LABORATORY INVESTIGATION OF STIFFNESS OF HOT MIX ASPHALT CONTAINING RECLAIMED ASPHALT MATERIALS

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ABSTRACT

Limitation of resources of mineral aggregates and bitumen, negative impacts of the disposal of reclaimed asphalt pavement (RAP) in the environment and economical concerns are among the main promising issues in reusing RAP materials in pavement construction and rehabilitation projects. Asphalt concrete hot mix recycling is becoming one of the most appropriate methods of pavement rehabilitation techniques in the recent years. In this method, the asphalt milled materials from the pavement surfacing will be reused in a new asphalt concrete composition consisting of virgin aggregates, RAP and additional new binders.

The structural design of asphalt pavements is based on the determination of the stiffness of pavement layers, including that of RAP or the combination of RAP and virgin materials. In this work, stability and stiffness properties of hot mix asphalt containing RAP materilas, at various combinations of RAP and virgin aggregates were determined. Different percentages of RAP (0, 25, 50, 75, and %100) and a 60/70 penetration grade bitumen were used.

The behaviour of RAP materials in hot mix asphalt was investigated through different experimentations, including Resilient Modulus testing. This test method was performed at various temperatures and loading frequencies. The findings of this study show that resilient modulus and Marshall Stability of mixes were increased with increasing the percentages of RAP materials. The increase was pronounced at higher testing temperatures. Also by decreasing the loading frequency, resilient modulus values were decreased.

Keywords: Reclaimed Asphalt Pavement, Resilient Modulus, Stiffness

INTRODUCTION

Generally, asphalt reclaiming is defined as the operation in that deteriorated HMA mixes are re-used to prepare asphalt mixes. Economical aspects and conservation of natural resources are the main reasons for using reclaimed asphalt pavement (RAP) in road and pavement industry. One of the commonly used applications of RAP is using these in hot mix asphalt (HMA) applications. RAP materials could be used in rehabilitation proccesses such as overlays or patch works to fill the potholes. Hence, investigating the behaviour of hot mix asphalt containing RAP materials is of great importance. In this work hot mixes containing different percentages of RAP materials were investigated for strength and stiffness properties. Their properties were compared with a conrol HMA. Resilient modulus test was performed using a UTM-5P universal testing machine. The tests were performed at three temperatures of 5, 25 and 40^{o}C and three loading frequencies of 0.33, 0.5 and 1 Hz as it is recommended by ASTM D4123 standard method, although shorter loading frequencies were recommended in some research works (Daniel and Chehab, 2008 and APA, 2012).

ASTM D4123 standard method covers procedure for preparing and testing bituminous mixtures to determine resilient modulus values using the repeated-load indirect tension test. The procedure can cover a range of temperatures, loads, loading frequencies, and load durations. The recommended test series which have been followed in this research consists of testing at 5, 25 and 40°C at one or more loading frequencies (e.g. at 0.33, 0.5, and 1.0 Hz) for each temperature. This recommended series results in nine test values for one specimen which can be used to evaluate the overall resilient behavior of the mixture.

RESEARCH BACKGROUND

The resilient modulus test is a non-destructive testing method, where the asphalt concrete sample is dynamically loaded. Sample loading is generally between 5 and 20% of the static indirect tensile strength of the samples as recommended by many researchers (e.g. Roberts et al, 1996 and Sondog et al, 2002). The applied load and the recovered strain are measured, and the resilient modulus is determined using the following equation:

$$M_R = \frac{P(0.27 + \upsilon)}{\Delta u \times t}$$

Where:

M_R = resilient modulus, Pa

P = applied load, Newtons

Δu = horizontal deformation, mm

t = sample thickness, mm

ν = Poisson's ratio

Kennedy and Perez (1978) conducted a study using different soft bitumens and rejuvenators, as well as RAP with no treatment. They obtained resilient moduli ranging from 1,720 MPa to 6,915 MPa at 25°C. They concluded that RAP mixes had stiffness values slightly higher than the previously evaluated conventional mixes. Noureldin and Wood (1990) conducted a laboratory study comparing the resilient moduli of four mixes, all having the same gradation. The only difference between the mixtures was that one was a virgin mixture which used an AC-20 binder, and the other three were RAP, with AC-20 binder, blended with three different types of rejuvenators. The mixes were tested at binder contents of 5.5, 6.0, and 6.5%. The results indicated that all three mixes containing rejuvenators yielded a lower resilient modulus than the virgin mixes. This would mean that the rejuvenators were functioning to both decreasing bitumen binder viscosity and lowering the mixture's stiffness.

Stroup-Gardiner and Wagner (1999) examined the use of RAP with Superpave guidelines. Three mixtures with above-the-restricted-zone Superpave gradations were used. The first was a virgin mixture which used a PG 64-22 bitumen (used as the virgin bitumen for all three mixtures) and 100 percent crushed granite (used as the virgin aggregate for all three mixtures). The second mixture contained 15 percent Georgia RAP and the third contained 15 percent Minnesota RAP. No rejuvenator was used in these mixtures. Resilient modulus testing was conducted on these mixtures at temperatures of 4, 25 and 40°C. The results of the above work showed that the addition of 15 percent RAP more than doubled the resilient modulus at 40°C, which is beneficial in terms of resistance to rutting at high temperatures. The authors did in fact see a reduction of in-laboratory rut depths with the RAP mixes. The RAP did not show much difference from the virgin mix at the lowest test temperature.

MATERIALS AND METHODS

In this study crushed aggregates from one quarry source in Tehran and a 60/70 penetration grade bitumen were used. The RAP was collected from a street in Tehran. In order to determine the bitumen content of the RAP and its gradation, centrifuge extraction method with solvent was applied, using kerosene as the solvent. After the separation processing, keeping the RAP in an oven at 105 °C (to make sure that the solvent is evaporated) the bitumen in the reclaimed asphalt pavement was measured to be 5.3%. Physical properties of the aggregate in the reclaimed asphalt pavement and the virgin aggregate are shown in Tables 1 and 2. The properties of the RAP bitumen after extraction are shown in Table 3.

Table 1 Physical properties of reclaimed aggregates from RAP

Flakiness and Elongation Particles (%)- BS 812		Aggregate Angularity (%) –ASTM D5821	Material
Flakiness Index	Elongation Index		
22.1	14.3	92	Coarse aggregates
-	-	-	Fine aggregates

Table 2 Physical properties of the virgin aggregate

Material	Flakiness and Elongation Particles (%)- BS 812		Aggregate Angularity (%)-ASTM D5821	Abrasion
	Flakiness Index	Elongation Index		
Coarse aggregates	14	8	95	25
Fine aggregates	-		-	-

In order to determine the optimum percentage of bitumen in mixtures and preparing Marshall size samples, Marshall testing method was performed according to ASTM D1559 standard method. The gradation of the RAP material is shown in Figure 1 which is within the specification limits of the Iranian Planning and Management Organization (2012). The control mix was selected from virgin aggregates to have the exact gradation as that on the RAP mix.

Table 3 Bitumen properties after extraction from RAP

Testing	Standard test method	Result
Penetration @ 25°C (0.1 mm)	ASTM D5	24
Ductility @ 25°C (Cm)	ASTM D113	44
Softening Point (°C)	ASTM D2398	61.5
Viscosity @ 135°C , c.Stocks	ASTM D2170	641

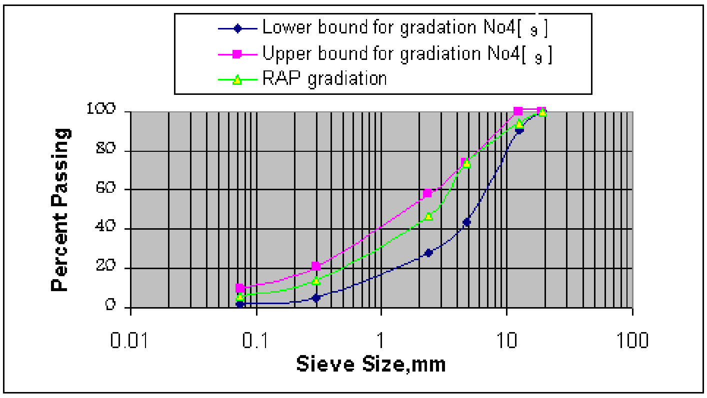

Figure 1 Gradation of the RAP and control mixes

The optimum bitumen contents needed in the different mixtures, as determined by the Marshall method is reported in Table 4. This table confirms that the RAP sample taken from Tehran project in this research lacked 1.7% binder content.

Table 4 Optimum bitumen content in the different mixes

Control Mix (R0)*	R25	R50	R75	R100
6.2 %	6.2 %	6.4 %	6.6 %	7 %

* R represents RAP and the numbers are the percentages of RAP in a mix

It should be mentioned that in preparing mixes containing reclaimed asphalt pavement, controlling the amounts of heat and heating time is of great importance. In this study the temperature and the heating times were kept to two hours and 150°C respectively.

RESULTS AND DISCUSSION

Resilient modulus testing was conducted on all samples to evaluate the temperature susceptibility of the various mixes. Though it was once believed that stiffer pavements have greater resistance to permanent deformation, some researchers noted that there is no solid correlation between resilient modulus and rutting (e.g. Gungor et al, 2012 and

Sebaaly et al, 2012). However, they concluded that resilient modulus at low temperatures is related to some extent to cracking; as stiffer mixes (i.e. with higher M_R values) at low temperatures tend to crack earlier than the more flexible mixes (i.e. with lower M_R values).

In this study resilient modulus testing was performed at 0.33, 0.5 and 1 Hz at three temperatures of 5, 25 and 40^{o}C according to ASTM-D4123 standard testing method. Each sample was tested at both zero and 90-degree orientations. The samples were given a two hour waiting period between zero and 90-degree tests to allow for recovery from the previous test. Prior to testing, samples were placed in a temperature control environmental chamber for a minimum of 24 hours in order to ensure equilibrium at the various testing temperatures. Since the Poisson's ratio determined from horizontal and vertical displacement measurements in resilient modulus testing is often inaccurate, the values of Table 5 were used in the testing calculations.

Table 5 Poisson's ratios adopted at various testing temperatures 11

Testing Temperature (^{o}C)	Poisson's Ratio
5	0.25
25	0.35
40	0.40

Table 6 Resilient Modulus testing results 13

Mixture	Loading Frequency (Hz)	Resilient Modulus (MPa)		
		Test Temperature (^{o}C)		
		5	25	40
R0	0.33	3651	1331	724
	0.5	4418	1651	1040
	1	4923	1708	1056
R25	0.33	3890	1710	970
	0.5	5835	1739	1190
	1	6239	1973	819
R50	0.33	6863	2988	1499
	0.5	7106	2938	1432
	1	7185	3341	1560
R75	0.33	7451	3862	1619
	0.5	8042	3227	1936
	1	8204	3760	1350
R100	0.33	7228	3672	1709
	0.5	7096	3863	1970
	1	6793	3997	2048

Testing results of the different mixes containing 60/70 pen bitumen and various percentages of the reclaimed asphalt pavement is reported in Table 6. The results show that resilient modulus increased with increasing quantities of the reclaimed asphalt materials.

A summary of results of the various combinations of mixes are reported in Figures 2, 3 and 4. These are the results of testing at three temperatures and three loading frequencies.

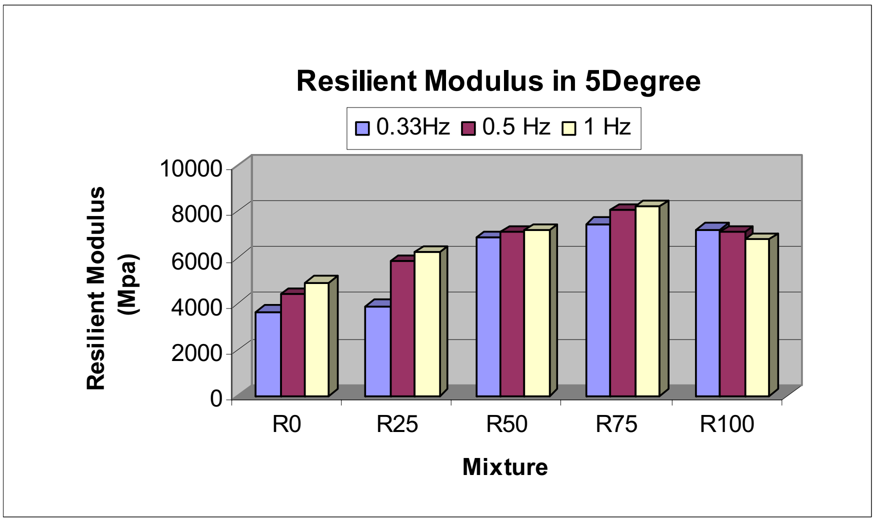

Figure 2 Resilient modulus of mixes containing different amounts of RAP at 5°C

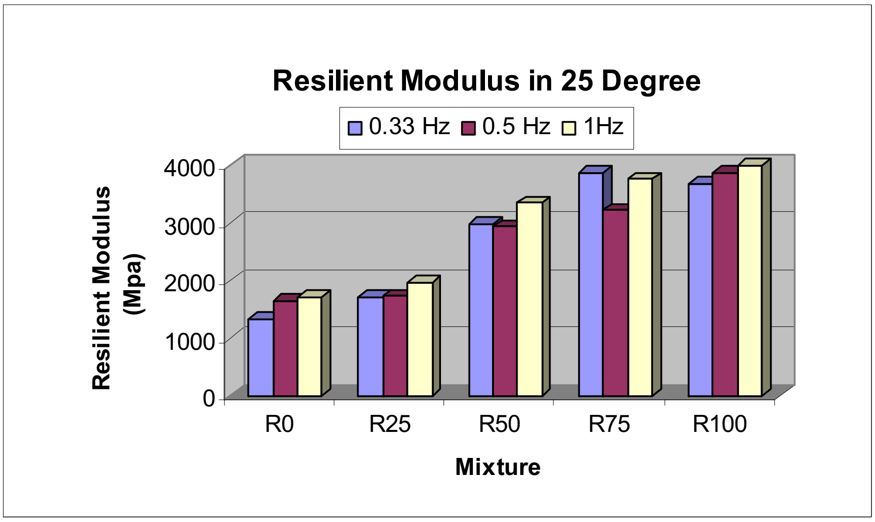

Figure 3 Resilient modulus of mixes containing different amounts of RAP at 25°C

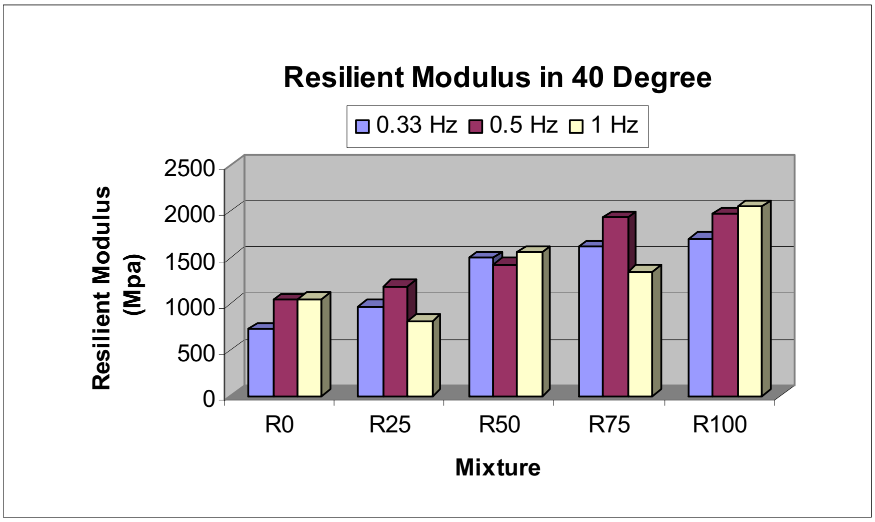

Figure 4 Resilient Modulus of mixes containing various amounts of RAP at 40°C

According to the above results, at each mix combination, a decrease in loading frequency will result in decreased resilient modulus. Also, an increase in testing temperature will result in decreased resilient modulus.

In the Marshall Test two parameters were determined, Marshall Stability and Marshall Flow. Marshall Stability is as an index of compressive strength of asphalt mixture and asphalt mixture cohesion parameter would be measured by Flow. It is also believed that Flow is a criterion for ductility and flexibility of asphalt mixes, showing the rate of internal friction in HMA mixes (Huang, 2004). The results of this test for the two parameters are reported in Figure 5 and Table 7. As it can be seen, increasrd RAP contents resulted in increased Marshall stability, while the flow values did not change appreciably. The other volumetric properties were not reported in this paper, however, the void contents of all the mixes varied between 2 to 4 percent.

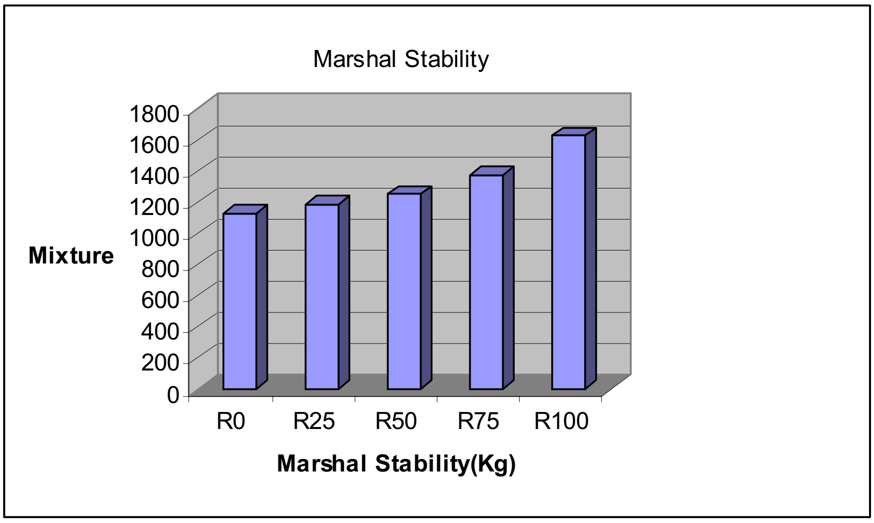

Figure 5 Marshall Stability results for mixes containing different amounts of RAP

Table 7 Marshall stability and Flow values for mixes containing various amounts of RAP

Mixture					
Testing	R0	R25	R50	R75	R100
Marshall Stability (Kg)	1127	1191	1254	1377	1629
Marshall Flow (mm)	3.1	3.0	2.9	2.8	3.0

CONCLUSIONS

The testing program of HMA mixes containing various amounts of RAP materials in a bituminous mix resulted in the following conclusions:

1. Determination of resilient modulus values of RAP mixes is an effective approach in evaluation of recycled mixes.
2. An increase in the amounts of RAP in a mix will result in increased stiffness values of HMA mixes. This, if it is limited, might enable the recycled mixes prone to be used in hot climatic zones, where rutting is the dominant distress mode.
3. Resilient modulus testing of high RAP content mixes resulted in excessive increased stiffness of mixes which makes these prone to cracking at law temperatures.
4. Resilient modulus testing results showed that increased loading frequencies in RAP mixes will result in increased resilient modulus values. With this regard, the follow up of the specification limits is recommended.
5. In the analysis of the Marshall testing results it was observed that increased RAP contents results in increased Marshall Stability, while flow values do not change appreciably.

REFERENCES

APA (2012), Aspahlt Paving Conference, Asphalt Pavement Association of West Virginia, February 16, Virginia, USA.

Daniel, Jo Sias D J and Chehab G R, (2008), “Use of RAP Mixtures in Mechanistic Empirical Pavement Design Guide”, Transportation Research Board, TRB 87th Annual Meeting, Washington DC, USA.

Gungor, A. G., Orhan F. And Kasak S. (2012), “The determination of Performance of Wearing Course Mixtures using Advanced Asphalt Tests”, Paper No. A5EE 452, Euroasphalt and Eurobitumen Conference, Istanbul, Turkey.

Iranian Planning and Management Organization (2012), "Hot and Cold Mix Asphalt Recycling Methods”, Transportation Division, Technical Affairs and Standards Bureau, Tehran, Iran.

Kennedy, T. W. and Perez, I., (1978), “Preliminary Mixture Design Procedure for Recycle Asphalt Materials,” Recycling of Bituminous Materials, ASTM STP 662, L. E. Wood, Ed., American Society for Testing and Materials, pp. 47-67.

Noureldin, A. S. and Wood, L. E., (1990), “Evaluating Recycled Asphalt Binders by the Thin- Film Oven Test”, Transportation Research Record 1269, Transportation Research Board, p 20.

Roberts, R. L., Kandhal, P. S., Brown, E. R., Lee D. Y., and Kennedy, T.W. (1996), “Hot Mix Asphalt Materials, Mixture, Design, and Construction,” NAPA Education Foundation, Lanham, Maryland, Second Edition.

Sebaaly, P., Hajj, E. And Hitti, E. (2012), “Mechanical Properties of Warm Mix Asphalt Mixtures”, Paper No. A5EE 388, Euroasphalt and Eurobitumen Conference, Istanbul, Turkey.

Sondog ,M.S., Chadbourn ,B.A., and Dreseher A., (2002), "Investigation of Recycled Asphalt Pavement (RAP) Mixtures", National Technical Information Services, Springfield, Virginia 22161.

Stroup-Gardiner M. and Wagner, C. (1999), “Use of RAP in Superpave HMA Applications,” Submitted for publication in Transportation Research Record.