ASTUDY ON THE TECHNICAL VIABILITY OF UTILIZING USED LUBRICATING OIL AS REJUVENATING AGENT IN RELAIMED ASPHALT PAVEMENT

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CHAPTER 1

INTRODUCTION

1.1 Introduction

After several years of service, bituminous binder of asphalt concrete is being aged. This ageing mainly leads to increasing the stiffness and also brings about changes in physicochemical properties such as ductility and adhesion. As a result, old asphalt layer becomes more brittle and therefore prone to fatigue cracking that leading to the reduced pavement strength and shortened service life.

By reclaiming old asphalt layer, the life of the pavement can be extended whereas the use of new materials reduced. A properly designed recycled asphalt mixtures can meet specification properties of conventional asphalt concrete. Another advantage of reclaiming asphalt is that it aged slower and has more resistant to the action of water relatively compare to conventional hot mix asphalts (Sullivan, 1996).

In asphalt recycling operations, new aggregate and binder are mixed together with reclaimed asphalt material. In order to reduce the negative effect of aged bitumen to a minimum, rejuvenator should be added, so that the final mix of old and new binder will have an acceptable consistency and a sound chemical constitution.

A number of materials with the purpose of altering properties of old binders at reclaimed asphalt have been proposed in the past. A distinction is made between softening agents and rejuvenating agents. Softening agents are aimed at lowering the viscosity of aged bitumen, whereas rejuvenating agents are added for the purpose of restoring physical and chemical properties of the old binder (Roberts et al. 1996). In this paper, the term rejuvenator or rejuvenating agent is used to denominate any product used for rejuvenation of old binders.

Aromatic oils from lube stock and aromatic fractions removed from lube stock probably suitable to be used as rejuvenating agent (Karlsson and Isacsson, 2006). Therefore, used lubricating oil is also potentially appropriate to be used as rejuvenator. However, due to the unknown history of used oil and the possibility of the contamination of material, it is not obvious whether used lubricating oil is able to restore the reclaimed binder characteristics to a consistency level appropriate for construction purposes and pavement performance and, at the same time, to optimize the chemical characteristics with regard to durability.

1.2 Problem Statement

As Malaysia is one of the most car dependent country, thousands gallons of used oil are produced annually. The disposal of used oil generates waste disposal problem and improperly disposed of used oil will contaminate the environment. Besides, since the concept of construct road is 'road is built to be destroy', each year billions of money are spent on the road maintenance and rehabilitation especially there are approximately 26,000 km in length for the Federal and State paved road network in Malaysia, which cost RM7.15 billions to maintain at 2004, therefore pavement recycling is probably the best choice for road maintenance since it allows very large savings as compared to conventional options. It also lower the needs for natural aggregates, reduces the use of oil-based hydrocarbon binders and solving the demolition waste problem. In the case of cold recycling, it also can minimizes the need to transport materials to and from the work site. During the recycled process, many agencies have resorted to the use of asphalt rejuvenators which is a based oil material as an alternative to revive aging in reclaimed asphalt pavement. With the proven performance of asphalt rejuvenators to revive an aging pavement, the pavement engineer has an economical method to extend pavement life.

However, the application of used oil in recycle pavement will be more complicating due to the complex constitution and unknown history of used oil. The possibility of material contamination, difficulty to category the type of used oil since there are varied from grad, quality and ingredient in the market and the uncertainty of its long term performance are the main problems in application of used oil as rejuvenator. Further research is required to understand the effect of used oil on bitumen especially on the recycling asphalt mixture properties.

1.3 Objective of Study

1. To determine the effective amount of used oil that needed to add into the ageing bitumen so that the rheology of the rejuvenated bitumen is approximate to the rheology of the fresh bitumen.
2. To determine the rheology of the aged bitumen rejuvenated with used lubricating oil.
3. To assess the laboratory performance of reclaiming asphalt pavement (RAP) with used lubricating oil as rejuvenator.

1.4 Scope of Study

1. The study was conducted into two phases.
2. In the first phase, the bitumen sample that be used in this study was not extracted directly from RAP, but is obtained by using an accelerated aging process in the laboratory. The aged bitumen used in this study will be modified through rolling thin film oven (RTFO) and the pressure aging vessel (PAV) test. This artificial aged bitumen represents the pavement which had exposed to five to ten years service.
3. In the second phase, the bitumen was extracted from RAP material taken from work upgrading construction work at F50 road.
4. The used lubricating oil will be act as rejuvenating agent.
5. The study will only focus on measurement which involves the properties of artificial aged bitumen, fresh bitumen, rejuvenated bitumen and used lubricating oil.
6. A thorough literature study regarding the agent rejuvenator is conducted in this study.
7. Performance of RAP mixture was assessed in term of its stiffness and resistance to permanent deformation.

1.5 Importance and Contribution of Study

This project is expected to provide information about the feasibility of used lubricating oil as the rejuvenating agent in reclaimed asphalt pavement. The findings may benefit the pavement construction industry since it provides another more economical method in selecting the rejuvenator for the recycled asphalt.

CHAPTER II

LITERATURE REVIEW

2.1 Asphalt Concrete

After several years of service, the binder in the reclaimed asphalt becomes aged and much stiffer than desired. As a result, the asphalt layer become more brittle therefore brings to crack. By reclaiming the asphalt layer, we can extend the life of the pavement. In hot in-plant or in-place asphalt recycling operations, new binders are mixed together with reclaimed asphalt material in order to reduce the negative influences of ageing to a minimum. The new binder should be rejuvenator or soft bitumen, so that the final mix of old and new binder will have an acceptable consistency and a sound chemical constitution.

As the general measure of the consistency of asphalt concrete is its viscosity, the performance of the asphalt concrete is closely related to the consistency of the bitumen used to glue the aggregate together (Karlsson and Isacsson, 2006). Mixing rules have being applied to determine the amount of rejuvenator require in order to meet specified target viscosities for recycled binder. The result presented by Davidson et al. (1994) indicates that Eq. (1a) is the suitable relationship describing viscosity mixtures of several bituminous binders.

$$\ln(\ln(\eta mix)) = x \ln(\ln(\eta 1)) + (1-x)\ln(\ln(\eta 2)) \qquad \text{Eq (1a)}$$

where,

ηmix = viscosity of the mixture

$\eta 1$ = viscosity of fresh binder

$\eta 2$ = viscosity of aged binder

x =volume percentage of fresh binder

The chemical constitution of the old binder and the rejuvenator has very close relationship with the aspect of structural stability, ageing properties and consistency. The main concern of the chemical composition of recycled binders should be the ability to restore the composition of reclaimed binders.

2.2 Recycled Hot Mix

The use of processed reclaimed asphalt pavement to produce conventional recycled hot mix (RHM) is the most common type of asphalt recycling and is now considered standard asphalt paving practice. All current available testing methods, devices, and techniques have shown that properly designed recycled mixtures can meet conventional design criteria including requiring the recycled binder to meet specification properties after production. Recycled hot mix asphalt mixtures also generally age more slowly and are more resistant to the action of water than conventional hot mix asphalt(Sullivan, 1996). This can be proof by the research which had indicated that hardening rates of asphalt cement in recycled HMA are less than asphalt cement hardening rates in conventional HMA (Report FHWA, 2000). This trend has been confirmed through long-term monitoring or recycling projects in Florida and Washington State (Ganung and Larson, 1987).

2.2.1 Hot in Place

The Asphalt Recycling and Reclaiming Association (ARRA) recognizes three basic hot in place recycling processes (HIRP): heater-scarification (multiple pass); repaving (single pass); and remixing. The first two processes involve removal, rejuvenation, and replacement of the top 25 mm (1 in) of the existing pavement. The remixing process involves incorporating virgin hot mix with the recycled paving material in a pugmill and placement to a depth of 50 mm (2 in). Generally,the hot process raises the temperature of the re-constituted mixture so as to provide an optimally flowable mixture which can be rolled to a suitable surface and which when cooled sets to a long-wearing pavement.

The major advantage of HIPR is the cost savings that it can potentially achieve over conventional recycled hot mix, eliminating the costs associated with transporting, processing and stockpiling RAP (Button et al. 1994). Since only the top 50 mm (2 in) of pavement can normally be reconditioned using this process, HIPR applications are limited to roadways that do not have any structural deficiencies and do not require additional materials. The major disadvantage of HIPR is the inability to make significant changes to the mix. Pavements that exhibit structural base failure, irregular patching or the need for major drainage or grade improvements are not suitable candidates for HIPR.

2.2.2 Cold in Place

Cold recycling is the processing and treatment with bituminous and/or chemical additives of existing asphalt pavement without heating to produce a restored pavement layer. Cold recycling normally consists of milling an existing asphalt pavement to a specified depth, mixing an additive or additives with reclaimed asphalt pavement (RAP), spreading and compacting the recycled mixture to a specified depth and cross slope.

This is followed by placement of a new asphalt surface course, usually a hot mix asphalt overlay but for some projects an asphalt surface treatment is used (AASHTO Report 1999).

The cold process relies more on viscosity derived from the properties of the modifier and the lubricating effect of the water. When properly proportioned with a modifier, a suitable pavement can be provided. The cold process has the advantage of a lesser consumption of energy because of the absence or lesser use of heat (Jahren et. al.1999).

2.3 Bitumen Ageing

Ageing mainly leads to increased stiffness but also bring about changes in physicochemical properties as ductility and adhesion. The degree of ageing depends on many factors, such as temperature, air void content of the mixture, and chemical composition of the binder (Robert and Ulf, 2006). A reduction in aging reduces the probability of embrittlement, which contributes to fatigue cracking or alligator crack that leads to reduced pavement strength and shortened service life. The main ageing mechanism is an irreversible one, characterized by chemical changes of the binder, which in turn has an impact on the rheological properties (Lu and Issacsson, 2002). The processes contributing to this type of ageing include oxidation, loss of volatile components and exudation migration of oily components from the bitumen into the aggregate. The second mechanism is a eversible process called physical hardening. Physical hardening may be attributed to molecular structuring, for example the reorganization of bitumen molecules or bitumen microstructures to approach an optimum thermodynamic state under a specific set of conditions (Lu and Isacsson, 2002).

2.3.1 Oxidation

Oxidation is an irreversible process mainly controlled by the reactivity of the binder and the amount of oxygen available through diffusion (Tuffour and Ishai, 1990). Oxidation changes the chemical composition of binders. A major outcome of aging is the formation of polar functional groups, which increases the viscosity by increasing the intermolecular interactions.

2.3.2 Evaporation

Evaporation of volatile components of binders, especially from thin films, can result in substantial changes in binder properties, if the binders are exposed to high temperatures (Van Gooswilligen, 1989). The sensitivity toward evaporation differs between binders and can be reduced by minimizing the amount of the most volatile components.

2.3.3 Exudation

Exudation results from loss of oily components, which exude from the bitumen into the aggregate. This type of aging is influenced by the chemistry of the bitumen as well as the porosity of the aggregate.

2.3.4 Physical Hardening

Physical hardening can occur over a long period of time and is believed to arise from molecular structuring. The degree of molecular structuring is influenced by temperature. The effect of physical hardening can be reversed by, for example, changing the temperature.

2.4 Asphalt Content and Properties

The asphalt content of most old pavements will comprise approximately 3 to 7 percent by weight and 10 to 20 percent by volume of the pavement. Due to oxidation aging, the asphalt cement has hardened and consequently is more viscous and has lower penetration values than the virgin asphalt cement

2.4.1 Viscosity

In general, viscosity is a resistance to flow. Kinematics viscosity is the quotient of the absolute or dynamic viscosity divided by the density.

Depending on the amount of time the original pavement had been in service, recovered reclaimed asphalt pavement binder may have penetration values from 10 to 80 and absolute viscosity values at 60°C (140°F) in a range from as low as 2,000 poises to as high 50,000 poises or greater. Pavements that are too severely aged which generally have an absolute viscosity greater than 200,000 poise should not be consider for recycle (FHWA report ,1997). Higher viscositis were sometimes encountered in the top of the base course indicating that hardening occuring between the base and surface course.(Richard et al.1990)

2.4.2 Gradation

The Asphalt Institute suggests that when twenty percent or less reclaimed asphalt pavement is used in a mix, no change in asphalt grade is required. However, for mixes with greater than twenty percent reclaimed asphalt pavement, a drop in one grade is recommended to compensate for the greater viscosity of the oxidized binder. Addition virgin aggregates may be required to satisfy gradation requirement to improve stability and to limit the reclaimed asphalt pavement content in recycled hot mixes. In the production of hot mix, superheated virgin aggregate is needed to provide indirect heat transfer to the reclaimed asphalt pavemnet while maintaining the proper mix temperature.

2.4.3 Void Content

The amount of rejuvenating agent that can be added through hot in place recycle is limited by the air voids content of the existing asphalt. An existing pavement being considered for hot in place recycle should have an air void content in excess of six percent, in order to accommodate the addition of a rejuvenating agent without the lost of stability in the recycled mix. When the air voids content of the old asphalt mix is too low to accommodate sufficient recycling agent for proper rejuvenating or softening of the old asphalt binder without mix flushing, it may be necessary to add additional fine aggregrate or to beneficiate with virgin hot mix to open up the mix or increase the air voids.

Low air void content is frequently reported in connection either recycled objects. The reason is often too much binder added for the purpose of softening the reclaimed asphalt concrete and making it workable (Rogge et al 1994).

2.5 Properties of recycled binders

The constitution of recycled binders is importance in influences the cohension,adhension, and durability of the asphalt recycling. A recycled binder has to be altered to performance satisfactorily in the service period by the addition of a properly selected rejuvenator (Robert and Ulf, 2006). Maintaining the good stability and durability which means a homogeneous system where the asphaltenes are well dissolved and prevented from precipitation or floccuration is essential for recycled pavement as well. However, the component that enchance stability and durability may not be very effective at reducing viscosity (Newcomb et al., 1984). Therefore, the required amount of agent rejuvenating must be determined based on the aspect of consistency and chemical constitution of recycled binders.

The constitution of a recycled binder depends on the composition of the origin binder, aging during services, the constitution of the new binder added or rejuvenator, and the final production including mixing, laying, and compaction.

2.6 Rejuvenators

The American Society of Testing and Materials (ASTM) defines the rejuvenator as "a dark brown to black cementitious material in which the predominating constituents are bitumens which occur in nature or are obtained in petroleum processing."

In general,rejuvenating agents can be divided into three main types: "super-soft" asphalt cements, napthenic or aromatic oils and paraffinic oils. These products consist of organic compounds derived from petroleum extracts during petroleum hydrocarbon processing.

Rejuvenator in asphalt recycling can be categorized into :

i. Softening agents
   - Asphalt flux oils (generally blended with bitumen to reduce the viscosity);
   - Lube stock (a fraction of cruel oil that has viscosity similar to
   - lube oils);
   - Lubricating or crankcase oil (usually highly aliphatic) and
   - Slurry oil (bottoms from the catalytic cracking process)

ii. Rejuvenating agents
   - Lube extracts (highly naphtenic or aromatic fractions removed from lube stock by solvent extraction); and
   - Extender oils (aromatic oils from lube stock, mostly used for extending asphlalt-rubber blends)

The different between softening agents and rejuvenating agents is where softening agents plainly are aimed at lowering the viscosity of aged bitumen, whereas rejuvenating agents also are added for the purpose of restoring physical and chemical properties of the old binder(Karlsson and Isacsson, 2006).

Rejuvenators can be used in the pavement in three situations which are new construction, maintenance, and re-construction (Boyer, 2000). The rejuvenator can restoring the original asphalt properties that were lost during the process of HMA manufacture, the chemical assists in sealing the pavement as well as in improving the durability of the surface course. Maintenance can be subdivided into preventive and corrective maintenance.

Preventive maintenance should be applied to pavements at the first signs of aging of the surface course, pitting, raveling, shrinkage, and cracking. By applying the rejuvenator at periodic intervals or a correct time is very essential since it can restore the asphaltene maltene balance to maintain a ductile, pliable pavement. Corrective maintenance involves reworking and salvaging existing road mixes. Using a rejuvenator in this type of maintenance can facilitate scarifying and mixing. It will aid in replasticizing old asphalt and improve its durability. This form of maintenance should be considered when the road mix surface appears weathered and crusted and cannot be restored by applying only a rejuvenator (Boyer, 2000).

The third category of rejuvenator use is that of re-construction. This involves more than applying a rejuvenator emulsion onto the surface and rolling the treated pavement. Work in the category is undertaken when the pavement has outlived its life; when preventive maintenance has failed to stop the pavement deterioration; or when a HMA overlay is to be placed over the existing pavement. The overlayment may be due to a need for increased structural strength, or it may be necessitated by failure of the old surface to respond to normal maintenance. If the existing pavement possesses good structural qualities and the overlay is being placed to increase its strength, a rejuvenator can be applied to the old surface several days before the overlay is constructed. This application will cause the existing surface to soften, regain some of its original ductility, and will promote a good bond between the old and new surfaces.

Procedures for selecting the quality of asphalt cement or recycling agent are outlined in ASTM D4887. This specification includes a viscosity blending chart, which enables the designer to determine the percentage of recycling or rejuvenating agent to add to the total binder in order to achieve a desired value of absolute viscosity for the recycled asphalt cement. Besides, ASTM D4552 provides a classification of recycling or rejuvenating agents.

2.6.1 Criteria for A Rejuvenator

Asphalt binders are fractionated into two subdivisions which are asphaltenes and maltenes. The high-molecular-weight asphaltenes are of a complex nature and are dispersed in low molecular weight hydrocarbons, known as maltenes (Katamine, 2000). Generally, asphaltenes (A) are defined as the fraction of the asphalt insoluble in n-pentane. The function of the asphaltenes is to serve as a bodying agent. Maltenes is the collective name for the remainder of the asphalt material left after precipitation of the asphaltenes (Boyer, 2000).

Four principle bodies of maltenes have been identified and each has a specific function. These four bodies are

- Polar compounds or Nitrogen bases (N) - components of highly reactive resins, which act as a peptizer for the asphaltenes.
- First acidiffins (A_1) - components of resinous hydrocarbons which function as a solvent for the peptized asphaltenes.
- Second acidiffins (A_2) - components of slightly unsaturated hydrocarbons that also serve as a solvent for the peptized asphaltenes.
- Saturated hydrocarbons or paraffins (P) – components of hydrocarbons, which function as a jelling agent for the asphalt components.

According to Kari et a.l. (1984) the blends of bitumen with rejuvenators of high content of saturates or paraffins (according to ASTM D2007) showed higher aging index, while high content of aromatics and polars contributed to improve ductility. As the paraffins, P, in the asphalt binder is a jelling agent, the increase of the composition P may increase the hardening of asphalt concrete, therefore contribute to the eversible ageing process. This is support by the test conducted by Peterson et al. (1994) which the blends with rejuvenators containing more than 30% of saturates failed to meet the specifications. Therefore the content of paraffins in rejuvenators should preferably show as low as possible.

According to Dunning and Mendenhall (1977); Newcomb et al. (1984), a high content of polar and aromatic, N, are believed to enhance dispersion of asphaltanes. The increase of component N in asphalt binder can improve the stability and ductility of the asphalt binder.

Rejuvenator must contain maltenes fractions of asphalt in order to improve and balance the maltenes to asphaltenes ratio (Boyer 2000), where the maltenes parameter, is express at Eq (1b)

$$\text{Maltenes parameter} = \frac{(N + A_1)}{(P + A_2)} \qquad \text{Eq (1b)}$$

McMillan and Palsat (1985) also tested viscosity of recycled binders after TFOT. It was suggested that maximum amount of distillate should be no more than 1% by volume, determined by *ASTM D402* to ensure that only distilled binders were used and not cut back bitumens. Noureldin and Wood (1990) observed substantial differences between TFO-aged blends of one old binder and three different rejuvenators. All blends were designed to correspond to a virgin binder AC-20 of penetration 65 dmm at 25°C.

In summary, the criteria for a rejuvenator should as below:

- A rejuvenator should contain low content of asphaltenes
- A high content of aromatic which manifested in high ductility and stability is more preferably to use as rejuvenator

- Rejuvenator contains high content of paraffins /saturates and waxe is not suitable to use as rejuvenator.
- Rejuvenator must contain maltenes fractions of asphalt in order to improve and balance the maltenes to asphaltenes ratio.

2.6.1.1 Type A Rejuvenating Agent

Type A is an emulsified blend of RA-1(ASTM designated recycling agent, grade 1 napthenic base oil) and water. The cured residue functions as a surface rejuvenator and is designed to be totally absorbed into the pavement surface. The properties of the rejuvenator refer to table 2.1.

2.6.1.2 Type B Rejuvenating Agent

Type B is an emulsified blend of RA-1(ASTM designated recycling agent, grade 1 napthenic base oil), and petroleum asphalt. The cured residue functions as a surface rejuvenation/preservative sealer. The properties of the rejuvenator refer to table 2.2.

2.6.1.2 Type B Modified Rejuvenating Agent

Type B Modified Agent is an emulsified blend of RA-1 napthenic base oil, petroleum asphalt, and a minimum of 15% Gilsonite (a naturally occurring, semi-solid hydrocarbon exhibiting a high softening point). The cured residue is less tacky than type B, functions as a surface rejuvenation/preservative sealer,and is less susceptible to re-emulsification than type B. The properties of the rejuvenator refer to table 2.2.

2.6.1.3 Type C Rejuvenating Agent

Type C is an emulsified blend of petroleum asphalt, Tall oil pitch, and a minimum of 10% Gilsonite. The cured base asphalt is harder than Type B Modified and functions as a surface seal. The properties of the rejuvenator refer to table 2.3

2.6.1.4 Type D Rejuvenating Agent

Type D Modified Agent is an emulsified blend of RA-1 napthenic base oil, petroleum asphalt, and polymer. Apply to pavement surfaces as a rejuvenating or preservative seal to retard age hardening, prevent, and/or retard raveling and to seal/heal small cracks. The properties of the rejuvenator refer to table 2.4.

Table 2.1 Properties of standard Asphalt Rejuvenating Agent Type A based on ASTM

Asphalt Rejuvenating Agent Type A			
Test	Test Method	Requirements	
		Minimum	Maximum
Viscosity, 25°C, SFS, sec.	AASHTO T 59	15	40
Miscibility Test	AASHTO T 59		No coagulation
Sieve, w%	AASHTO T 59		0.10
Residue, w%	CTM 351	60	
	AASHTO T 201	100	
	ASTM D 2006-65		
Asphaltenes, w%	ASTM D 2006-65		0.75
Saturates, w%	ASTM D 2006-65	21.0	28.0
Maltenes Distribution Ratio			
(PCA+A1)/(S+A2)		0.30	0.60
PC/S Ratio		0.50	
Particle Charge Test	AASHTO T 59		Positive
pH of Emulsion	AASHTO T 59		
Dilution Stability	AASHTO T 59		5.0
% Light Transmittance			
Cement Mixing, w%	AASHTO T 59		2.0

Table 2.2 Properties of standard Asphalt Rejuvenating Agent Type B based on ASTM

Asphalt Rejuvenating Agent Type B			
Test	Test Method	Requirements	
		Minimum	Maximum
Viscosity, 25°C, SFS, sec.	AASHTO T 59	40.0	120.0
Sieve, w%	AASHTO T 59		0.10
Residue, w%	AASHTO T 59	64.0	
Viscosity, 60°C, P	AASHTO T 201	1000	4000
Component Analysis, w%	ASTM D 2006-65		
Asphaltenes, w%	ASTM D 2006-65		11.0
Maltenes Distribution Ratio			
(PCA+A1)/(S+A2)		0.70	1.10
PC/S Ratio		0.50	
Particle Charge Test		Pos.	
Pumping Stability		Pass	
Settlement, 5 Day, %	AASHTO T 59		5.0
Cement Mixing	AASHTO T 59		2.00

Table 2.3 Properties of standard Asphalt Rejuvenating Agent Type C based on ASTM

Asphalt Rejuvenating Agent Type C			
Test	Test Method	Requirements	
		Minimum	Maximum
Viscosity at 25°C, SFS, sec.	AASHTO T 59	20	80
Sieve, w%	AASHTO T 59		0.01
5 Day Settlement, %	AASHTO T 59		5.0
Particle charge	AASHTO T 59	Positive	
pH	AASHTO T 59	2.0	7.0
Residue, w%	AASHTO T 59	57	
Tests on Recovered Residue:			
Viscosity at 135°C, cSt	AASHTO T 201	475	1500
Flash point, Cleveland Open Cup, °C	AASHTO T 48	232	
Solubility in TCE	AASHTO T 44	97.5	
Specific Gravity (1- Water)	AASHTO T 228	0.98	
Asphaltenes, w%	ASTM 2007	20	40
Polar Compounds, w%	ASTM D 2007	30	
Aromatics,w%	ASTM D 2007	15	
Saturates, w%	ASTM D 2007		10
Tests on diluted dispersion, 1:1 dilute:			
Residue, w% (1:1)	AASHTO T 59	29	
Pumping Stability		Pass	

Table 2.4 Properties of standard Asphalt Rejuvenating Agent Type D based on ASTM

Asphalt Rejuvenating Agent Type D			
Test	Test Method	Results	
		Minimum	Maximum
Viscosity at 25°C, SFS, sec.	AASHTO T 59	30	150
Residue, w%	AASHTO T 59	65	
pH	AASHTO T 200	2.0	5.0
Sieve, w%	AASHTO T 59		0.1
Oil distillate, w%	AASHTO T 59	0.5	
Tests on Residue:			
Viscosity @ 60°C, P	AASHTO T 201		2000
Penetration @ 4°C	AASHTO T 49	80	
Modified Torsional Recovery(a),% min. or Elastic Recovery on residue by distillation(b,c),%,min.	CTM 332	45	
	AASHTO T 59, T 301	60	
Toughness @ 25°C, N-m	ASTM D 5801	2.0	
Tenacity @ 25°C, N-m	ASTM D 5801	1.0	
Asphaltenes, w%	ASTM D 2006-65	18.0	
Saturates, w%	ASTM D 2006-65		16.0

2.7 Diffusion of Rejuvenator

Diffusion can be defined as transport of matter due to random molecular mevements termed Brownian motions, and is temperature dependent. The diffussion process occuring when a rejuvenator is added to recycled asphalt consisted of the following four steps (Carpenter and Wolosick, 1980):

1. The modifier forms a very low viscosity layer that surrounds the aggregate, which is coated with very high viscosity aged asphalt cement.
2. The modifier begins to penentrate the aged asphalt cement layer, thereby reducing the amount of new modifier that coats the particles and softening the old asphalt cement.
3. No raw modifier remains, and the penetration continues: the viscosity of the inner layer decreases and the viscosity of the outer layer gradually increases.
4. Equilibrium is approached over the majority of most of the shell of asphalt cement except right at the binder/aggregate interface, which may continue to have a higher viscosity.

Two implications of imcomplete mixing may cause major problems in predicting performance and affect the long term field pavement performance

2.9 The Application of the Asphalt Rejuvenator

A study sponsored by the Air Force Weapons Laboratory, dated May 1970, entitled "Rejuvenation of Asphalt Pavement"(Rostler and White, 1970) which consisted of a laboratory investigation of five products. The method of investigation entailed preparation of sand/asphalt briquettes composed of graded Ottawa sand, Portland cement and asphalt of specified penetration values. Test briquettes were subjected to equal application rates of five rejuvenator products, aged until one-half of the volatile constituents of the rejuvenating agent was lost, and subsequently, subjected to various tests, including permeability, depth of penetration, viscosity, and pellet abrasion. The conclusion of this study revealed that Reclamite and Koppers Bituminous Pavement Rejuvenator (BPR) performed as asphalt rejuvenators in that the viscosity of the asphalt binder was improved and the loss of aggregate from the pellet abrasion test was substantially reduced by application of both products. This conclusion was based on comparisons with untreated control samples and the other products.

In the research that conducted by Shen. et al. (2006) had showed the effects of rejuvenator on performance-based properties of rejuvenated asphalt binder and mixtures. They use a soft binder with low asphaltene of 2 wt% as a rejuvenator for the aged asphalt binder which was produced artificially with straight-run Pen 60–80 by Rolling Thin Film Oven (RTFO) and Pressure Ageing Vessel (PAV) process. The viscosity of the rejuvenator at 60 C is 202 Pa s and the flash point is 232°C. The percentages of the rejuvenator used were 0, 6.0, 9.0 and 14.0wt% of the aged binder. They concluded that the rejuvenator percentage affected greatly the performance-based properties of the blend of aged binder and the rejuvenator. The rejuvenator percentage also affected significantly the selected performance-based properties of the mixtures containing rejuvenated aged binders in the same ways it affected blends. Therefore, by adjusting the amount of the used lubricating oil in the rejuvenating process, the used oil should be able to function effectively in the recycle process. The rejuvenator percentage is very crucial to the properties of the blended aged asphalt so that the properties under low temperature are improved while the properties under high temperature are not adversely affected.

A research carried out by Thomas and Harnsberger (1995) to evaluate an Eastern Shale Oil (ESO) residue as an asphalt additive conducted a rheology analysis on the mixing of three common petroleum-derived asphalt blended with 0, 5 and 15mass %of ESO, respectively. The samples had satisfied the high pavement temperatures stiffness requirement which relates to rutting. However, the result showed that upon RTFO/PAV aging, the addition of the ESO residue does not mitigate the chemical aging of the petroleum-derived asphalts. The reasonable explanation could be the shale oil did not subjected to any treatment before the analysis, therefore reduce the stability of ESO residue. Another similar test also conducted by Katamine (2000) using Jordan shale oil to soften the binder and reduced the solvency of the maltenes and, accordingly, softened the domains that are required to be strong, to ensure a stiff binder at normal temperatures. This experiment showed that the shale oil act as an additive to decreased softening points, increased penetration, and provided less ductility to the binder.

2.10 Motor Oil

Motor oil is used as a lubricant in various kinds of internal combustion engines in automobiles and other vehicles, boats, lawn mowers, trains, airplanes, etc. In engines there are contacting parts which move against each other at high speeds, often for prolonged periods of time. Such rubbing motion causes friction, absorbing otherwise useful power produced by the motor and converting the energy to useless heat. Friction also wears away the contacting surfaces of those parts, which could lead to lower efficiency and degradation of the motor.

Lubricating oil makes a film between surfaces of parts moving against each other so as to minimize direct contact between them decreasing friction, wear, and production of excessive heat. Also motor oil carries away heat from moving parts. Materials tend to become softer and less abrasion-resistant at high temperatures. Some engines have an additional oil cooler.

2.11 Used Oil

It is estimated that less than 45% of used engine oils being collected worldwide while the remaining 55% is thrown by the end user in the environment. Used oil affects both marine and human life. Oil in bodies of water raises to the top forming a film that blocks sunlight, thus stopping the photosynthesis and preventing oxygen replenishment leading to the death of the underwater life. In addition, used oil contains some toxic materials that can reach humans through the food chain. Health hazards range from

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