Effects of RAP on the Mechanical Properties of Asphalt Mixes and Binder, and on the Predicted Pavement Performance

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1. Introduction

- Use of RAP in Hot Mix Asphalt (HMA) provides many benefits
  - Decrease in cost of construction,
  - Decrease in cost of transportation,
  - Reduce disposal of materials,
  - Preserve aggregate, asphalt binders and energy (contribute to sustainability)
  - Reduce the greenhouse gas emissions.
- For a reliable pavement design using the AASHTOWare Pavement ME Design Program, the inputs for asphalt mixes and binders should reflect the actual properties of the mixes used in construction.
- The default inputs for asphalt mix and binder in the AASHTOWare Pavement ME Design Program do not include the properties of mixes that contain the RAP. The properties of these mixes must be determined through laboratory testing for use in this design program.

2. Project Description and Inputs Data

- The RAP contents in this research vary from 0% (virgin mix) to 50%.
- Mechanical properties such as the dynamic modulus, creep compliance, and indirect tensile test (IDT) have been determined for several lab and field asphalt mixes collected from road PTH 8 (Manitoba).
- Table 1 shows the project traffic and climate for the project section.
- Complex shear modulus and phase angle for virgin and recovered (from the recycled mixes) for these mixes have also been determined.
- All of the four mixes have the same subgrade, subbase, base and asphalt binder course properties and thickness.

Table 1 : Project traffic data and climate

	Annual Average Daily Truck Traffic (AADTT)	Trucks in design direction	Trucks of each direction on design lane	Design life of pavement	Environmental condition and historical climate
Mixture (0-50% RAP)	60	50%	100 %	20	Winnipeg

- The pavement structural thicknesses are shown in Figure 1.

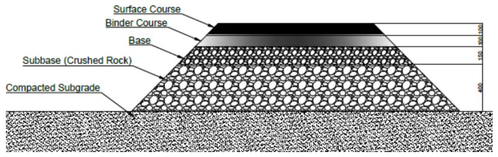


Figure 1: Pavement layer thicknesses.

3. Materials Properties

Materials properties of different layers (subgrade, subbase, base, binder course and surface course) are presented in Tables 3-6.

Table 2: Unbound materials properties

Properties	Subgrade	Subbase	Base
Materials Type	A-7-6	Crushed rock	Crushed lime stone A-base
Thickness (mm)	-	400	150
Resilient Modulus (MPa)*	40	120	140
Moisture Content (%)	29	9.4	10.8
Maximum Dry Density (Kg/m^3)	1413	1973	2169
Plasticity index	42	NP	NP
Liquid Limit	75	NP	NP

* at maximum dry density and optimum moisture

Table 3: Asphalt mixture properties from the mix designs

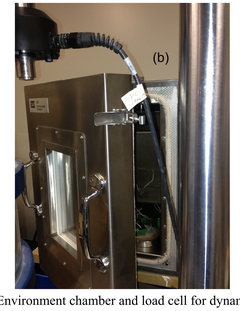
Mix design	Layer thickness (mm)	Asphalt mixture properties			
		Maximum aggregate size (mm)	Air void (%)	VMA (%)	Unit weight (kg/m3)
0 % RAP	100	19	4	13.5	2409
10 % RAP	100	19	4.7	13.6	2415
40 % RAP	100	19	4.5	13.1	2405
50 % RAP	100	19	3.8	12.4	2425
50 % RAP – Binder course	100	19	2.4	12.2	2421

Table 4: Binder properties (extracted asphalt binders)

Mix	Temperature (degree C)	Complex shear modulus (Pa)	Phase angle (degree)
0 % RAP	15	3130000	56.1
	35	119000	70.6
	58	3710	82.5
	64	1720	85
10 % RAP	15	5950000	48.7
	35	246000	65.6
	64	3410	81.8
	70	1570	84.1
40 % RAP	15	622000	49.2
	35	226000	68.7
	52	4590	82.7
	58	1950	85.1
50 % RAP	15	7580000	44.3
	35	331000	63.4
	52	3690	81.2
	58	1640	83.8
50 % RAP – Binder course	15	6640000	46.2
	35	202000	68.2
	58	5030	81.8
	64	2150	84.4

Table 5: Asphalt mix mechanical properties (Inputs Level 1)

Mix Design	Dynamic Modulus (E*), Mpa						IDT Strength at -10 °C (MPa)	Creep Compliance, 1/Gpa			
	Temp., ° C	0.1 Hz	1 Hz	5 Hz	10 Hz	25 Hz		Loading Time	Low Temp. (-20 °C)	Mid Temp. (-10 °C)	High Temp. (0 °C)
0% RAP	-10	17030	23020		28420	30030	1.97	1 Sec.	0.0399	0.0844	0.2906
	5	5220	9410		15090	17630		2 Sec.	0.0418	0.0902	0.3556
	25	800	1740		3900	5340		5 Sec.	0.0462	0.1058	0.4493
	40	370	620		1280	1810		10 Sec.	0.0509	0.1306	0.5803
	54	320	400		700	930		20 Sec.	0.0569	0.1548	0.8072
								50 Sec.	0.0692	0.2255	1.2173
								100 Sec.	0.0847	0.2822	1.7494
10% RAP	-10	19500	24458		28530	29702	2.29	1 Sec.	0.0470	0.0757	0.1427
	5	9325	13045		18345	19972		2 Sec.	0.0488	0.0813	0.2080
	25	1537	3047		6023	7447		5 Sec.	0.0526	0.0953	0.2950
	40	504	885		1910	2584		10 Sec.	0.0566	0.1105	0.3889
	54	345	459		752	1001		20 Sec.	0.0621	0.1335	0.5387
								50 Sec.	0.0715	0.1802	0.8724
								100 Sec.	0.0815	0.2171	1.2247
40% RAP	-10	22565	29126		32859	34172	2.60	1 Sec.	0.0375	0.0562	0.1089
	5	9470	14283		19601	20926		2 Sec.	0.0386	0.0595	0.1261
	25	1654	3409		6750	9064		5 Sec.	0.0412	0.0672	0.1665
	40	471	855		1938	2642		10 Sec.	0.0439	0.0743	0.2141
	54	340	458		767	1033		20 Sec.	0.0469	0.0850	0.2821
								50 Sec.	0.0519	0.1077	0.4318
								100 Sec.	0.0576	0.1380	0.6111
50% RAP	-10	26252	32219		37688	39141	2.45	1 Sec.	0.0418	0.0603	0.1237
	5	9356	14140		19537	21769		2 Sec.	0.0430	0.0637	0.1392
	25	2303	4454		8223	9862		5 Sec.	0.0454	0.0704	0.1702
	40	746	1424		3068	3986		10 Sec.	0.0478	0.0778	0.2096
	54	424	596		1140	1540		20 Sec.	0.0498	0.0878	0.2671
								50 Sec.	0.0539	0.1089	0.3954
								100 Sec.	0.0594	0.1333	0.5555
50% RAP Binder course	-10						2.43	1 Sec.	0.0416	0.0595	0.1122
	5	9356	14140	18041	19537	21769		2 Sec.	0.0430	0.0630	0.1281
	25	2303	4454	7019	8223	9862		5 Sec.	0.0454	0.0702	0.1619
	40	746	1424	2424	3068	3986		10 Sec.	0.0477	0.0781	0.2004
	54	424	596	949	1140	1540		20 Sec.	0.0504	0.0885	0.2618
								50 Sec.	0.0540	0.1086	0.3873
								100 Sec.	0.0578	0.1320	0.5264



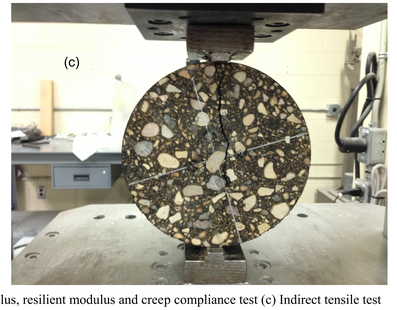


Figure 2 : (a) Dynamic shear rehometer (b) Environment chamber and load cell for dynamic modulus, resilient modulus and creep compliance test (c) Indirect tensile test

4. Results

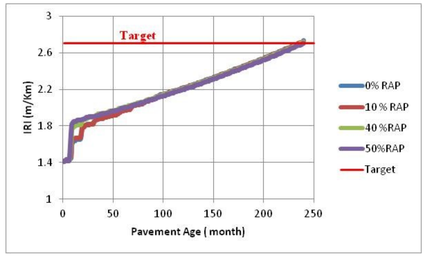


Figure 3: Predicted roughness for asphalt mixes

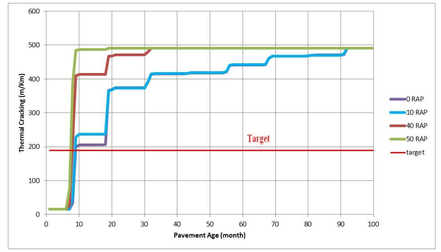


Figure 4: Predicted thermal cracking for asphalt mixes

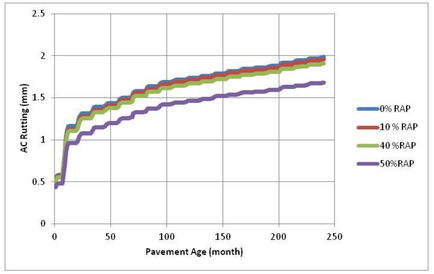


Figure 5: Predicted total asphalt rutting for asphalt mixes (Target was 6 mm)

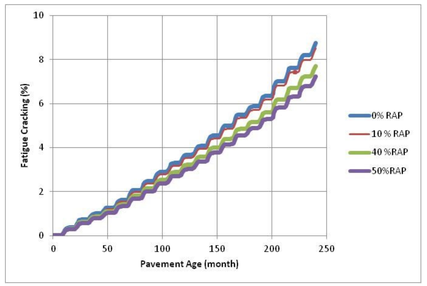


Figure 6 : Predicted bottom up cracking for asphalt mixes (Target was 25%)

Table 6: Pavement ME output for different RAP percentages

Distresses		Level 1 Input data			
		0% RAP	10% RAP	40% RAP	50% RAP
Terminal IRI	Target (m/Km)	2.7	2.7	2.7	2.7
	Predicted (m/Km)	2.73	2.72	2.72	2.7
	Reliability predicted (%)	89.16	89.31	89.49	89.9
	Acceptance	Fail	Fail	Fail	pass
	Predicted life at 90% reliability (yrs)	19.5	19.5	19.75	20
AC Surface Down Cracking	Target (m/Km)	378.8	378.8	378.8	378.8
	Predicted (%)	49.08	49.05	49.06	49.20
	Reliability predicted (%)	100	100	100	100
	Acceptance	Pass	Pass	Pass	Pass
	Predicted life at 90% reliability (yrs)	>20	>20	>20	>20
AC Bottom Up Cracking	Target (%)	25	25	25	25
	Predicted (%)	9	8.5	7.7	7.2
	Reliability predicted (%)	100	100	100	100
	Acceptance	pass	Pass	pass	pass
	Predicted life at 90% reliability (yrs)	>20	>20	>20	>20
AC Thermal Fracture	Target (m/Km)	189.4	189.4	189.4	189.4
	Predicted (m/Km)	491.04	491.04	491.04	491.04
	Reliability predicted (%)	0.15	0.15	0.15	0.15
	Acceptance	Fail	Fail	Fail	Fail
	Predicted life at 90% reliability (yrs)	< 1	< 1	< 1	< 1
Permanent Deformation (AC Rutting only)	Target (mm)	6	6	6	6
	Predicted (mm)	1.99	1.96	1.91	1.68
	Reliability predicted (%)	100	100	100	100
	Acceptance	Pass	Pass	Pass	Pass
	Predicted life at 90% reliability (yrs)	-	-	-	-
Permanent Deformation (Total Pavement Rutting)	Target (mm)	19	19	19	19
	Predicted (mm)	9.59	9.43	9.23	8.81
	Reliability predicted (%)	100	100	100	100
	Acceptance	Pass	Pass	Pass	Pass
	Predicted life at 90% reliability (yrs)	>20	>20	>20	>20

5. Conclusions

- All the mixes passed the asphalt concrete top-down cracking (Longitudinal cracking) and bottom-up cracking (Alligator cracking) criteria with 100% reliability. The bottom-up fatigue cracking decreases with increase in RAP contents.
- The predicted rutting in AC and total pavement layers met the criterion for all the mixes. However, the predicted AC rutting and total rutting decrease by increasing the amount of RAP in mix.
- Changes in IRI due to variable in RAP contents is insignificant. This is expected because negative influence on thermal cracking is compensated by positive influence in rutting and fatigue cracking.
- The predicted thermal cracking exceeded the target in the first year after pavement construction. This indicates that the virgin asphalt used for the mix design was too stiff for this climate.
- Thermal cracking increased dramatically for high RAP mixes compared to mixes containing 0% and 10% RAP.