Influence of Waste Cooking Oil on the Rheological Properties of Aged Bituminous Binder

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ABSTRACT

Recycled asphalt pavement (RAP) has been considered as an alternate material in construction of pavement which decrease construction cost and enhance reutilizing of materials. Main challenge is incorporating the virgin material properties back to aged binder material. The present study deals with the evaluation of waste cooking oil as rejuvenator for long term aged Viscosity Grade VG-40 binder to achieve back the properties of virgin VG-40 binder. Long term age simulation was carried in the laboratory by Rolling Thin Film Oven (RTFO) and Pressure ageing vessel (PAV). The study mainly comprises of basic rheological characterisation of virgin VG-40 binder and Waste Cooking Oil (WCO) rejuvenated Long Term Aged (LTA) VG-40 binder using Brookfield rotational viscometer at different temperature increments from 60 ˚C to 160 ˚C. The results from the study indicated that the incorporation of 11% waste cooking oil into LTA VG-40 has shown improvement in its physical properties and selected as optimum dosage of rejuvenator. The mixing and compaction temperatures are about 4.5 °C less for WCO rejuvenated LTA VG-40 binder relative to virgin VG-40 binder. Results from graphs depict that virgin and rejuvenated binders are showing shear thinning behaviour at almost all temperature conditions.

Keywords: Reclaimed Asphalt Pavement; Pressure Ageing Vessel; Rolling Thin Film Oven; Waste Cooking Oil; Long Term Aged Asphalt.

1.INTRODUCTION

1.1 Reclaimed Asphalt Pavement (Asphalt institute MS-2)

Reclaimed Asphalt Pavement (RAP) has been used as a valuable component of new asphalt mix for years. The old road can either be completely removed or have only the top few inches ground off, a procedure called milling as shown in figure 1.2. Most RAP is produced from milling. RAP is also produced from any existing asphalt pavement by processing it to an appropriate size to be used as a component of a new asphalt mixture. Since RAP consists of the same components as virgin HMA— aggregate and asphalt binder—it can readily be incorporated into a new mixture. Economically, there is a benefit to using RAP since these components can be reused, thereby lessening the need to purchase and use as much new (virgin) materials. In addition to the economic benefits, the use of RAP in asphalt mixtures also has an environmental benefit. Reuse of a resource such as RAP lessens the depletion of non-renewable natural resources, such as virgin aggregate and asphalt binder.

1.2 Ageing of bitumen

The physical and rheological properties of bitumen change over time on exposure to high temperature and atmosphere is defined as ageing. Increasing age, hardening and embrittlement of the bitumen (binder agent) lead to a decrease of the elasticity and ductility of the pavement structure, resulting in reduced resistance against cryogenic cracks and premature formation of fatigue cracks.

As bitumen ages, due to volatilization there is a loss of aromatics that takes place. Recall from earlier, the polar and non-polar aromatics are two of the three sub compounds contained within maltenes. Upon oxidation, the maltenes will yield asphaltene type molecules (NCAT 1996). Since the maltenes are converted to asphaltenes, there is an overall loss of maltenes as a pavement ages. The loss of maltenes translates to a stiffer pavement that is more brittle due to a lack of cohesion inside the binder.

The aging of asphalt paving binders is one of the critical factors causing asphalt pavements to fail. These binders need to pass aging tests to meet the harsh climate encountered. The rolling thin film oven (RTFO) and pressure aging vessel (PAV) tests were developed by the Strategic Highway Research Program (SHRP) to simulate the aging that paving binders experience primarily due to thermal and oxidation aging in mixing plants and during service life of the pavements. Thermal aging is caused mainly by volatilization and some polymerization of smaller size molecules, while oxidation aging is caused by either the reaction of oxygen with, or the absorption of oxygen by the binders. Oxidation aging is usually characterized by the production of the functional carbonyl group in molecules.

1.3 Ageing levels of bitumen

a. Short-term ageing

This kind of aging occurs during the production and compaction of HMA, when bitumen is mixed with aggregate at temperatures of around 160˚C. Within this process, thin layers of bitumen are formed leading to a large reactive surface, which is susceptible for ageing promoting thermal effects such as the distillation of volatile fractions and chemical processes such as oxidation or polymerisation. The binder samples were simulated and artificially aged at 163˚C for 85 minutes using the rolling thin film oven test (RTFOT) in accordance with ASTM D 2872 (2006).

b. Long-term ageing

This kind of aging during service life of the pavement construction and takes much longer (decades).Besides local climate and air void content of the built-in material, especially the position of the bitumen inside the pavement plays an important role. Since the short-term ageing is only subjected to heating and oxidation, it is rather practical to simulate in the lab, which correlates well with the field results. In practice, this is frequently done in accordance with RTFOT method (EN 12607-1) or AASHTO R30 method. The main challenge comes in simulating long-term ageing because it is an extremely complex phenomenon which is a slow ageing process and occurs at ambient temperature during a long period. To simulate long- term field aging in laboratory, different types of test methods are currently available.

Pressure ageing vessel (PAV) is the commonly used methods for simulating long-term ageing of bitumen. In this method bitumen get exposed to relatively high temperature (90-110°C) and pressure (2.1MPa), which is irrespective of environmental conditions and mix morphology. Another method of asphalt mix ageing is AASHTO R30, which recommends 5 days at 85°C to simulate ageing for a period of 5 to 7 years. These accelerated ageing tests, by assuming time-temperature superposition principle, are generally conducted at artificially severe conditions, for example at temperatures higher than pavement service temperature and at pressures higher than ambient pressure.

1.4 Factors influencing aging of bitumen

Hardening of bitumen takes under the influence of external factors in the following ways:

i. **Oxidative hardening:** When bitumen is exposed to atmosphere for a prolonged period the oxygen starts reacting with the bitumen constituents and higher molecular weight molecules are formed. Larger molecules results in lesser flexibility and hence increased hardness. The degree of hardness is dependent on factors like ambient temperature, exposure time & thickness of bitumen film. It is observed that for 10^0C increase in temperature above 100^0C, the rate of oxidation doubles.

ii. **Hardening due to loss of volatiles:** Over a period of time the volatile components in bitumen evaporate. The rate of evaporation is dependent on temperature only. The volatiles in bitumen are relatively very low and hence hardening due to loss of volatiles is relatively small.

iii. **Physical hardening:** At ambient temperatures bitumen molecules slowly reorient themselves. This results in physical hardening. This process is an extremely slow process and hence actual hardening due to the above factor is very low.

iv. **Exudative hardening:** Exudative hardening takes place due to the movement of oily components out of bitumen over a period of time. The rate of hardening due to this process is dependent on the type of bitumen and also on the porosity of the aggregate.

v. **Hardening of bitumen during storage:** Bitumen is stored in above ground tanks at high temperatures and presence of oxygen are the two primary factors responsible for hardening of bitumen. Hence it is very important that bitumen be handled at the lowest possible temperature, consistent with efficient use. Also the storage tanks should have low surface to volume ratio so as to minimize the exposed surface area. Lower exposed surface area would mean lower oxidation rate.

vi. **Hardening of bitumen on road:** Some hardening of bitumen can also take place on the road due to oxidation. The level of oxidation is purely dependent on the access to oxygen. If the pavement is well graded and well compacted the hardening is nominal as the void content will be low.

1.5 Viscosity

Viscosity is "the internal friction of a fluid, caused by molecular attraction, which makes it resist a tendency to flow". Friction becomes apparent when a layer of fluid is made to move in relation to another layer. Greater the friction, greater will be the amount of force required to cause the movement, which is called "shear". To study the viscosity of a material shearing must induce stationary flow of the material i.e., steady shear. Flow occurs through, re- arrangement of particles, deformation of particles, and breaking of bonds in structure. That is shearing occurs whenever the fluid is physically moved or distributed, as in pouring, spreading, spraying, and mixing. Highly viscous fluids, therefore, require more force to move than less viscous materials.

1.5.1 Newtonian Fluids

Newtonian fluids are named after Sir Issac Newton who described the flow behaviour of fluids with a simple linear relation between shear stress [mPa] and shear rate [1/s] as shown in equation 1.1. This relationship is known as Newton's Law of Viscosity, where the proportionality constant η is the viscosity [mPa-s] of the fluid:

$$\tau = \eta \times \gamma \qquad \text{...........} \quad (1.1)$$

Some examples of Newtonian fluids include water, organic solvents, and honey. For those fluids viscosity is only dependent on temperature. As a result, if we look at a plot of shear stress versus shear rate (See Figure 1.5) we can see a linear increase in stress with increasing shear rates, where the slope is given by the viscosity of the fluid. This means that the viscosity of Newtonian fluids will remain a constant no matter how fast they are forced to flow through a pipe or channel (i.e. viscosity is independent of the rate of shear) as shown in Figure 1.5.

An exception to the rule is Bingham plastics, which are fluids that require a minimum stress to be applied before they flow. These are strictly non-Newtonian, but once the flow starts they behave essentially as Newtonian fluids (i.e. shear stress is linear with shear rate). A great example of this kind of behaviour is mayonnaise.

Newtonian fluids are normally comprised of small isotropic (symmetric in shape and properties) molecules that are not oriented by flow. However, it is also possible to have Newtonian behaviour with large anisotropic molecules. For example, low concentration protein or polymer solutions might display a constant viscosity regardless of shear rate. It is also possible for some samples to display Newtonian behaviour at low shear rates with a plateau known as the zero shear viscosity regions.

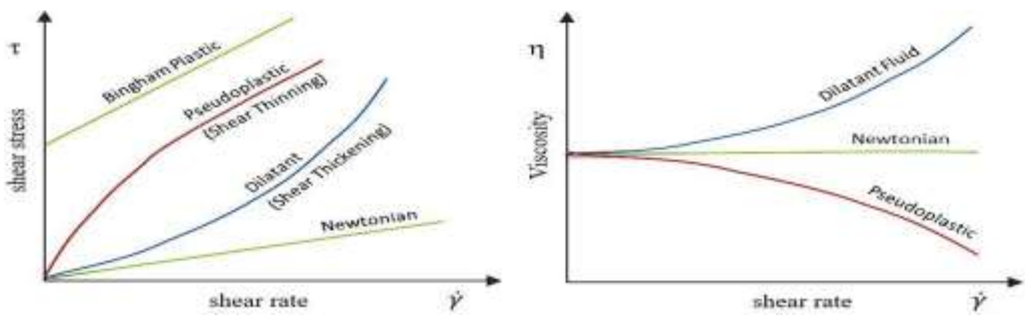

Figure 1.4 Flow curve and viscosity curve for a fluid.

1.5.2 Non - Newtonian Fluids

In reality most fluids are non-Newtonian, which means that their viscosity is dependent on shear rate (Shear Thinning or Thickening) or the deformation history (Thixotropic fluids). In contrast to Newtonian fluids, non-Newtonian fluids display either a non-linear relation between shear stress and shear rate (see Figure 1.1), have a yield stress, or viscosity that is dependent on time or deformation history.

A fluid is shear thickening if the viscosity of the fluid increases as the shear rate increases. A common example of shear thickening fluids is a mixture of cornstarch and water. Fluids are shear thinning if the viscosity decreases as the shear rate increases. Shear thinning fluids, also known as pseudo-plastics, are ubiquitous in industrial and biological processes. Common examples include ketchup, paints and blood.

Non-Newtonian behavior of fluids can be caused by several factors, all of them related to structural reorganization of the fluid molecules due to flow. In polymer melts and solutions, it is the alignment of the highly anisotropic chains that results in a decreased viscosity. In colloids, it is the segregation of the different phases in the flow that causes a shear thinning behavior.

1.6 Recycling agent

To improve the properties of aged binder, some chemical additives known as recycling agents are added to the asphalt mixture. Recycling Agents generally used are made up of a petroleum product composed of either highly polar or aromatic oils. The purpose of using recycling agents is to restore asphalt consistency. There are two types of chemical additives that can be added to pavements containing RAP i.e., rejuvenating agents and softening agents. The primary difference between a softening and rejuvenating agent is that a rejuvenating agent will try to restore the chemical structure of aged asphalt while a softening agent blends into a mix to reduce the overall viscosity of the binder (Chen et al. 2007). Unless it can be proven the recycling agent is chemically altering the asphalt binder, it is considered a softening agent. Addition of rejuvenating agent to RAP helps in restoring the binder properties.

1.6.1 Benefits of Rejuvenating Agents

a. Improve the low temperature PG grade and increase crack resistance in the HMA.

b. Improve workability/compaction of the RAP mix design.

c. Restore the aromatic resins to the high RAP asphalt binder that were lost due to oxidative field aging.

d. Do not cause continuous age softening of the RAP asphalt binder which could lead to increased rutting potential.

e. Increase aromatic resins lost during oxidation.

f. Reduce the high temperature Performance Grade (PG).

1.6. 2 Common rejuvenating agents

a. Tetra ethylene pentamine (TEPA)

b. Vegetable oil-based rejuvenator

c. Used cooking oil

1.7 Waste cooking oil

Oils abandoned from any cooking oils process for human consumption other than those from house hold regardless whether they have been used for their original purposes. Is one of the materials which can be used as rejuvenating agent. The production of waste automotive cooking oil (WCO) is estimated at 3 million tons each year throughout the world, posing a significant treatment and disposal problem for modern society. One gallon of used oil can create an eight-acre slick on surface water, threatening fish, waterfowl and other aquatic life. The preferred disposal option in most countries is incineration and combustion for energy recovery, though vacuum distillation and hydro-treatment have been researched to recycle this waste. The cost associated with Regeneration of waste cooking oil is also known to be high. Thus, considering the above shortcomings related to WCO, the most practical and eco- friendly way is to adopt it as a construction material such as in pavement construction. Just one gallon of Used/Waste oils can make a million gallons of fresh water undrinkable. Very small concentrations of Used/Waste oils (50 to 100 ppm) in the waste water can foul sewage treatment plants, resulting in increased maintenance costs and reduced treatment efficiency. Used/Waste oils applied to land can render the soil unproductive. Used/Waste oil placed in landfill may seep through the bottom of such landfill and subsequently contaminate groundwater supplies. People's heath can be affected if Used/Waste oils are handled improperly. Most Used/Waste oils contain small amounts of materials that can cause cancer and other health problems if these materials are inhaled and ingested. Used/Waste oils can be ingested if they get into drinking water sources and are not detected and removed. Uncontrolled burning of Used/Waste oils may result in significant levels of hazardous emissions to the environment. This may expose humans, wildlife and vegetation to harmful substances. Thus, considering the above shortcomings related to WCO, the most practical and eco-friendly way is to adopt it as a rejuvenating agent for bituminous binder in pavement construction. Figure 1.5 shows the color difference between fresh oil and Waste cooking oil where fresh oil has a gold and translucent color and after the heating, the oil turns black and opaque.

Fig. 1.5: Different colour between fresh (right) and Used (left) cooking oil

1.7.1 Physical properties of Waste cooking oil

(i) Density, mass of a unit volume of a material substance. The formula for density is d = M/V, where d is density, M is mass, and V is volume. Density is commonly expressed in units of grams per cubic centimetre.

(ii) Saponification value: a measure of the total free and combined acids especially in a fat, wax, or resin expressed as the number of milligrams of potassium hydroxide required for the complete saponification of one gram of substance.

(iii) Kinematic Viscosity: Viscosity is a state function of temperature, pressure and density. There is an inverse relationship between viscosity and temperature, when the temperature of the engine oil decreases the viscosity increases and vice versa. The oxidized and polymerized products dissolved and suspended in the oil may cause an increase of the oil viscosity, while decreases in the viscosity of cooking oils indicate fuel contamination.

(iv) Acid value: is a common parameter in the specification of fats and oils. It is defined as the weight of KOH in mg needed to neutralize the organic acids present in 1g of fat and it is a measure of the free fatty acids (FFA) present in the fat or oil.

(v) Iodine number: The iodine value (or iodine adsorption value or iodine number or iodine index) in chemistry is the mass of iodine in grams that is consumed by 100 grams of a chemical substance. Iodine numbers are often used to determine the amount of unsaturation in fatty acids.

2. LITERATURE

Asli et al. (2012) investigated the feasibility of waste cooking oil as a rejuvenator in recycled mixtures. Authors indicated that the use of waste cooking oil rehabilitated the properties of aged bitumen. It is said that the rejuvenated bitumen behaved similar to virgin bitumen in terms of penetration and softening point. The researchers also claimed more amount of RAP within the recycled mixtures could be accessible by implementation of waste cooking oil. The original 80/100 bitumen was heated in the oven at a constant temperature of 160ºC for about one and a half hours to 2 h until it was fluid enough to pour. Thereafter, approximately 900 g of the bitumen was poured into several 5 l cylindrical containers after it had melted completely. Then, the melted bitumen was placed on the hot plate and mixing of the bitumen commenced using the propeller mixer. The ageing process was continuous for 6 h at a speed of 350 rpm at 130ºC. After the ageing process was completed, the aged bitumen was tested using the penetration test to determine the group of the aged bitumen.

Azahar et al. (2017) the performance of asphalt binder modified with waste cooking oil (WCO) is affected by the quality of the WCO itself because of the degradation process during frying activity. The quality of WCO can be determined by conducting an acid value test, wherein an increased acid value has caused the decreasing of rheological performance. Therefore, untreated WCO with a high acid value is chemically modified and pre-treated with alkaline catalysts to undergo transesterification. The transesterification of WCO is performed as a pre-treatment to reduce high free fatty acid (FFA) content, which is equivalent to the acid value. The treated WCO sample undergoes a chemical test (acid value), physical test (penetration and softening test), and rheological test through a dynamic shear rheometer (DSR). The rheological performance of rutting, which is analyzed using DSR, is compared between the untreated and treated WCO to determine any improvement in rutting resistance after chemical modification. Results show that the acid value reduces from 1.65 mL/g to 0.54 mL/g after the chemical treatment of WCO. The decrease in acid value affects the improvement of penetration, softening point test, and rheological performance test, wherein increased failure temperature is achieved at 70ºC for treated WCO compared with the untreated WCO at 64ºC. WCO was collected from a restaurant three times a year, specifically, during April, August, and December. Different months of WCO collection represent the different frequent duration times WCO was used, which affected the acid value result. Normally, the FFA content ranges from 2% to 7% in WCO.

Hill et al. (2016) the overall national emphasis on sustainability in pavement construction has led to the promotion of recycled materials such as reclaimed asphalt pavement (RAP) and reclaimed asphalt shingles. In general, the inclusion of these materials has led to reduced performance at low temperatures leading to thermal cracking. Previous research by the authors showed that the application of bio-binder from swine manure could alleviate the effect of RAP while improving the overall low temperature bulk viscoelastic and fracture properties of the asphalt mixture. The current paper expands on the previous research on bio- modified asphalt mixtures by investigating three additional bio-asphalts produced by introducing wood, miscanthus and corn stover based bio-oils to a neat asphalt. These bio- asphalt mixtures were introduced in both virgin and reclaimed asphalt pavement mixtures to evaluate interaction between the bio-oils and reclaimed asphalt pavement, with a focus on properties related to low temperature pavement performance. Low temperature characterization was conducted using disk-shaped compact tension fracture (DC(T)) and indirect tension (IDT) bulk viscoelastic characterization tests. The IDT test, completed in accordance with AASHTO T-322, evaluated the creep compliance of mixtures at 0, −12 and −24 °C to examine the ability of the mixture to relax thermal stress development. The DC(T) test was completed according to ASTM D-7313 to determine the fracture energy of the mixtures at −12 °C. Test results demonstrate that the bioasphalt mixtures had superior physical properties in terms of fracture resistance and creep compliance. Furthermore, the effect of increased RAP contents was less detrimental to low temperature properties in the bio-asphalt mixtures as compared to the reference hot-mix asphalt mixture.

Karim M.R. and Asli H., (2011) decreasing supplies of locally available quality aggregate in many regions around the world, growing concern over waste disposal, and the rising cost of bitumen binder have resulted in greater use of reclaimed asphalt pavement (RAP) for road construction. Recycling Hot Mix Asphalt (HMA) is the process in which reclaimed asphalt pavement (RAP) materials are combined with new materials (the virgin aggregates and asphalt binder) and a rejuvenating agent to produce HMA mixtures. Recycled HMA mixtures, properly designed, must have similar properties to those of conventional HMA, fulfilling the same technical prescriptions that are demanded for conventional ones. Experience has indicated that the recycling of asphalt pavements is a beneficial approach from technical, economical, and environmental perspectives (Chen *et al.* 2007; Romera *et al.* 2006). Furthermore, RAP can be acquired by several ways such as from removed or reconstructed asphalt pavement. In addition, the old asphalt pavement can be crushed and screened for use as future pavements consists of rejuvenator. In this research, old pavement or exist pavement is subject of RAP materials. Bitumen with penetration grade of 80/100 is used in this research has the most popular usage in Malaysia. Two method of accelerated ageing process on the virgin bitumen was undergone in laboratory which are unconventional method by using propeller mixer to attempt different classification of aged bitumen (i.e. aged bitumen grade 60/70, aged bitumen grade 50/60, aged bitumen grade 40/50 and aged bitumen grade 30/40) that have penetration in range of 60 to 70, 50 to 60, 40 to 50 and 30 to 40, respectively and standard ageing method based on ASTM which is rolling thin film oven test, (RTFOT). As mentioned earlier, rejuvenator that used in this study was waste cooking oil, (WCO) that easily acquired from the residential houses, cafes or restaurants. The waste cooking oil has low viscosity rather than aged bitumen. The fresh bitumen will be compared to rejuvenated bitumen by blending the aged bitumen by various percentages of waste cooking oil which are 1%, 2%, 3%, 4% and 5% by weight of bitumen. The waste cooking oil is mixed with the aged bitumen simultaneously by propeller mixer for 15 minute each percentage for every condition by 200 revolutions per minute at fixed temperature, 160°C. Aged bitumen penetration grade of 30/40, approximately 3.6% added waste cooking oil is changed the brittle bitumen to soft bitumen as similar as fresh bitumen. Similarly, when 2.7% of waste cooking oil by weight of bitumen binder is added into the aged bitumen penetration grade 40/50, the penetration value is alike the original bitumen with the penetration value of 84.

Li et al.,(2020) has found that the optimal dosage of waste cooking oil in epoxy asphalt binder is determined as 4% by the consideration of viscosity, microstructure, damping behaviors and mechanical performance. The viscosity of the binder and particle size of the dispersed phase is reduced, the damping behavior and elongation at break are improved, and the construction time of the modified asphalt is extended to be long as 24%. The influence of waste cooking oil on the performance of asphalt is closely related to the base asphalt as well as the dosage and quality of waste cooking oil.

Liu et al.,(2020) has pointed out that the storage stability of SBS/EVA-modified asphalt is improved by the addition of waste cooking oil, and the compatibility of the SBS and EVA is better when the dosage of waste cooking oil is 10%. Due to waste cooking oil being mainly composed by low-weight components, the light components of polymer-modified asphalt with waste cooking oil are supplemented, the content of medium molecular size is increased, and the internal microscopic structure of asphalt becomes more smooth.

Ma et al.,(2020) has studied the preparation process, and the dosage of waste cooking oil residue of rubber asphalt modified with waste cooking oil residue are determined by an orthogonal design method, and the best preparation process is sheared for 2 h at 220 °C with 6.0% waste cooking oil residue. The storage stability of rubber asphalt is improved by the addition of waste cooking oil residue, which can help to promote the swelling and degradation of rubber particles, and the aging resistance of rubber asphalt with waste cooking oil residue is also improved. The interaction between crumb rubber and asphalt is reduced by the addition of waste cooking oil residue, and the waste cooking oil residue can increase the proportion of lubricant phase.

Maharaj and Singh-Ackbarali et al.,(2017) have found that the influence of waste cooking oil on the asphalt elasticity is closely related to the chemical composition of binder. Upon increasing the dosage of waste cooking oil, the phase angle of rock asphalt-modified asphalt with waste cooking oil is gradually increased, the phase angle of blended asphalt with waste cooking oil and petroleum asphalt is declined, and the phase angle of composite-modified asphalt with waste cooking oil is first decreased and then increased.

Mahrez et al. (2012) the construction of new motorways or the improvement of the existing ones signifies, in most cases, the use of virgin materials (aggregates and bitumen). This implies an extensive exploitation of quarries, originating a negative environmental impact. This is not the sole environment problem because it is usual to mill-up asphalt layers and place waste material in a landfill. Decreasing supplies of locally available quality aggregate in many regions around the world, growing concern over waste disposal, and the rising cost of bitumen binder have resulted in greater use of reclaimed asphalt pavement (RAP) for road construction. Recycling Hot Mix Asphalt (HMA) is the process in which reclaimed asphalt pavement (RAP) materials are combined with new materials (the virgin aggregates and asphalt binder) and a rejuvenating agent to produce HMA mixtures. Recycled HMA mixtures, properly designed, must have similar properties to those of conventional HMA, fulfilling the same technical prescriptions that are demanded for conventional ones. Experience has indicated that the recycling of asphalt pavements is a beneficial approach from technical, economical, and environmental perspectives. Bitumen ageing occurs during the mixing and construction process as well as during long term service in the road. Several methods have been proposed to replicate the effect of ageing and, therefore, to foresee bitumen behaviour during application and service life. In this research ageing of the original binders was performed using two different methods. The first method uses Rolling Thin Film Oven Test (RTFOT, ASTM D 2872). Samples were aged according to standardised conditions, i.e. temperature of 163 ºC for a period of 85 minutes for RTFOT. The second method which was used simulates the long term ageing process.

In this method original bitumen (as supplied) was aged using a propeller mixer. Mixing was done at a speed of 80 rpm for 15 hours at 160°C. After the aged bitumens were produced (by using the ageing methods mentioned above), they were consequently mixed with various percentages of waste cooking oil using propeller mixer to produce a homogenous blend. Mixing was done at temperature of 160°C for 18 hours with a constant mixing speed of 200 rpm to ensure no voids created in the blend. Four different levels of rejuvenating agent content were used, namely 2%, 3%, 4% and 6% by mass of bitumen. Binders were characterised by using a number of standard physical tests such as penetration test (temperature, load and time are 25ºC, 100g and 5sec respectively), softening point test, viscosity test using Brookfield viscometer (temperature, spindle and a rotating speed of 135ºC, No.27 and 20rpm, respectively), and rheological measurements by using a Dynamic Shear Rheometer (temperature and frequency equal to 76ºC and 1.159Hz, respectively).

Wang et al. (2018) this process inevitably increases the cost of renovating and preserving bituminous pavements. The main aging mechanisms of bitumen include the loss of volatiles and oxidation, both of which lead to a higher viscosity or stiffer material. A thermal absorbing–releasing process was deigned to generate break of micro WCOs in aged bitumen using a temperature-controlled chest. The bitumen/ micro WCOs samples had been melted at 260 ºC under stirring speed of 300 r min_1 for 5 min and moved into a thermostats at 0 ºC for 60 days. The states of micro WCOs in bitumen were consistently observed by a fluorescence microscope.

XiaoyangJia et al.,(2015) performed a laboratory study about the influence of waste cooking oil on the performance of hot-mix asphalt (HMA) containing reclaimed asphalt pavement (RAP). They conducted tests on bituminous binder and mixture. For binder test, the extracted RAP binder was blended with virgin binder and waste oil to investigate the rheological properties as well as fatigue properties. Performance Grade 64-22 was selected as virgin binder and waste cooking oil was collected from a local auto repair shop. For mixture test, the HMA containing RAP was evaluated at three RAP contents (0%, 25%, and 40%) and three waste cooking oil contents (0%, 2%and 5%).Binder master curves, linear amplitude sweep, Superpave indirect tension, beam fatigue, and asphalt pavement analyzer rutting tests were conducted to evaluate the engineering properties of asphalt and asphalt mixtures. Results from the research indicated that the addition of waste engine oil into HMA with RAP may counteract the increase of stiffness caused by aged binder in RAP, decreased optimum asphalt content, and reduced rut resistance.

Used four plant-produced mixtures containing 0%, 20%, 30%, 40% RAP and PG 64-28 base binder long-term oven aged in the laboratory to three levels. Mixture testing of uniaxial complex modulus and fatigue, recovered binder testing of performance grading (PG) and rheological characterisation was conducted. Mixture testing showed that the RAP mixtures stiffen due to laboratory ageing at a slower rate than virgin mixtures, relative fatigue performance of the mixtures changes dramatically in stress versus strain control. The complex shear modulus shows an increase in stiffness and a decrease in phase angle with ageing, recovered binder properties show increase in the high continuous PG, minimal impact at the intermediate continuous PG and a slight increase in the low continuous PG with ageing time.

3. MATERIALS AND METHODOLOGY

3.1 Study Methodology

The study methodology is represented in the schematic flow diagram as shown in figure 3.1.

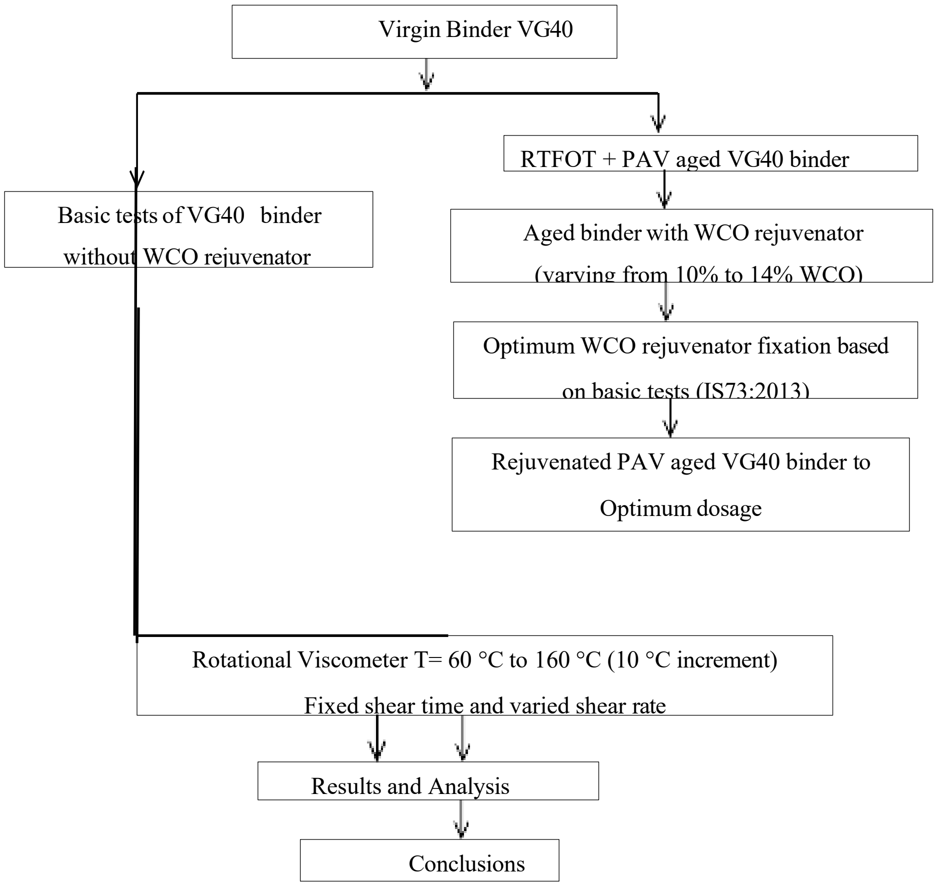

Figure 3.1: Schematic flow diagram of study methodology.

3.1 Materials

Materials used for the experimental work are Virgin VG40 binder and waste cooking oil as rejuvenator. A brief discussion about the materials is mentioned below.

3.1.1 Virgin binder

In the present study, Viscosity grade (VG) 40 is selected because it is the stiffer binder mostly used in India in the layer of DBM below the wearing course for highway of heavy traffic where air temperature may be 40 °C or higher in summer. Stiffer VG 40 binder is used where richer bituminous mixes are required as per IRC 37:2012. From literature review, it is observed that no studies were carried on VG-40 binder rejuvenation and viscosity tests using rotational viscometer. The following requirements must be satisfied by VG-40 binder as per IS: 73-2013 as shown in Table 3.1.

Table 3.1: IS: 73-2013 specifications

S No	Characteristics	Method of Test, Refer to	Viscosity Grade VG-40
1	Penetration at 25 °C, 100 g, 5 s, 0.1 mm,	IS 1203	Min 35
2	Absolute viscosity at 60 °C, Poise	IS 1206 (Part 2)	3200-4800
3	Kinematic viscosity at 135 °C, cSt,	IS 1206 (Part 3)	Min 400

4	Flash point (Cleveland open cup), °C,	IS 1448 [P : 69]	Min 220
5	Softening point, °C,	IS 1205	Min 50
6	Tests on residue from rolling thin film oven test		
	a) Viscosity ratio at 60 °C,	IS 1206(Part 2)	Max 4.0
	b) Ductility at 25 °C, cm,	IS 1208	Min 25

3.1.2 Rejuvenator

In the present study, Waste cooking oil is selected as a rejuvenator because Cooking oil typically is formulated with saturated, high molecular weight alkenes with few branches, possessing low volatility which reduces the viscosity of viscoelastic material on addition. Moreover, improperly disposed waste cooking oil ends up in landfills, sewers, backyards, or storm drains where soil, groundwater and drinking water may be contaminated. Worldwide dispersion and effects on the environment, used motor oil is considered a serious environmental problem.

3.2 Binder Basic Tests

3.2.1 Penetration test

It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimetre to which a standard loaded needle will penetrate vertically in 5 seconds.

Penetration test procedure (IS: 1203-1978):

1. The bitumen is softened to a paving consistency between 75 °C and 100 °C above the approximate temp at which bitumen softens.
2. The sample material is thoroughly stirred to make it homogeneous and free from air bubbles and water.
3. The sample containers are cooled in atmosphere of temperature not lower than 13°C for one hour. Then they are placed in temperature controlled water bath at a temperature of 25°C for a Period of one hour.
4. The weight of needle, shaft and additional weight are checked. The total weight of this assembly should be 100 g.
5. Using the adjusting screw, the needle assembly is lowered and the tip of the needle is made to just touch the top surface of the sample.
6. The needle assembly is clamped in this position. The contact of the tip of the needle is checked using the mirror placed on the rear of the needle.
7. The initial reading of the penetrometer dial is either adjusted to zero or the initial reading is noted.
8. Then the needle is released by pressing a button and a stop watch is started. The needle is released exactly for a period of 5.0 seconds.
9. At least 3 measurements are made on this sample by testing at distance of not less than 100 mm apart.

3.2.2 Softening point test

Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specified condition of test.

Softening Point test procedure (IS:1205-1978) :

1. Sample material is heated to a temperature between 75° and 100°C above the approximate softening point until it is completely fluid and is poured in heated rings placed on the metal plate.
2. To avoid sticking of the bitumen to metal plate, coating is done to this with a solution of glycerin and dextrin.
3. After cooling the rings in air for 30 minutes, the excess bitumen is trimmed and rings are placed in the support.
4. At this time the temperature of distilled water is kept at 5 °C. This temperature is maintained for 15 minutes after which the balls are placed in position.

5. Then the temperature of water is raised at uniform rate of 5 °C per minute with a controlled heating unit, until the bitumen softens and touches the bottom plate by sinking of balls. At least two observations are made. For material whose softening point is above 80°C, glycerin is used for heating medium and the starting temperature is 35°C instead of 5°C.

3.2.3 Viscosity test

Viscosity denotes the fluid property of bituminous material and it is a measure of resistance to flow.

i. Absolute viscosity test procedure (IS 1206):

1. The bitumen sample is heated to pouring temperature not exceeding 90°C above the softening point
2. From the set of viscometers, a viscometer tube is selected that will give a flow time more than 60 seconds for the material to be tested and pre-heated to 60 °C.
3. The prepared sample is poured into the filling tube of viscometer until the level of the bitumen reaches within 2mm of the fill line
4. The charged viscometer is placed in the oven maintained at 135± 5.5° C for 10 minutes to allow air bubbles to escape.
5. The viscometer is now transferred to the oil bath maintained at the test temperature of 60 ± 1° C and is fixed in bath in vertical position with the help of the holder such that upper most timing mark is at least 20 mm below the surface of the bath liquid.
6. The vacuum unit with its suction pressure maintained at a vacuum pressure of 40 ± 0.07 kPa or 300 ± 0.5 mm of mercury connected to the vacuum tube of viscometer with the valve closed
7. After being in the water bath for period of 30 to 35 minutes, the valve is opened and the liquid bitumen is allowed to flow into the capillary viscometer under the vacuum suction pressure.
8. The time taken for the leading edge of the meniscus to pass between successive pairs of bulb marks is recorded in seconds.

ii. Kinematic viscosity test procedure (IS 1206):

1. The bitumen sample is heated to pouring temperature not exceeding 90°C above the softening point.
2. The sample is thoroughly mixed and about 20 ml of the fluid binder is transferred in a container.
3. The viscometer is inverted and suction pressure is applied to the tube of the viscometer and the tube is inserted in liquid bitumen sample to be tested.
4. The bitumen is filled up to the mark on the viscometer.
5. The viscometer is placed in the oil bath and is held in vertical position by a holder.
6. The temperature of the bath with the viscometer in position is maintained at 100°C for about 25 minutes and at the test temperature of 135°C for 30 minutes.
7. The stoppers are removed and the sample of the bitumen binder is allowed to flow from the bulb into the capillary tube under gravity.
8. The time required for the leading edge of the meniscus to pass start mark and end mark of bulb is measured accurately with the timer unit.

3.3 Rolling Thin-Film Oven Test (RTFOT)

Rolling Thin-Film Oven Test (RTFOT) provides simulated short term aged asphalt binder for physical property testing. Asphalt binder is exposed to elevated temperatures to simulate manufacturing and placement aging. The RTFOT also provides a quantitative measure of the volatiles lost during the aging process.

RTFOT procedure (ASTM D2872):

1. Heat the sample in its container with a loosely fitted cover in an oven not to exceed 302°F (150°C) for the

minimum time necessary to ensure that the sample is completely fluid.

2. Manually stir the sample but avoid incorporating air bubbles. Pour 35 +/- 0.5 g of the sample into each of the required glass containers.

3. Immediately after pouring the sample into a glass container, turn the container to a horizontal position. Rotate the container slowly for at least one full rotation, and attempt to pre-coat its cylindrical surface.

4. Place the container horizontally in a clean cooling rack that is maintained in a draft-free, room-temperature location away from ovens and other sources of heat.

5. Allow the glass sample containers to cool in the cooling rack for a minimum of 60 min, and a maximum of 180 min.

6. With the oven at operating temperature and the airflow set at 4000 +/- 200 mL/min, arrange the containers holding the asphalt in the carriage so that the carriage is balanced. Fill any unused spaces in the carriage with empty containers. Close the door and rotate the carriage assembly at a rate of 15 +/- 0.2 r/min.

7. Maintain the samples in the oven with the air flowing and the carriage rotating for 85 min. The test temperature of 325 +/- 1 °F (163 +/- 0.5 °C) shall be reached within the first 10 min; otherwise, discontinue the test.

3.4 Pressure Ageing Vessel (PAV)

The Pressure Aging Vessel (PAV) (Figure 3.4) provides simulated long term aged asphalt binder for physical property testing. Asphalt binder is exposed to heat and pressure to simulate in-service aging over a 7 to 10 year period.

PAV procedure (ASTM D6521):

1. Place the pan holder inside the pressure vessel. Select a conditioning temperature and follow the manufacturer's instructions for preheating the pressure vessel.

2. Combine the hot residue from the RTFOT bottles into a single container, stir to blend, and then transfer to PAV pans in accordance with step 3 for PAV conditioning, or allow the hot residue in the container to cool to room temperature and cover and store at room temperature for PAV conditioning at a later date. If conditioned asphalt binder is allowed to cool to room temperature, heat it until it is sufficiently fluid to pour and stir it before pouring it into the PAV pans.

3. Place each PAV pan on a balance and add 50 +/- 0.5 g mass of asphalt binder to the pan. This will yield approximately a 3.2-mm thick film of asphalt binder.

4. Perform the operations described in step 5 as quickly as possible to avoid cooling of the vessel and pan holder.

5. Place the filled pans in the pan holder. Place the pan holder with filled pans inside the pressure vessel and close the pressure vessel. Unused slots in the pan holder need not be filled with empty pans.

6. Follow the manufacturer's instructions regarding the desired preheating temperature to pressurize the vessel to 2.1 +/- 0.1 MPa and start timing the conditioning run. If the temperature inside the vessel has not reached the desired temperature for applying pressure within 2 h of loading the pan holder and pans, discontinue the procedure and discard the asphalt samples.

7. If the temperature indicated by the temperature recording device rises above or falls below the target conditioning temperature +/- 0.5°C for more than a total of 60 min during the 20-h conditioning period, declare the conditioning process invalid and discard the material.

8. Vacuum degas the aged samples.

9. Remove the pan holder and pans from the PAV, and place the pans in an oven set to 168

+/- 5°C for 15 +/- 1 min. Preheat the vacuum oven to 170 +/- 5°C.

10. Remove the pans from the oven and scrape the hot residue from all pans containing the same sample into a single container. Select a container of dimensions such that the depth of the residue in the container is between 15 and 40 mm. Transfer containers to the vacuum oven within one min. Once the last container has been placed in the vacuum degassing oven, maintain the temperature at 170 +/- 5°C for 15 +/- 1 min.

3.7 Rejuvenation process and determining optimum rejuvenator content

The Aged VG40 binder obtained after the long term ageing simulation using RTFOT and PAV is collected and modified with rejuvenator (Waste cooking oil) using Lab stirrer. Based on literature review from previous studies, rejuvenation processed for 30 minutes at 160 °C using a laboratory stirrer at shear rate of 3000 rpm as shown in 3.7 to obtain a homogenous rejuvenated VG40 binder.

Considering the basic bitumen test results for virgin and rejuvenated VG40 binder, the objective was to rejuvenate Aged binder in order to obtain a binder similar to virgin binder in terms of BIS 73:2013 specifications. A rejuvenating agent is supposed to enhance and cure the Aged VG40 binder in terms of physical and chemical properties. Several studies address the penetration value as an indicator for determining the optimum rejuvenator content. In present study, optimum rejuvenator content was determined as the content required to achieve a rejuvenated binder having the same absolute viscosity value of the virgin VG40 binder.

3.8 Experimental Program

The characteristics of virgin VG-40 binder and waste cooking oil rejuvenated laboratory long term aged VG-40 binder are to be tested and their responses at different temperatures, shear rate and fixed shear time is to be evaluated using Brookfield's rotational viscometer. In this study, Brookfield DV-II+ Pro programmable rotational viscometer is used. The standard rotational viscometer procedure from AASTHO T316 and ASTM D4402: Viscosity determination of asphalt binder using rotational viscometer is followed.

Shear rate of each binder at each temperature are fixed based on the maximum and maximum permissible torque limits of the equipment. The test protocol consists of subjecting the asphalt samples to two continuous cycle of shearing (ramp up and ramp down). Each shearing cycle consists of one forward sweep and one reverse sweep. The forward and reverse sweep in each cycle includes same increments and decrements respectively. In each ramp of a forward and reverse sweep, the material is subjected to a constant shear rate.

To analyze the data and find out the material characterization, Shear stress and viscosity value for given shear rates at given temperature and shearing time is obtained from the Rheocalc software output data. Plot between different parameters are drawn and important observations are to be noted and analyzed.

3.9 Viscosity test using Brookfield's rotational viscometer

Rotational viscometer is used for measurement of viscosity at different test conditions. Viscosity i.e., the resistance to flow, is a fundamental characteristic of bitumen as it describes the behaviour of the material at a particular temperature or over a temperature range. The resistance to flow or shear stress governed by the internal friction and can be measured, expressed in units of stress required to overcome this friction. The ratio of applied shear stress and the rate of shear are called the coefficient of viscosity, dynamic viscosity or more often simple viscosity. The dynamic viscosity, or resistance to shear, of bitumen can be determined by measuring the torque required to rotate a spindle which is immersed in asphalt. The viscosity of asphalt is measured using SC-4 type spindles in a Brookfield rotational viscometer with a provision to control temperature of the sample using a thermosel. By varying the spindle size, the viscosity can be determined over a large range of asphalt grades from very viscous to very liquid materials. The SI unit of dynamic viscosity is the Pascal second (Pa-s). In the (CGS) system, the unit of viscosity is the poise, such that 1 Pa-s = 10 poises. Viscosity can be measured over a wide range of temperatures, including maximum asphalt application and operating temperatures.

The present study Brookfield rotational viscometer provides additional speeds for a superior viscosity measurement range. RV DV-II+ Pro Viscometer have 54 selectable speed options from 0.01-200 rpm and two-line LCD display. Up to four selectable test programs can be programmed to memory. A lab stand, guard leg, output cable, carrying case, and a certificate of calibration are included. RHEOCALC Software automates data collection and allows complete computer control.

Material characterization can be done from obtained shear stress, shear rate, temperature, and viscosity. From this data, flow curves and viscosity curves can be drawn. Hence the behaviour of the material at different temperatures can be studied.

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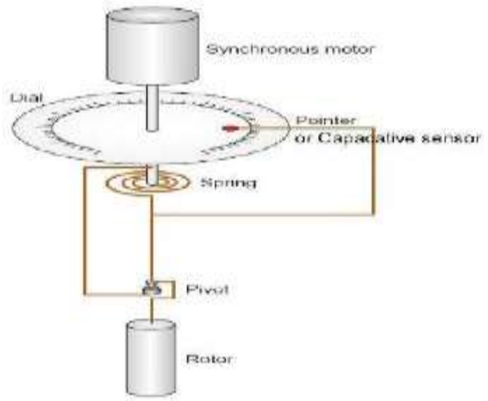
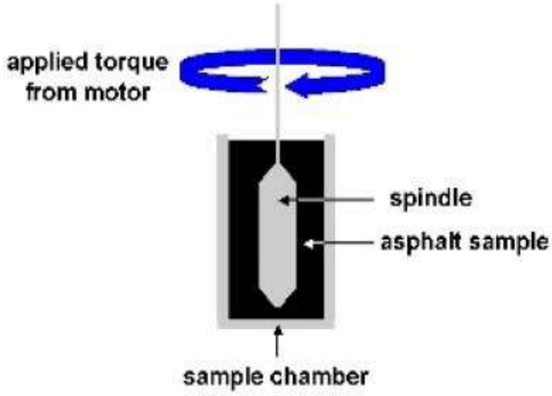
3.10 Working Principle of Brookfield Viscometer

The least expensive commercial variant of the controlled-rate rotational viscometer is commonly referred to as a Brookfield type viscometer. This device measures fluid viscosity at fixed rotation speeds by driving a measurement tool (spindle), immersed in the test fluid,through a calibrated torsion spring. Viscous drag of the fluid against the spindle causes the spring to deflect, and this deflection is correlated with torque. The calculated shear rate depends on the rotation speed, the tool geometry, size and shape of the sample container. Conversion factors are needed to calculate viscosity from the measured torque, and are typically pre-calibrated for specific tool and container geometries. For Newtonian fluids, the torque is proportional to the product of viscosity and rotational speed, but this proportionality is lost in the case of a Non-Newtonian fluid. Because these instruments are robust and fairly simple to use, they have found wide application in industry. The working principle of Brookfield Viscometer is depicted in the figure.

3.11 Rotational viscometer test procedure

The sample of asphalt binder of weight 10.5 g is taken in the container and placed in the thermoses for maintaining the test temperature. Weight of the sample is taken as 10.5 g based on the spindle number used and the model of the viscometer. Spindle geometry plays a major role in obtaining the viscosity values of the specimen. SC4-27 number spindle is used for the present investigation. Asphalt having high viscosity values or resistance to flow selects SC4- 27 spindle number. The shear rate (1/s) to RPM conversion for the spindle used in this investigation is 0.34. Temperature controller and viscometer with thermocel is connected to a computer which is installed with RHEOCALC Software.





Equipment can be operated either manually or through the software. Temperature can be set and program is written as per the test requirements. For the investigating three continuous cycles of forward sweep and reverse sweep is given with five steps of increments and decrements in speed. The data collected is exported to Excel and analysis is been carried out. Figure 3.9 shows the experimental setup (Viscometer, thermocel and temperature controller) connected to a computer and operated using software called RHEOCALC.

4. RESULTS AND DISCUSSION

4.1 Physical Properties of Materials

4.1.1 Virgin binder

The binder used in this study is Viscosity grade (VG)-40. VG-40 is selected because it is the stiffer binder mostly used in India in the layer of DBM below the wearing course for highways with heavy traffic where air temperature may be 40 °C or higher in summer. All physical properties specified in IS 73:2013 are determined and represented in table 4.1 below.

Table 4.1: Properties of the virgin VG-40 binder

S.No	Characteristics	Viscosity Grade VG-40	
		Obtained values	Specifications (IS:73-2013)
1	Penetration at 25 °C, 100 g, 5 s, 0.1 mm,	38	Min 35
2	Absolute viscosity at 60 °C, Poise	3913.93	3200 - 4800
3	Kinematic viscosity at 135 °C, cSt,	422.76	Min 400
4	Flash point (Cleveland open cup), °C,	290	Min 220
5	Softening point, °C,	52.75	Min 50
	Tests on residue from rolling thin film oven test		
6	c) Viscosity ratio at 60 °C,	3.81	Max 4.0
	d) Ductility at 25 °C, cm,	37	Min 25

4.1.1 Waste cooking oil rejuvenated LTA VG-40

Waste cooking oil used in the present study was collected from Ganga mess in Visakapatanam. The aged VG-40 binder obtained after the long-term ageing simulation using RTFOT and PAV is was and blended with rejuvenator (waste cooking oil) using a laboratory stirrer at 160 °C using a at shear rate of 3000 rpm to for 30 minutes obtain a homogenous rejuvenated VG-40 binder. Different proportions of waste cooking oil was added to the LTA VG-40 binder ranging from 10% to 14% to attain the perfect proportion of waste cooking oil that can rejuvenate the LTA VG-40 binder to obtain the absolute viscosity value virgin VG- 40 binder.

The properties of virgin VG-40, LTA VG-40 and waste cooking oil rejuvenated LTA VG-40 binder are shown in Table 4.2.

Table 4.2: Properties of virgin VG-40, LTA VG-40 and WCO rejuvenated LTAVG-40 binder

S.No	Characteristics	Virgin VG- 40	LTA VG- 40	11% WCO rejuvenated LTA VG- 40	IS:73(2013) specification s
1	Penetration at 25 °C, 100 g, 5 sec, 0.1 mm,	38	8	43	Min 35
2	Absolute viscosity at 60 °C, Poise	3913.93	108530.22	4103.14	3200 - 4800
3	Kinematic viscosity at 135 °C, cSt,	422.76	1339.90	444	Min 400
4	Flash point (Cleveland open cup), °C,	290	-	270	Min 220
5	Softening point, °C,	52.75	62.25	52.5	Min 50
	Tests on residue from rolling thin film oven test				

6	a) Viscosity ratio at 60 °C,	3.81	-	3.59	Max 4.0
	b) Ductility at 25 °C, cm,	37	13.6	43	Min 25

The Table 4.3 represents the different proportions of waste cooking oil added in different percent's by weight of the binder. From the results, it is observed that there is a decreasing trend in absolute viscosity and kinematic viscosity with increase in waste cooking oil percent in LTA VG-40 binder.

Table 4.3: Properties of WCO rejuvenated LTA VG-40 binder

Characteristics	LTA VG 40 binder rejuvenated with WCO(%) by weight of binder				
	0%	10%	11%	12%	14%
Absolute viscosity at 60 °C, Poise	108530.22	5187.21	4103.14	2595.95	2592.72
Kinematic viscosity at 135 °C, cSt.	1339	485	444	345	367

4.1 Rotational viscometer testing

Protocol used in this study is Step up–down shear rate cycles i.e., the shear rate was varied in steps. Waiting time for shear was fixed based on the wait time interval measured at different temperatures. Step rise or down rate was varied accordingly to increase the torque from 10% to 90% for all the temperatures (Figure 4.1). Two cycles of step rise and down were followed and the apparent viscosity values from the first cycle and second cycle were measured.

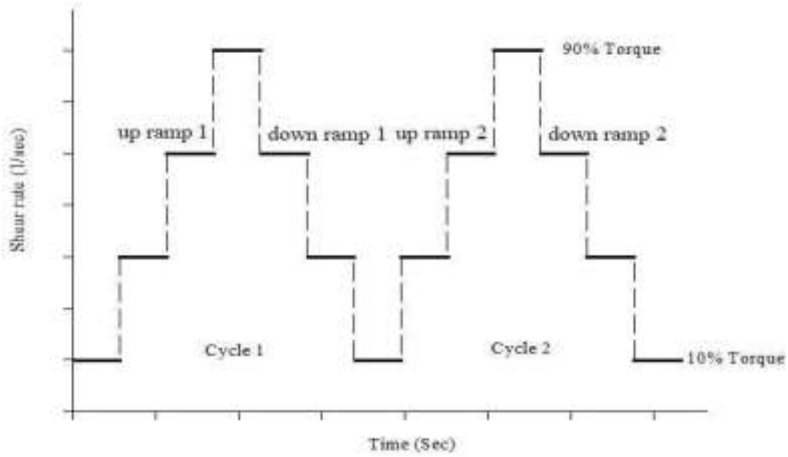


Figure 4.1: Test protocol for rotational viscometer testing.

Table 4.4 represent the difference in viscosity for VG-40 and rejuvenated LTA VG-40 binder at all temperature conditions at same shear rate.

Table 4.4: Difference in viscosity for virgin VG-40 and rejuvenated LTA VG-40

Temperature (°C)	Shear rate (1/sec)	Viscosity(Pa-s)	Viscosity(Pa-s)	Difference in Viscosity (Pa-s)
		Virgin VG-40	WCO Rej LTA VG-40	
60	0.31	423.88	462.22	-38.34
70	1.33	108.97	122.82	-13.84615
80	1.36	12.7	12.62	33.5

90	8.5	12.7	11.18	0.08
100	3.4	4.95	6	-1.05
110	61.2	2.08333	2.4611	0.8465
120	57.8	1.28824	1.27059	0.27941
130	61.2	0.63611	0.70833	-0.07222
140	61.2	0.38333	0.41111	-0.02778
150	61.2	0.26	0.19	0.07
160	61.2	0.15	0.13	0.02

Figure 4.2,4.3 and 4.4 represent the decrease in the difference in apparent viscosity with increase in the temperature from 60 °C to 160 °C except at 60 °C, 80 °C and 110 °C. As the scale did not fit the graph at all temperatures, graphs are drawn for different temperature combinations.

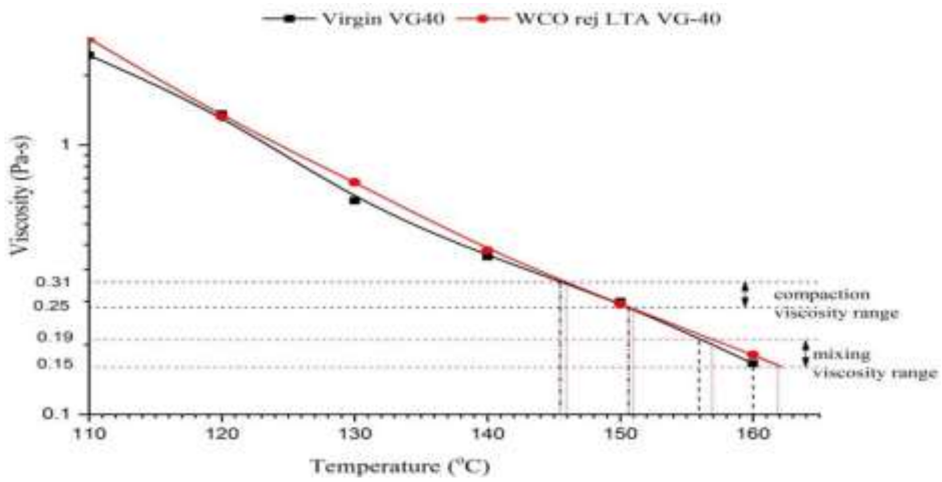


Figure 4.2: Viscosity at all temperature conditions

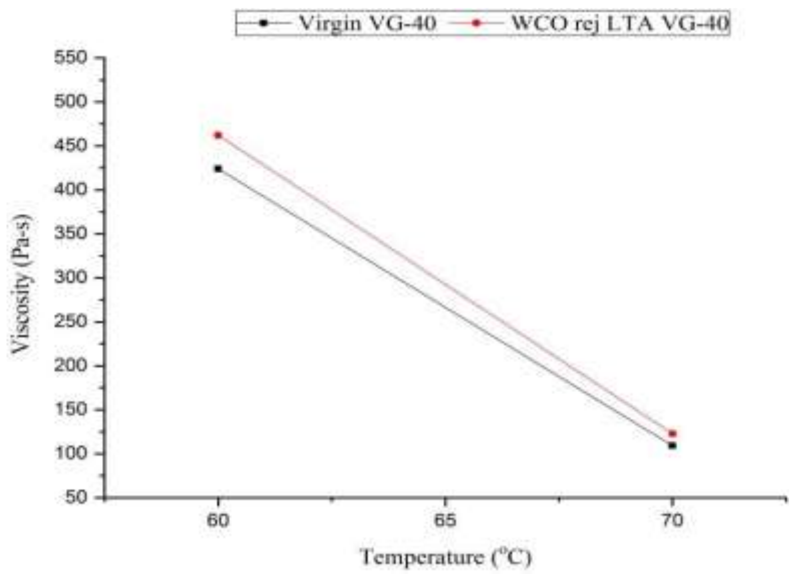


Figure 4.3 Difference in viscosity for virgin VG-40 and WCO rejuvenated LTA VG-40 at 60 °C and 70 °C.

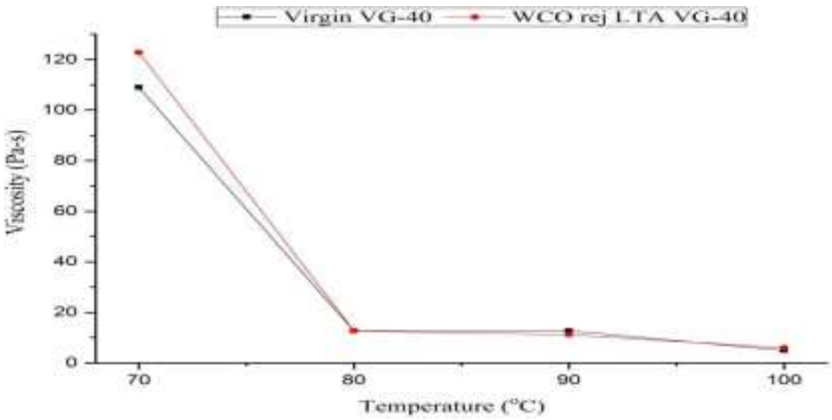


Figure 4.4 Difference in viscosity for virgin VG-40 and WCO rejuvenated LTA VG-40 at 70 °C to 100 °C.

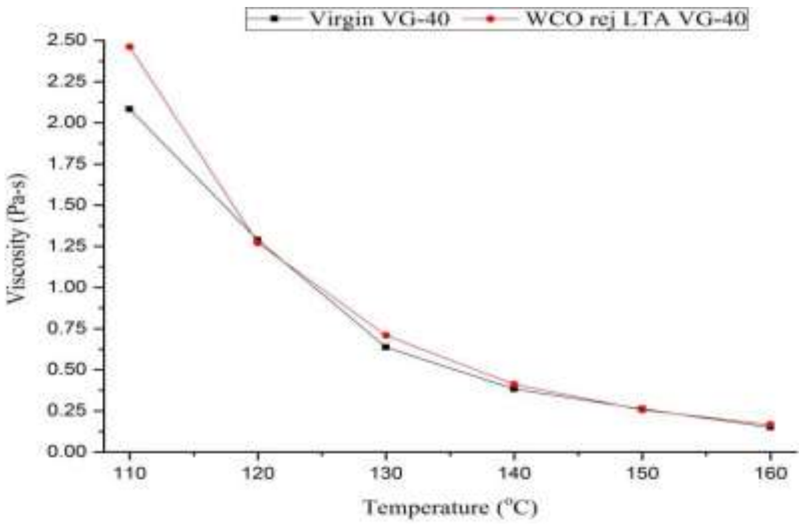


Figure 4.5 Difference in viscosity for virgin VG-40 and WCO rejuvenated LTA VG-40 at 110 °C to 160 °C

Figure 4.6 represent the viscosity of waste cooking oil at different temperature conditions from 60 °C to 160 °C. From Figure 4.6, waste cooking oil exhibiting high viscosity of 20 mPa-s gradually decreasing with increase in temperature. At high temperatures of 120 °C to 160 °C, waste cooking oil exhibiting high viscosity of 0 mPa-s.

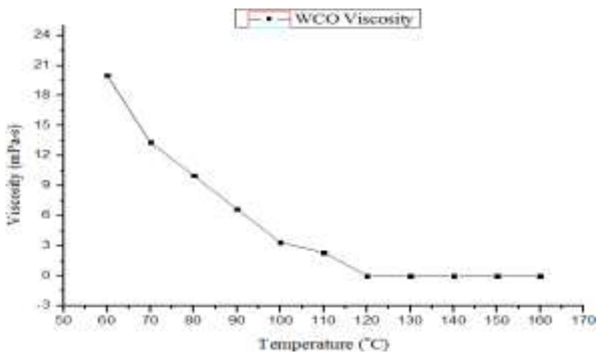


Figure 4.6 Variation of waste cooking oil viscosity with temperature

5. CONCLUSIONS

The experimental results reported in this study have provided information regarding the performance of waste cooking oil rejuvenated asphalt binders. The following conclusions are proposed.

1. The addition of waste cooking oil (WCO) significantly reduced the absolute viscosity of aged bitumen, enhancing its workability and processing behavior at high temperatures.
2. Over dosage of WCO (>10%) may lead to overly soft binders with poor rutting resistance. Therefore, dosage optimization is crucial.
3. The optimum rejuvenator content for LTA VG-40 is 11% of waste cooking oil for which it is exhibiting same absolute viscosity as virgin VG-40.
4. The efficacy of WCO as an asphalt pavement rejuvenator is well-established. Assessing the ageing performance of RAP rejuvenated with WCO is crucial for understanding its potential. Asphalt binder's ageing resistance, particularly in rejuvenated asphalt, hold significance.
5. Virgin VG-40 and rejuvenated LTA VG-40 binder are showing shear thinning behaviour at almost all temperature conditions as shear stress is increasing and viscosity is increasing with increase in shear rate.
6. The mixing and compaction temperatures are about 5 °C less for waste cooking oil rejuvenated LTA VG-40 binder relative to virgin VG-40 binder.
7. At all temperatures time vs shear rate virgin binder and LTA VG-40 binder relative to virgin VG-40 binder no changes from graphs.
8. The apparent viscosity of virgin VG-40 binder is higher than rejuvenated long term aged VG-40 binder at all temperatures except at 60 ˚C which indicates that waste cooking oil is acting as good rejuvenator at almost all temperature conditions.
9. The difference in viscosity value between virgin VG-40 and WCO rejuvenated LTA VG-

40 is increase with increase in temperature because with decreases in temperature viscosity of binder as well as waste cooking oil increase.

5.1 Scope for Future Work

The scope to carry out future work on present study summarized below:

- Tests on rheological parameters like complex modulus and phase angle can be carried.
- A mathematical model could be developed using the parameters affecting the viscosity of the binder.

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