8.16E+02	8.19E+02	1.00E-01
	58.04	1.60E+00	84.56	3.20E+03	3.04E+02	3.19E+03	3.19E+02	3.24E+02	1.01E-01
	64.04	1.60E+00	86.2	1.34E+03	8.91E+01	1.34E+03	1.34E+02	1.36E+02	1.01E-01
	Pass Fail Temp(°C)	60.7							
	Grade :	58							
15	Temperature	Frequency	Phase Angle	Complex Modulus	Elastic Modulus	Viscous Modulus	Complex Viscosity	Shear Stress	Strain
	(°C)	(Hz)	(°)	(Pa)	(Pa)	(Pa)	(Pas)	(Pa)	(%)
	58	1.60E+00	84.47	5.17E+03	4.99E+02	5.15E+03	5.16E+02	5.12E+02	9.91E-02
	63.95	1.60E+00	86.17	2.17E+03	1.45E+02	2.17E+03	2.16E+02	2.17E+02	9.99E-02
	Pass Fail Temp(°C)	63.9							
Grade :	58								
25	Temperature	Frequency	Phase Angle	Complex Modulus	Elastic Modulus	Viscous Modulus	Complex Viscosity	Shear Stress	Strain
	(°C)	(Hz)	(°)	(Pa)	(Pa)	(Pa)	(Pas)	(Pa)	(%)
	57.99	1.60E+00	86.36	4.22E+03	2.68E+02	4.21E+03	4.21E+02	4.23E+02	1.00E-01
	64.05	1.60E+00	87.48	1.77E+03	7.78E+01	1.77E+03	1.77E+02	1.81E+02	1.02E-01
	Pass Fail Temp(°C)	62.5							
Grade :	58								
35	Temperature	Frequency	Phase Angle	Complex Modulus	Elastic Modulus	Viscous Modulus	Complex Viscosity	Shear Stress	Strain
	(°C)	(Hz)	(°)	(Pa)	(Pa)	(Pa)	(Pas)	(Pa)	(%)
	57.98	1.60E+00	85.52	8.31E+03	6.49E+02	8.29E+03	8.29E+02	8.48E+02	1.02E-01
	64.16	1.60E+00	86.98	3.45E+03	1.82E+02	3.45E+03	3.44E+02	3.45E+02	1.00E-01
	69.97	1.60E+00	87.88	1.56E+03	5.77E+01	1.56E+03	1.55E+02	1.57E+02	1.01E-01
Pass Fail Temp(°C)	67.5								
Grade :	64								
45	Temperature	Frequency	Phase Angle	Complex Modulus	Elastic Modulus	Viscous Modulus	Complex Viscosity	Shear Stress	Strain
	(°C)	(Hz)	(°)	(Pa)	(Pa)	(Pa)	(Pas)	(Pa)	(%)
	57.99	1.60E+00	86.41	7.92E+03	4.96E+02	7.90E+03	7.90E+02	8.23E+02	1.04E-01
	64.05	1.60E+00	87.49	3.63E+03	1.59E+02	3.63E+03	3.62E+02	3.57E+02	9.84E-02
	70.04	1.60E+00	88.13	1.68E+03	5.50E+01	1.68E+03	1.68E+02	1.70E+02	1.01E-01
Pass Fail Temp(°C)	68								
Grade :	64								

MSCR RESULTS

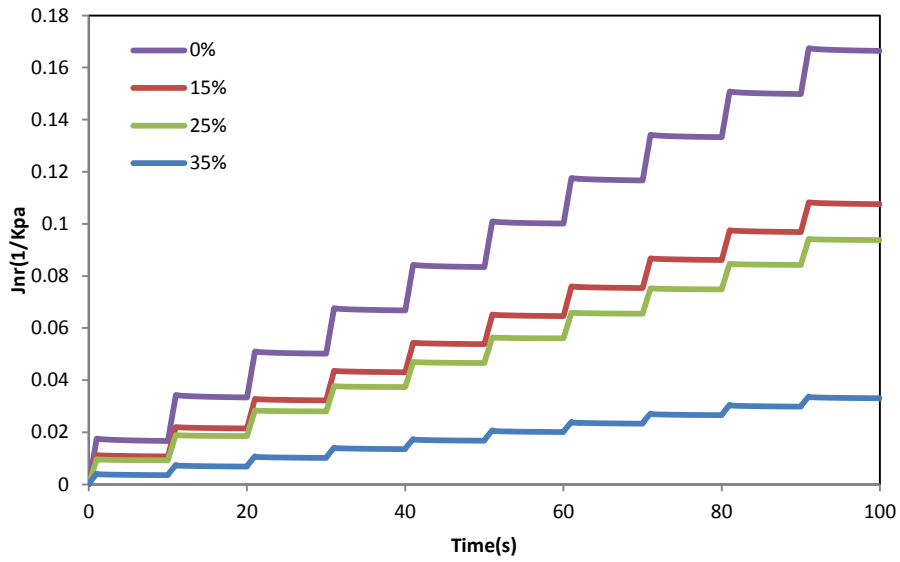


Figure.B.13.MSCR at 70°c for different % RHBat 100Pa

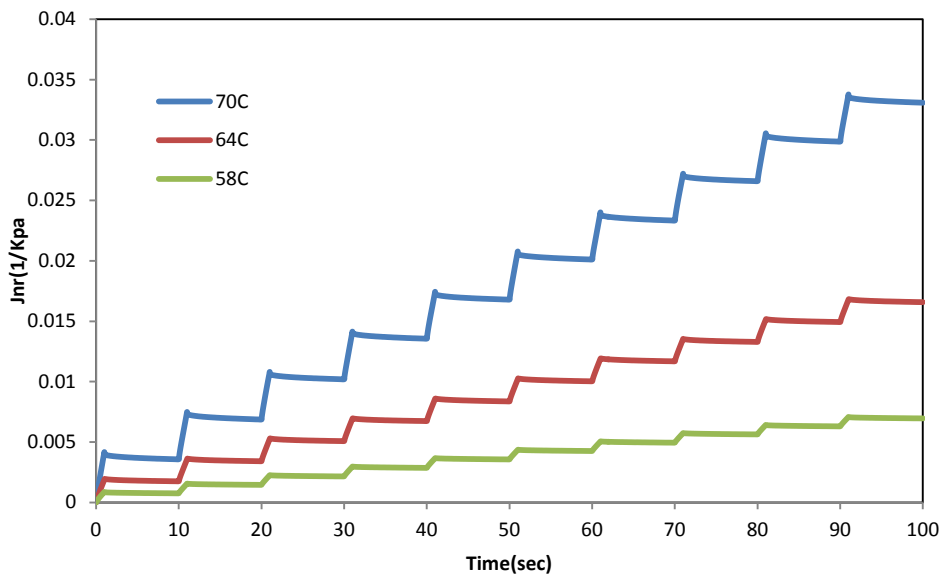


Figure.B.14.MSCR for 35% RHB fordifferent temperatures at 100Pa

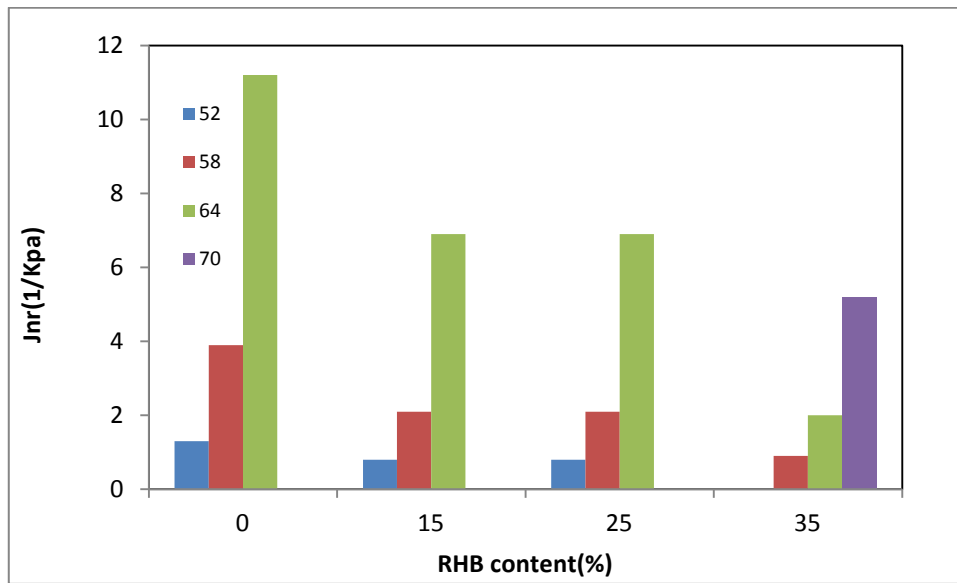


Figure.B.15.Jnr values of the mastics for different temperatures at 3.2Kpa

Appendix C

Statical Analysis

RTFO Aged at (0.1 Hz)			
0% RHB	15%RHB	25%RHB	35%RHB
199.82	286.60	216.81	940.67
205.58	259.22	202.14	780.45

SUMMARY

Groups	n	df	df	Sum	Mean	Variance	SSW
0% RHB	2	1	4	405.4	202.70	16.59	13334.25
15%RHB	2	1		545.82	272.91	374.83	
25%RHB	2	1		418.95	209.48	107.60	
35%RHB	2	1		1721.12	860.56	12835.22	

VARIANCE ANALYSIS

Source	SS	% SS	df	VAR	F	P Value	F Critical
Between Groups (SSB)	605511.66	97.85%	3	201837.22	60.55	0.0009	6.59
Within Groups (SSW)	13334.25	2.15%	4	3333.56			
Total (SST)	618845.91		7				

Un Aged at 0.1 Hz			
0% RHB	15%RHB	25%RHB	35%RHB
45.32	164.81	216.81	326.21
44.8	163.69	196.84	318.25

SUMMARY

Groups	n	df	df	Sum	Mean	Variance	SSW
0% RHB	2	1	4	90.12	45.06	0.14	231.84
15%RHB	2	1		328.5	164.25	0.63	
25%RHB	2	1		413.65	206.83	199.40	
35%RHB	2	1		644.46	322.23	31.68	

VARIANCE ANALYSIS

Source	SS	% SS	df	VAR	F	P Value	F Critical
Between Groups (SSB)	78643.0026	99.71%	3	26214.3342	452.2761	0.0000	6.5914
Within Groups (SSW)	231.8436	0.29%	4	57.9609			
Total (SST)	78874.8463		7				

Assessment on the utilization of Recycled Hollow Block as Asphalt Mastic Material

RTFO Aged at 10Hz			
0% RHB	15%RHB	25%RHB	35%RHB
4614	5683.44	9629.6	18143
4585.46	5738.98	9690.62	14352

SUMMARY

Groups	n	df	df	Sum	Mean	Variance	SSW
Data 1	2	1	4	9199.46	4599.73	407.27	7188779.93
Data 2	2	1		11422.42	5711.21	1542.35	
Data 3	2	1		19320.22	9660.11	1861.72	
Data 4	2	1		32494.29	16247.15	7184968.60	

VARIANCE ANALYSIS

Source	SS	% SS	df	VAR	F	P Value	F Critical
Between Groups (SSB)	166246938.67	95.86%	3	55415646.22	30.83	0.0032	6.59
Within Groups (SSW)	7188779.93	4.14%	4	1797194.98			
Total (SST)	173435718.60		7				

Unaged at 10 Hz			
0% RHB	15%RHB	25%RHB	35%RHB
394.15	5299.99	6211.85	7011.3
380.77	5295.86	9629.6	6986.78

SUMMARY

Groups	n	df	df	Sum	Mean	Variance	SSW
0% RHB	2	1	4	774.92	387.46	89.51	5840906.19
15%RHB	2	1		10595.85	5297.93	8.53	
25%RHB	2	1		15841.45	7920.73	5840507.53	
35%RHB	2	1		13998.08	6999.04	300.62	

VARIANCE ANALYSIS

Source	SS	% SS	df	VAR	F	P Value	F Critical
Between Groups (SSB)	67599056.75	92.05%	3	22533018.92	15.43	0.0115	6.59
Within Groups (SSW)	5840906.19	7.95%	4	1460226.55			
Total (SST)	73439962.93		7				

Assessment on the utilization of Recycled Hollow Block as Asphalt Mastic Material

RTFO Aged at 1 Hz			
0% RHB	15%RHB	25%RHB	35%RHB
1069.92	1417.78	1524.08	4529.1
1066.1	1331.98	1466.54	3670.8

SUMMARY

Groups	n	df	df	Sum	Mean	Variance	SSW
0% RHB	2	1	4	2136.02	1068.01	7.30	373682.99
15%RHB	2	1		2749.76	1374.88	3680.82	
25%RHB	2	1		2990.62	1495.31	1655.43	
35%RHB	2	1		8199.9	4099.95	368339.44	

VARIANCE ANALYSIS

Source	SS	% SS	df	VAR	F	P Value	F Critical
Between Groups (SSB)	11847037.03	96.94%	3	3949012.34	42.27	0.0017	6.59
Within Groups (SSW)	373682.99	3.06%	4	93420.75			
Total (SST)	12220720.02		7				

Un Aged at 1 Hz			
0% RHB	15%RHB	25%RHB	35%RHB
163.1	1135.53	1524.08	1681.06
163.35	1142.19	1255.01	1665.24

SUMMARY

Groups	n	df	df	Sum	Mean	Variance	SSW
0% RHB	2	1	4	326.45	163.23	0.03	36346.68
15%RHB	2	1		2277.72	1138.86	22.18	
25%RHB	2	1		2779.09	1389.55	36199.33	
35%RHB	2	1		3346.3	1673.15	125.14	

VARIANCE ANALYSIS

Source	SS	% SS	df	VAR	F	P Value	F Critical
Between Groups (SSB)	2582169.24	98.61%	3	860723.08	94.7237	0.0004	6.5914
Within Groups (SSW)	36346.68	1.39%	4	9086.67			
Total (SST)	2618515.91		7				