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THE INFLUENCE OF ASPHALT RHEOLOGICAL BEHAVIOR AND DURABILITY OF RECYCLED ASPHALT CONCRETE UNDER HIGH VISCOSITY RAP AND HIGH ADDITION

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Abstract: This study performs laboratory investigation to discover the rejuvenating effect of Rejuvenating Agent (RA) on the performance of aged asphalt binder and asphalt concrete in order to increase Recycled Asphalt Pavement (RAP) usage. It also distinguishes between asphalt binder employing viscosity blending chart from AI MS-2, and penetration grade from Japanese blending chart, to find the optimum necessary RA in the blends and therefore solve the rutting problem. The material used was 20% and 40% of a 100,000 poises Recycled Asphalt Binder (RAB) with AC 20 as virgin binder and RA. Control samples, short-term aging, and long-term aging samples were used to describe the durability of the mixtures. Penetration blends decreased the RA needed about 40% compared to the viscosity blends and showed better rutting performance, especially for a higher percentage of RAP. Viscosity blending yielded a misleading in the addition of RA and resulted in softer RAB, which is susceptible to rutting. Thus, for the case of rejuvenating severely aged and quite high content of RAP mixtures, relying on only viscosity test and AI MS-2 is not adequate.

Keywords: Recycled Asphalt Pavement (RAP), Rejuvenating agent (RA), AI MS-2、Japanese recycled asphalt pavement handbook

1 INTRODUCTION

Taiwan has been facing limited natural resources due to pavement construction and maintenance projects. In order to reduce the use of natural resources and the big piles of construction waste, Public Works Committee of Executive Yuan promoted the Recycled Asphalt Pavement (RAP) by using Rejuvenating agent (RA). In the first place, RAP waste materials were promoted to reduce harmful environmental impacts during a pavement life cycle, reduce the use of natural resources and reduce their cost. In Taiwan, the optimum rejuvenator agent content is usually determined using the blending chart developed by the Asphalt Institute (AI) . This chart shows a linear relationship between the logarithm of viscosity at 60°C and the percentage of new asphalt or the percentage of rejuvenating agent in the blend. However, when the viscosity of an aged binder exceeds 100 kP, the blending chart might over predict the rejuvenator optimum dose, consequently resulting in rejuvenated RABs that are softer than expected. At RAP binder percentages over 25%, blending charts or equations should be used. NCHRP 9-12. results showed that the predictability of linear blending theory becomes unstable as replaced binder contents approach and exceed the 40%.

The addition of unusually soft binders to compensate high amounts of recycled binder can deviate from the predicted performance expected using blending analysis. Therefore, the Asphalt Institute recommends in no case should the selected virgin binder grade to be more than two grades softer than the binder grade that would be used in a 100 percent virgin (0% RAP) mixture for that location and application. As before, if the project's binder grade is intended to be a modified binder, then the selected virgin binder should also be a modified binder. A modified binder may not be necessary depending on the properties and quantity of the RAP being utilized. Asphaltenes are portions of an asphalt that are insoluble in low molecular weight (MW)-saturated alkanes. Asphaltenes are black, friable solids.

The solvents used to precipitate asphaltenes are usually a straight-chain alkanes ranging in carbon number from 3 (propane) to 10 (n-decane). The branched-chain alkane iso-octane also may be used. In most investigations, n-pentane and n-heptane are the precipitants. Asphaltene contents provide a basis for classification of asphalts into sol-or-gel types. An asphalt high in asphaltene content will have properties characteristic of gel-type asphalts. Among these properties are high degree of complex flow, relatively low change of viscosity with temperature, low ductility, and susceptibility to oxidative age hardening. Asphalts with low asphaltene content will have properties characteristic of sol-type asphalts. Such asphalts are frequently observed to yield "tender" pavements. Sol-type asphalts are ductile, have low degrees of complex flow, and exhibit large changes of viscosity with temperature. Asphalts with intermediate asphaltene content will have properties intermediate between the extremes of sol- and gel-type behavior.

The fractions of saturates, aromatics, resins and asphaltenes directly affects the rheological properties of asphalt. At constant temperature, the viscosity of asphalt increases as the concentration of asphaltenes increases. Likewise, the constant ratio of resins to aromatics and increasing saturates, soften the asphalt. In contrast, addition of resins content, increases the viscosity of asphalt. The viscoelastic behavior of asphalt can be explained by spring and dashpot models The formation of asphaltenes that results from weathering (oxidation and/or volatilization), has long been observed. The increase in viscosity (hardening of asphalt) and the change in colloidal structure (from sol or sol-gel to gel-type materials) or the increase in complex flow that accompanies the increase in asphaltene content have been postulated by many researchers as the cause for asphalt failure by cracking.

Thus the change in asphaltene content was used in this study as an important parameter in asphalt durability evaluation. A refinement of absorption chromatographic separation of asphalts for the purpose of rapid "fingerprinting" is the iatroscan method. This is a thin-layer chromatographic procedure. Solutions of asphalts in carbon disulfide are "spotted" on specially prepared glass rods coated with silica. The spotted rods are then "developed" by partial elution with a series of three solvents, n-heptane, toluene, and THF. Each of the solvents causes different compound types to move along the rods from the original spot. Saturates, naphthene aromatics, and polar aromatics are eluted three solvent, respectively. Iatroscan can provide rapid results similar to those obtained in Corbett analyses. Iatroscan is a method of analysis rather than a physical separation of asphalt fractions, so handling substantial quantities of solvents is not required.

2 STUDY PLAN

According to the RAP limitation to 40% in Taiwan, this study will use 0%, 20%, and 40% RAP in order to compare and investigate the physical, rheological, and chemical properties of the materials. This analysis includes viscosity test, penetration test, lactoscan (TLC-FID), Dynamic Shear Rheometer (DSR) test, Marshall Test, and Hamburg Wheel Tracking test. Moreover, due to the rapid rutting of roads with RAP in Taiwan, this research was carried out using two types of RA blending charts (viscosity index from AI MS-2 and penetration index from Japan) in three conditions (original, short term aging (RTFOT), and long-term aging (PAV)) and compare their performances.

3 MIXTURE DESIGN

RAP with 100,000 poises of viscosity was used in this study. The targeted values for viscosity and penetration are 3,000 poises and 55, respectively, for the additives removal (20% and 40%). Since the Rejuvenating agent will be exposed to a high temperature during both of the mixing and paving processes; then the Rejuvenating agent needs to be characterized by a certain trait of high degrees heat resistance, that should not be lost due to high temperature or rapid aging. Therefore, the RTFOT and PAV tests are used to simulate how would the Rejuvenating agent react to the aging process. Laboratory tests results on the physical properties, chemical properties, rheological properties, and recycled asphalt concrete of asphalt cement would be analyzed in this study.

3.1 Basic physical property test

3.1.1 Rejuvenating Agent

This study used RA-1 to increase the performance and durability of asphalt concrete. RA-1 was subject to properties and chemical analysis to inspect its accordance with Taiwan standards.

3.1.2 Virgin Asphalt Binder

In this study, basic physical tests were carried out using AC-20 grade asphalt mastic and passed the National Association of the People's Republic of China (CNS) related asphalt specifications.

3.1.3 Recycle Asphalt Pavement Properties

RAP material was examined following the standard ASTM D2172 to know its viscosity and asphalt content. The properties are shown in Table 1.

Table 1: RAP properties

Properties	Experimental value	Specification
Viscosity (%)	5.4	>3.8
Penetration (0.1mm)	20	>20
RAP viscosity	100,000	-

3.2 Calculate the Additional amount of Rejuvenating agent

Based on the AI MS-2 graphic method and the Japanese recycled asphalt pavement handbook, the amount of Rejuvenating agent to be added is determined based on the target viscosity of AC-30, which is 3,000 poises, and the target penetration that is of 55. The calculated results are shown in Table 2.

Table 2: Percentage of rejuvenating agent in different materials

Method	0% RAP (Additives %)	20% RAP (Additives %)	40% RAP (Additives %)
AI MS-2	0	6.7	16.2
Japanese recycled asphalt pavement handbook	0	3.6	4.8

3.3 Aging Test

3.3.1 Rolling Thin Film Oven Test (RTFOT)

Following the ASTM-D2872 to simulate short-term aging of asphalt binders, which is preceded by production, and construction of asphalt pavement.

3.3.2 Pressure Aging Vessel (PAV)

By following the ASTM-D6521. Simulating the in-service oxidative aging of asphalt binder was conducted by exposing the asphalt to elevated temperatures in a pressurized environment. The improved PAV prevents the complications from running and documenting asphalt binder aging operations.

3.4 Chemical Analysis Thin Layer Chromatography – Flame Ionization Detection (TLC-FID)

SARA separation results suggested that changes in chemical fractions were responsible for the stiffening effect with aging and the improvement of mechanical properties with the addition of the rejuvenators. Resins mainly affect the asphalt's viscosity by decreasing it and therefore softening the asphalt, unlike the Asphaltene that hardens the asphalt.

3.5 Rheological Analysis Dynamic Shear Rheometer (DSR)

Analysis under different frequencies, temperatures, and torsions are carried out in order to classify and evaluate the bitumen binders according to their performance properties. This has led to a better knowledge of the bitumen behavior that occurs when subjected to different thermal and mechanical conditions, as seen during road construction and service in the field.

In order to simulate the fatigue and rutting behavior of Asphalt cement after repeated loading, the study referred to the experimental configuration of SHRP-A-379 (Specifications, Test Methods and Practices of SUPERPAVE Hybrid Design System Manual), by applying continuous torsion to asphalt cement. Shear force simulates the stoppage of the vehicle, the frequency of the up and down vibrations simulates the rolling of the traffic flow, and adjusts their values to predict the effectiveness of the asphalt cement in different environments.

3.6 Rutting Wheel Track Test

To obtain the rutting resistance of the asphalt concrete; The Public Construction commission Executive Yuan in Taiwan regulated the procedure according to "Chapter 02798 V1.0 Porous asphalt concrete paving" to simulate the field traffic effects on hot mixture asphalt specimens in terms of rutting and moisture-susceptibility. This study used rectangular slabs (30 cm long, 30 cm wide and 5 cm thick) with 6 to 8% of air voids. The test temperature is usually set at 40° C (104° F) or 60° C (140° F) for a time length of approximately 0.5 to 2 hours. Each wheel makes about fifty passes per minute under 686±10N, then by using the equation [1], [2]   and , which can evaluate the rutting resistance of the asphalt concrete, are computed.

[1] Dynamic stability, $DS(\text{passes/mm}) = \frac{\Delta n}{\Delta d}$

[2] Rate of Deformation, $RD(\text{mm/min}) = \frac{\Delta d}{\Delta t}$

ΔN = difference in number of times of rolling (number of times).

Δd = difference in deformation (mm).

RD = Deformation rate (in centimeters per minute)

△T = rolling time (minutes)

4 RECYCLED ASPHALT PAVEMENT PERFORMANCE RESULTS

4.1 Viscosity and Penetration Physical Test Results

Four different ratios: AI-20%, AI-40%, J-20%, J-40%'s penetration and viscosity all fall within the target AC-30. After long and short-term aging, the viscosity is expected to increase, while the penetration is expected to drop. The Asphalt bitumen acquired a hardening behavior, as shown in Figure 1 and Figure 2, the ratio with a 20% of RAP: AI-20% and J-20%'s performances are the same, but AI-40% and J-40% that used the same additional amount of RAP (40%) showed very different performances. AI-40% has the lowest viscosity and the highest penetration in both short-term aging and long-term aging while the J-40% showed an opposite performance. AI-40% asphalt bitumen is even softer than the one using only 20% of RAP.

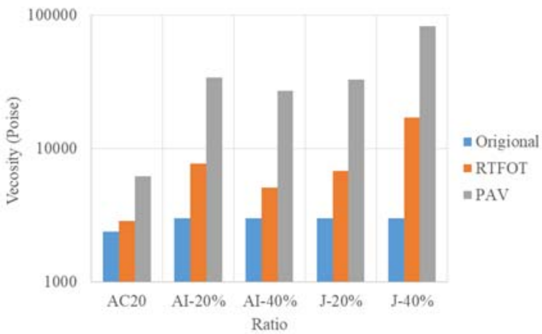

Figure 1: Viscosity of the blend

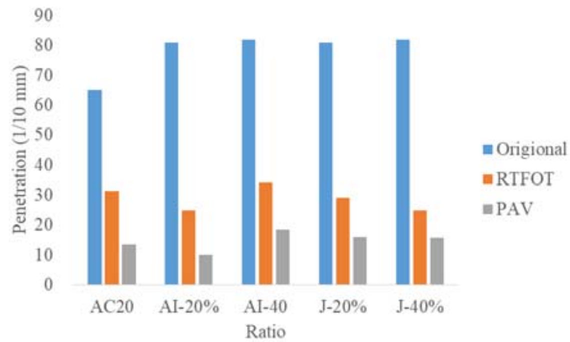

Figure 2: Penetration of the blend

4.2 Chemical Analysis (TLC-FID)

RA are able to change the chemical components of RAB. Figures 3, 4 and 5 show that each RAB Blend behaves differently. However, all of the blends increase the amount of Resin and asphaltene after the aging process, indicating that the asphalt becomes more brittle after aging. In which support our result in Figure 1 and Figure 2.

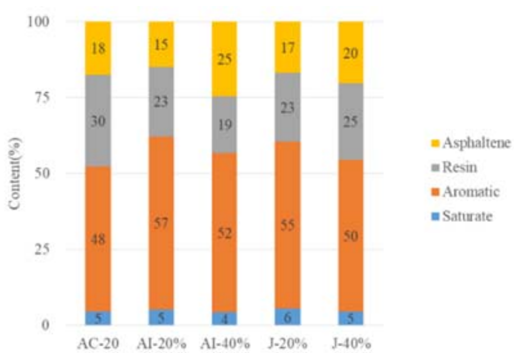

Figure 3: Chemical analysis on non aging

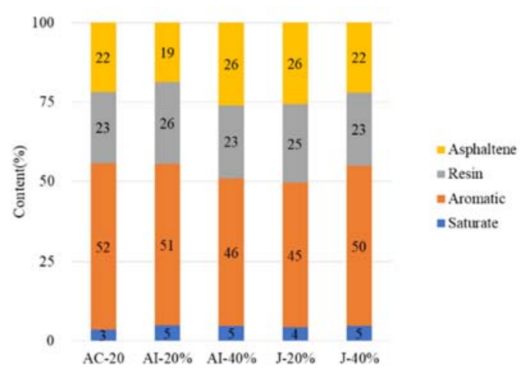

Figure 4: Chemical analysis on short term aging

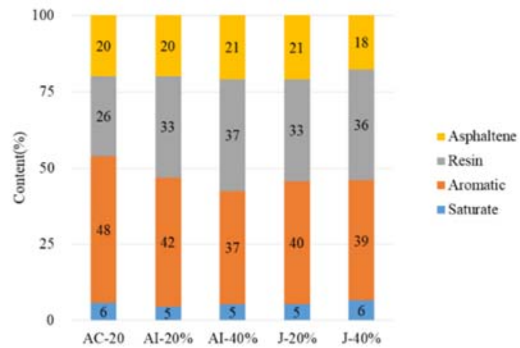

Figure 5: Chemical analysis on long term aging

4.3 Rheological Analysis Dynamic Shear Rheometer (DSR)

4.3.1 G* Value and Δ Angle at Multiple Temperatures for Different Ratio

Figure 6 and 7 show the complex shear modulus (G*) and the phase angle (δ) subjected to the change of temperature. G* decreases with the increasing of temperature, while δ increases. It shows that the RAB softens with the increasing of temperature and leads to rutting. J-40% shows as the strongest blend, and AI-40 shows as the softer blend.

Rheological analysis by G* and δ on figure 8 and 9 show that after subjection to RTFO and PAV. G* gets higher with the asphalt's aging. It indicates that the asphalt binder become stiffer due to the aging treatments. However, δ of all blends slightly decreases. Hence, the results show that asphalt binders will act from viscous to more elastic with the increase of the traffic speed.

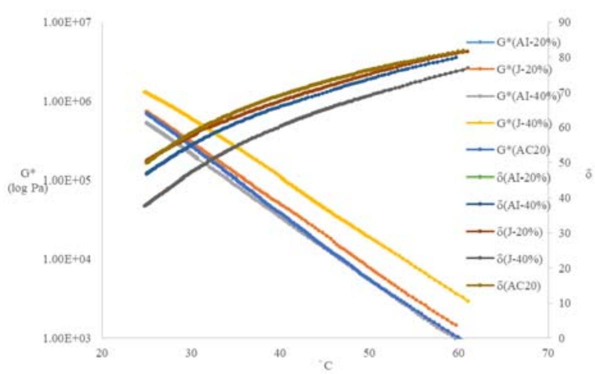

Figure 6: G* and δ for short term aging

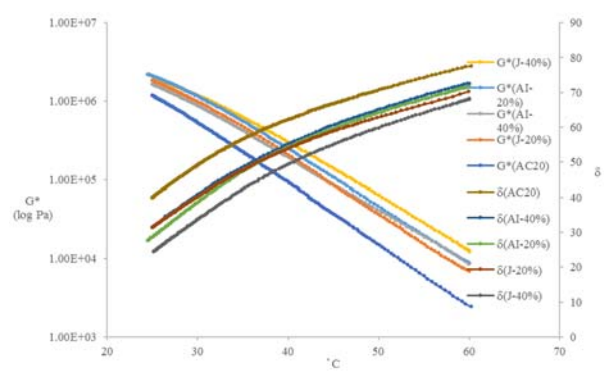

Figure 7: G* and δ for long term aging

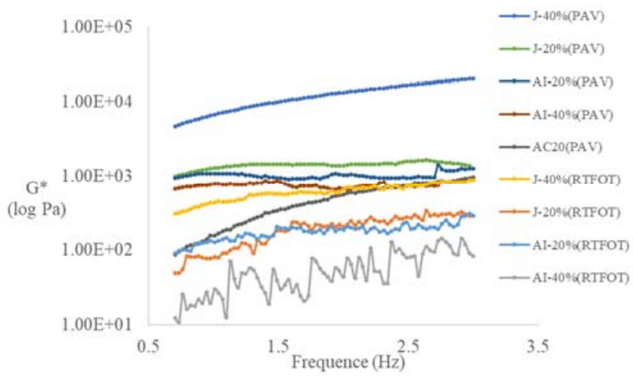

Figure 8: Phase angle for short and long term aging

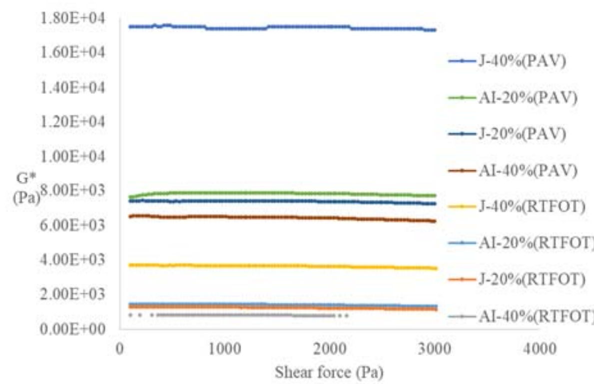

Figure 9: G* for short and long term aging

4.4 Rutting Wheel Track Test

The Rutting wheel track test results from figure 10 show the evaluation of the rut depth with the increase of number of passes. The curve will stop when the wheel reaches 1260 passes. The results of AI-40 shows the highest rutting, while the other blends have not shown any similar behavior. From Table 3 we can notice the RD from AI-40% is almost the double compared to the others, indicating AI-40% is not recommended and still susceptible to rutting. High rejuvenate agent amount in this blend increases its softness than any other blend.

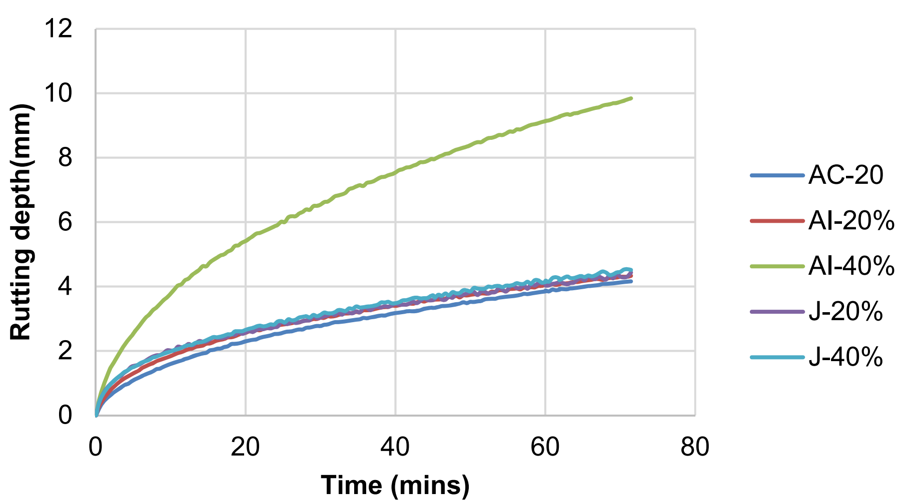

Figure 10: Rutting Hamburg Wheel Track Test for different ratio

Table 3: Dynamic stability and Deformation rate for different ratio

Ratio	DS(passes/mm)	RD(mm/min)
AC-20	1,341.0	0.03
AI-20%	1,074.1	0.04
AI-40%	534.8	0.08
J-20%	1,279.4	0.03
J-40%	1,203.3	0.04

5 CONCLUSION

5.1 Conclusion

1. The addition of a rejuvenating agent can effectively recover the recycled asphalt pavement in most cases and the resulted strength is similar to AC-20.

2. It is known from the Hamburg Wheel Track Test that the AI-40% ratio is significantly softer than the others. The AI MS-2 calculation graph depends on the hand drawing and will lead to errors. The amount of added RA is not accurate, the amount of addition would be overestimated. As a result, AI-40% asphalt concrete is too soft and less resistant to rutting.

5.2 Recommendations

It is recommended that follow-up studies can be considered based on the Japanese recycled asphalt pavement handbook to compare the impact of penetration and viscosity on asphalt in order to increase the amount of addition of the recycled asphalt to be used in the study of pavement and also to improve the problem of stock recycled asphalt pavement.

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