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Concrete Containing RAP for Use in Concrete Pavement

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Abstract: The feasibility of using concrete containing recycled asphalt pavement (RAP) in concrete pavement applications was evaluated. Concrete containing 0, 10, 20, and 40% of RAP were produced in the laboratory and evaluated for their properties that are relevant to performance of concrete pavements. Results of the laboratory testing program indicate that compressive strength, splitting tensile strength, flexural strength, and elastic modulus of the concrete decreased as the percentage of RAP increased. The coefficient of thermal expansion and drying shrinkage did not appear to be significantly affected by RAP content. When a finite element analysis was performed to determine the maximum stresses in typical concrete pavements in Florida under critical temperature and load conditions, the maximum stresses in the pavement were found to decrease as the RAP content of the concrete increased, due to a decrease in the elastic modulus of the concrete. Though the flexural strength of the concrete decreased as RAP was incorporated in the concrete, the resulting maximum stress to flexural strength ratio for the concrete was reduced as compared with that of a reference concrete with no RAP. This indicates that using a concrete containing RAP could possibly result in improvement in the performance of concrete pavements.

Key words: *Concrete; FEACONS; Pavement; RAP; Stress-strength ratio; Temperature differential.*

Introduction

The modulus of elasticity of concrete is known to have a major effect on the performance of concrete pavements. Modulus of elasticity of concrete is an important input parameter to the American Association of State Highway Transportation Officials (AASHTO) Mechanistic Empirical Pavement Design Guide. Concrete pavements using concrete with a lower modulus of elasticity would have a lower stress due to the same applied load and thus could have a lower chance of cracking. In an investigation of the performance of Interstate 75 (I-75) concrete pavements in Sarasota and Manatee counties [1], it was reported that the percentage of cracked slabs increased with an increase in modulus of elasticity of the concrete. In another research study on pavement concrete, it was reported that the optimal concrete mixture for concrete pavement was not necessarily a concrete with a high flexural strength, but a concrete with a proper combination of low modulus of elasticity, low coefficient of thermal expansion, and adequate flexural strength [2].

Every year in the United States, more than 100 million tons of reclaimed asphalt pavement (RAP) is generated by asphalt pavement (AC) rehabilitation and reconstruction [3]. Some have been recycled into new asphalt mixtures; some have been used as pavement base materials. However, a large quantity of RAP still remains unutilized and needs to be put to good use. An alternative use of RAP is to use it as an aggregate in Portland cement concrete (PCC). RAP has been used as an aggregate in PCC to improve the toughness and ductility of the PCC. According to studies by Huang et al. [4, 5], RAP aggregate coated with asphalt forms a film with thickness about 6 to 9 μm. This asphalt film acts as asphalt interface layer between aggregate and cement mortar, which can blunt or even arrest the micro-cracking and delay the widening and propagating of the micro-cracking. Delwar et al. [6] examined the stress-strain behavior of PCC containing RAP and found that PCC containing a higher amount of RAP fails at a higher strain level indicating that RAP may contribute to the ductility of PCC.

This study evaluated the feasibility of using concrete containing RAP in concrete pavement applications. Concrete containing different percentages of RAP were produced in the laboratory. Properties of the concrete that are relevant to performance of concrete pavements were evaluated. Analysis was then performed to determine how the concrete containing different amounts of RAP would perform if it were used in a typical concrete pavement in Florida.

Laboratory Testing Program

RAP and Virgin Aggregates Used

Two different RAP materials were used in this study. They were obtained from RAP stockpiles at an asphalt plant in Gainesville, Florida. The RAP was separated into a coarse portion and a fine portion using a #4 sieve. A Miami Oolite (porous limestone) coarse aggregate and silica sand from Goldhead were used as the virgin aggregates in this study.

Tests were run on the RAP and the virgin aggregates to determine their specific gravity, water absorption, and gradation. The tests performed on them are shown in Table 1. The results of sieve analysis on the virgin aggregates are shown in Table 2. The results of sieve analysis on the coarse and fine portions of the RAP-1 and RAP-2 are shown in Table 3 and Table 4. The gradation of the recovered aggregate from the RAP-1, RAP-2, and the asphalt content of the RAP-1 is also shown in Table 3 and Table 4. The specific

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Table 1. Tests on Virgin Aggregates and RAP.

Physical Property	Coarse Aggregate	Fine Aggregate
Gradation	ASTM C136	ASTM C136
Moisture Content	ASTM C566	ASTM C566
SSD Specific Gravity	ASTM C127	ASTM C128
Absorption	ASTM C127	ASTM C128

Table 2. Results of Sieve Analysis on the Virgin Aggregates.

Sieve Size	Sieve Size (*mm*)	% Passing	
		CA	FA
1½”	37.5	100	/
1”	25	100	/
1/2”	12.5	50	/
#4	4.75	8	100
#8	2.36	5	97
#16	1.18	/	85
#30	0.6	/	57
#50	0.3	/	18
#100	0.15	/	1
#200	0.075	/	/
Fineness Modulus		/	2.41

gravity and water absorption of the virgin aggregates and RAP are shown in Table 5.

Concrete Mixtures Evaluated

Table 6 shows the mix proportions of the concrete mixes containing RAP-1, and Table 7 shows the mix proportions of the concrete containing RAP-2, which were evaluated in this study. The tests run on the fresh concretes are shown in Table 8.

The results of the fresh concrete tests are shown in Tables 9 and 10. It can be seen that both air content and unit weight of concrete mixes with RAP did not change much as compared with the control mix (Mix 1). However, the slump increased slightly with increasing RAP content.

Characterization of the Hardened Concrete Containing RAP

The tests to be run on the hardened concrete are shown in Table 11.

Table 3. Results of Sieve Analysis on RAP-1.

Sieve Size	Sieve Size (*mm*)	% Passing		
		Coarse RAP	Fine RAP	Recovered Aggregate
2”	50.0	100.0	/	/
1½”	37.5	98.3	/	/
1”	25.0	97.1	/	/
3/4”	19.0	87.5	/	/
1/2”	12.5	67.4	/	100
3/8”	9.5	51.0	/	98
#4	4.75	0.0	100.0	76
#8	2.36	/	81.0	60
#16	1.18	/	60.7	51
#30	0.60	/	37.5	40
#50	0.30	/	12.1	24
#100	0.15	/	2.0	9
#200	0.075	/	0	5.2
Fineness Modulus		/	3.07	/
Asphalt Content		/	/	6.3%

Table 4. Results of Sieve Analysis on RAP-2.

Sieve Size	Sieve Size (*mm*)	Percent Passing Coarse RAP	Percent Passing Fine RAP	Recovered Aggregate
2"	50.0	100	/	/
3/2"	37.5	100	/	/
1"	25.0	100	/	/
3/4"	19.0	96	/	100
1/2"	12.5	80	/	92.74
3/8"	9.5	60	/	79.58
#4	4.75	14	100	43.79
#8	2.36	8	81	34.31
#16	1.18	/	61	29.51
#30	0.6	/	40	25.24
#50	0.3	/	20	19.42
#100	0.15	/	5	11.33
#200	0.075	/	1	6.53

Tables 12 and 13 present the average compressive strength, elastic modulus, splitting tensile strength, and flexural strength of the concrete incorporating RAP-1 and RAP-2, respectively. It can be seen that the compressive strength, elastic modulus, splitting tensile

Table 5. Specific Gravity and Water Absorption of Virgin Aggregates and RAP.

	Coarse Aggregate	Fine Aggregate	Coarse RAP-1	Fine RAP-1	Coarse RAP-2	Fine RAP-2
SSD S.G.	2.374	2.641	2.231	2.185	2.309	2.325
Dry Bulk S.G.	2.276	2.633	2.186	2.125	2.259	2.283
Apparent S.G.	2.523	2.654	2.290	2.261	2.377	2.383
Absorption	4.31%	0.30%	2.08%	2.84%	2.20%	1.77%

Table 6. Mix Proportions of Concrete Containing RAP-1.

Mix No.	W/C	Cement (*kg/m³*)	Water (*kg/m³*)	Virgin Fine Aggregate (*kg/m³*)	Virgin Coarse Aggregate (*kg/m³*)	Coarse RAP (*kg/m³*)	Fine RAP (*kg/m³*)	% RAP
Mix-1	0.53	301	160	735	1057	/	/	0
Mix-2	0.53	301	160	662	952	99	61	10
Mix-3	0.53	301	160	588	846	199	122	20
Mix-4	0.53	301	160	441	634	397	243	40

Table 7. Mix Proportions of Concrete Containing RAP-2.

Mix No.	W/C	Cement (*kg/m³*)	Water (*kg/m³*)	Virgin Fine Aggregate (*kg/m³*)	Virgin Coarse Aggregate (*kg/m³*)	Coarse RAP (*kg/m³*)	Fine RAP (*kg/m³*)	% RAP
Mix-1	0.43	373	160	704	1030	/	/	0
Mix-2	0.43	373	160	462	916	130	196	20
Mix-3	0.43	373	160	228	802	260	394	40
Mix-4	0.43	373	160	228	802	260	394	40
Mix-1	0.48	333	160	720	1044	/	/	0
Mix-2	0.48	333	160	494	927	131	200	20
Mix-3	0.48	333	160	268	774	264	399	40
Mix-1	0.53	301	160	735	1057	/	/	0
Mix-2	0.53	301	160	504	926	134	203	20
Mix-3	0.53	301	160	459	623	268	405	40

Table 8. Tests on Fresh Concrete Containing RAP.

Test	Slump	Air Content	Unit Weight	Temperature
Test Standard	ASTM C143	ASTM C173	ASTM C138	ASTM C1064

Table 9. Results of Tests on Fresh Concrete with RAP-1.

Mix No.	Slump (*mm*)	Air Content (%)	Unit Weight (*kg/m³*)	Temperature (ºC)
Mix-1	108	1.20	2275	23
Mix-2	134	2.20	2291	23
Mix-3	158	1.00	2291	23
Mix-4	178	1.50	2227	23

Table 10. Results of Tests on Fresh Concrete with RAP-2.

Mix No.	Slump (*mm*)	Air Content (%)	Unit Weight (*kg/m³*)	Temperature (ºC)
Mix-5	51	2.40	2259	24
Mix-6	153	5.00	2179	21
Mix-7	229	6.00	2130	19
Mix-8	127	3.00	2179	23
Mix-9	57	3.00	2243	26
Mix-10	76	2.90	2211	23
Mix-11	184	3.40	2179	25
Mix-12	89	2.50	2243	20
Mix-13	83	3.00	2195	22
Mix-14	89	3.20	2162	23

strength, and flexural strength of the concrete decrease as the %RAP increases. It can also be seen that the percentage of reduction in flexural strength of the concrete containing RAP was lower than the corresponding percentage of reduction in compressive strength and splitting tensile strength of the concrete mix containing RAP.

For the concrete containing RAP, the elastic modulus and strengths can be seen to decrease significantly with increasing *w/c*. However, for the concrete containing RAP, the effects of *w/c* on elastic modulus and strengths appeared to be less pronounced.

The results of the shrinkage tests for concrete incorporating RAP-1 and RAP-2 are displayed in Tables 14 and 15, respectively. There is no clear trend on the effects of RAP content on the shrinkage strain of the concrete.

The measured coefficients of the thermal expansion of the concrete incorporating RAP-1 and RAP-2 are shown in Tables 16 and 17, respectively. It can be seen from Table 16 that the coefficient of thermal expansion appeared to increase slightly with increasing RAP content. However, there is no clear trend observed from Table 17 on the effects of RAP content on the coefficient of thermal expansion.

Fig. 1 shows the failure of the concrete beam containing RAP in the flexural strength test. Fig. 2 shows the typical fracture surface of a concrete sample containing RAP. From these Figures, it can be

Table 11. Tests on Hardened Concrete Containing RAP.

Test	Test Standard	Specimen Size	Curing Period
Compressive Strength	ASTM C39	102×203*mm* Cylinder	14, 28,and 90d
Modulus of Elasticity	ASTM C469	102 × 203*mm* Cylinder	14, 28,and 90d
Splitting Tensile	ASTM C496	153 × 305*mm* Cylinder	14,and 28d
Flexural Strength	ASTM C78	153×153×508*mm* Beam	14, 28,and 90d
Shrinkage	ASTM C157	76×76×286*mm* Prism	14, 28,and 90d
Coefficient of Thermal Expansion	AASHTO TP60	102×203*mm* Cylinder	14, 28,and 90d

Table 12. Elastic Modulus, Compressive strength, Flexural Strength, and Splitting Tensile Strength of Concrete Containing RAP-1.

% RAP	Modulus of Elasticity (*GPa*)	Compressive Strength (*MPa*)	Flexural Strength (*MPa*)	Splitting Tensile Strength (*MPa*)
14 Days				
0	30.61	37.54	6.08	3.61
10	26.33	30.91	5.56	2.61
20	23.09	21.98	5.71	2.15
40	15.92	16.85	4.93	1.80
28 Days				
0	32.95	38.58	6.48	3.73
10	27.57	34.03	6.48	3.11
20	23.44	26.05	5.17	2.52
40	16.20	17.38	3.93	2.34
90 Days				
0	32.54	41.59	6.73	/
10	28.47	34.30	5.83	/
20	24.61	27.28	5.21	/
40	17.23	18.32	4.67	/

Table 13. Elastic Modulus, Compressive Strength, Flexural Strength, and Splitting Tensile Strength of Concrete Containing RAP-2.

W/C Ratio	% RAP	Modulus of Elasticity (*GPa*)	Compressive Strength (*MPa*)	Flexural Strength (*MPa*)	Splitting Tensile Strength (*MPa*)
14 Days					
0.43	0	28.61	43.39	5.26	3.60
0.43	20	19.30	24.29	4.22	2.27
0.43	40	12.20	16.96	3.17	1.78
0.43	40	16.13	16.54	3.86	/
0.48	0	27.09	37.33	4.98	3.35
0.48	20	20.40	25.25	4.08	2.69
0.48	40	14.82	18.20	3.49	1.90
0.53	0	23.85	27.67	4.65	2.63
0.53	20	19.65	22.16	3.97	2.26
0.53	40	12.82	15.04	3.21	1.93
28 Days					
0.43	0	28.19	45.56	6.28	3.75
0.43	20	19.99	26.25	4.86	2.79
0.43	40	12.75	16.48	3.62	1.93
0.43	40	14.34	20.34	3.99	/
0.48	0	28.06	41.77	5.54	3.65
0.48	20	20.61	27.59	4.37	2.79
0.48	40	14.27	18.96	3.99	1.92
0.53	0	25.71	32.33	5.09	2.84
0.53	20	20.47	24.88	4.08	2.33
0.53	40	13.51	16.55	3.33	1.84

Table 14. Free Shrinkage of Concrete Mixtures Containing RAP-1.

Curing Time (days)	Free Shrinkage (10^{-6}) Mix-1 0% RAP	Mix-2 10% RAP	Mix-3 20% RAP	Mix-4 40% RAP
14	130	115	135	138
28	279	201	219	257
90	353	353	334	422

Table 15. Free Shrinkage of Concrete Mixtures Containing RAP-2.

		Free Shrinkage (10^{-6}) 14 Days	28 Days
Mix-5	0% RAP	190	300
Mix-6	10% RAP	167	275
Mix-7	20% RAP	150	273
Mix-8	40% RAP	/	/
Mix-9	0% RAP	130	280
Mix-10	20% RAP	250	340
Mix-11	40% RAP	230	350
Mix-12	0% RAP	130	250
Mix-13	20% RAP	120	233
Mix-14	40% RAP	106	227

Table 16. Coefficient of Thermal Expansion of Concrete Mixtures Containing RAP-1.

Curing Time (days)	Coefficient of Thermal Expansion (10^{-6}/ºC) Mix-1	Mix-2	Mix-3	Mix-4
14	10.01	10.67	9.85	10.40
28	9.75	9.99	10.29	10.60
90	10.78	10.71	10.78	11.05

Table 17. Coefficient of Thermal Expansion of Concrete Mixtures Containing RAP-2.

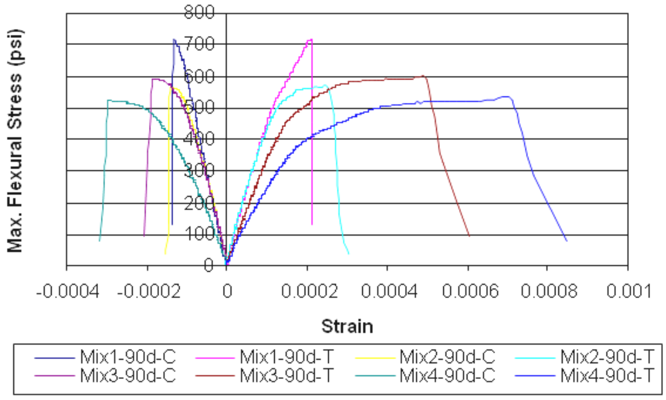
W/C Ratio	% RAP	Coefficient of Thermal Expansion (10^{-6}/ºC) 14 Days	28 Days
0.43	0	9.50	9.77
0.43	20	10.85	11.41
0.43	40	10.69	11.10
0.48	0	8.82	9.45
0.48	20	9.00	9.20
0.48	40	9.45	9.14

seen that the cement paste is well-bonded to the RAP particles in the concrete samples.

Fig. 3 shows the stress-strain plots from beam tests on concrete mixtures containing RAP-1 with a *w/c* ratio of 0.53. It can be observed from the plot that the failure strain generally increases as the percentage of RAP used in the concrete mix increases. Fig. 4 presents the results of the elastic modulus test. It shows that there was a reduction of the elastic modulus of concrete containing RAP. For the concrete containing RAP-1 with a 0.53*w/c* ratio, the elastic modulus at 14 days for Mixes 2, 3, and 4 was 88, 75, and 54%, respectively, of that of the reference mix. For concrete containing RAP-1 with a 0.53*w/c* ratio at 28 days, the elastic modulus of Mixes 2, 3, and 4 was 86, 73, and 49%, respectively, of that of the reference mix. For concrete containing RAP-1 with a 0.53*w/c* ratio at 90 days, the elastic modulus of Mixes 2, 3, and 4 was 79, 70, and 55%, respectively, of that of the reference mix. Therefore, consistent reduction in the elastic modulus for mixtures containing RAP at different curing periods was observed. Fig. 5 shows the

Fig. 1. Failure of Concrete Beam Containing RAP.

Fig. 2. Typical Fracture Surfaces of Concrete Sample Containing RAP.



Note: C – Compression T- Tension 1*psi* = 6894.76*Pa*

Fig. 3. Stress-Strain Plots for Concrete Containing RAP at 90 days.

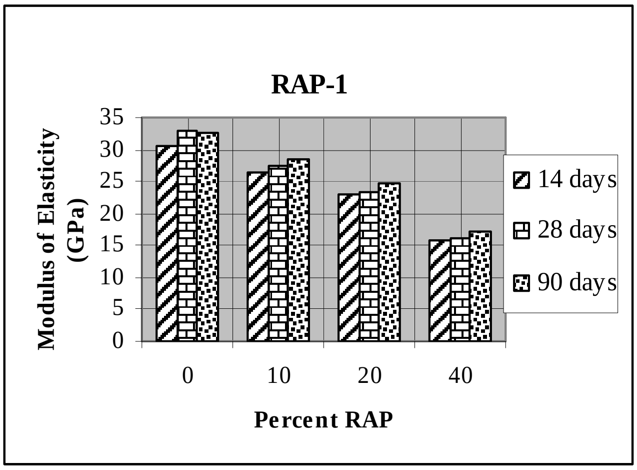


Fig. 4. Effect of RAP on Modulus of Elasticity of Concrete.

comparison in the reduction in splitting tensile strength with the corresponding reduction in compressive strength and flexural strength for the concretes using RAP. The average reduction in compressive strength was 18, 38, and 58% for Mixes 2, 3, and 4, respectively. The average reduction in flexural strength was 10, 20, and 30% for Mixes 2, 3, and 4, respectively. The average reduction in splitting tensile strength was 25, 30, and 60% for Mixes 2, 3, and 4, respectively. Reduction in splitting tensile strength was higher than that in flexural strength for this set of mixtures containing RAP.

Evaluation of Potential Performance of Concrete Containing Rap in Pavement

Analysis was done to determine how each of the concrete mixes with different RAP contents would perform if it were used in a typical concrete pavement in Florida. Using the measured elastic modulus and the coefficient of thermal expansion to model the concrete, analysis was performed to determine the maximum stresses in the concrete slab if it were loaded by a 98*kN* axle load applied at two critical loading positions, namely (1) at the slab corner and (2) at the middle of the slab edge. Temperature differentials of +11 and −11°C in the concrete slab were used in the analyses.

The Finite Element Analysis of Concrete Slabs, version IV (FEACONS IV) program was used to perform the stress analysis. The FEACONS program was previously developed at the University

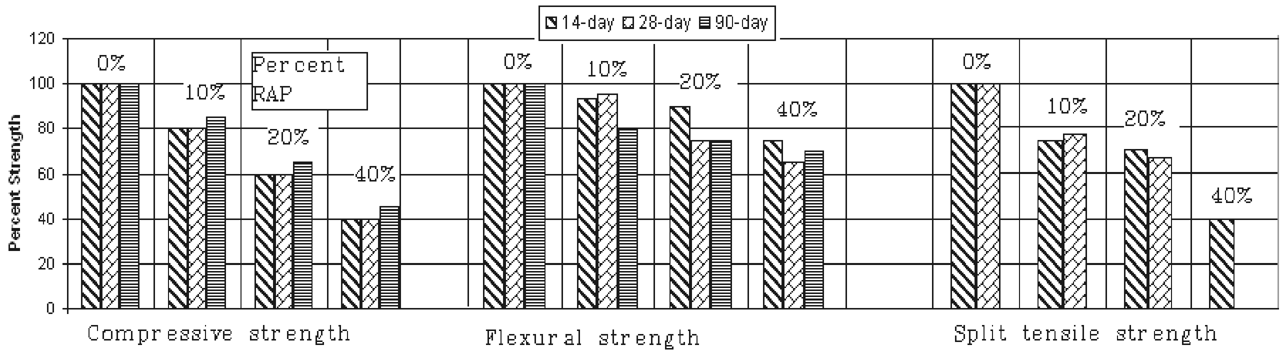


Fig. 5. Reduction in Compressive, Flexural and Splitting Tensile Strength for the Concrete Containing RAP.

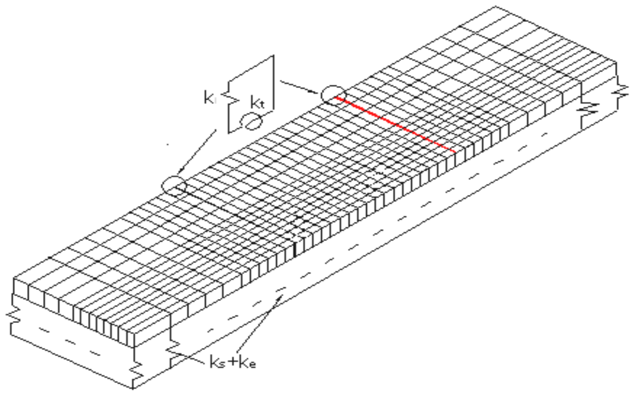


Fig. 6. Finite Element Model Used in FEACONS IV Analysis.

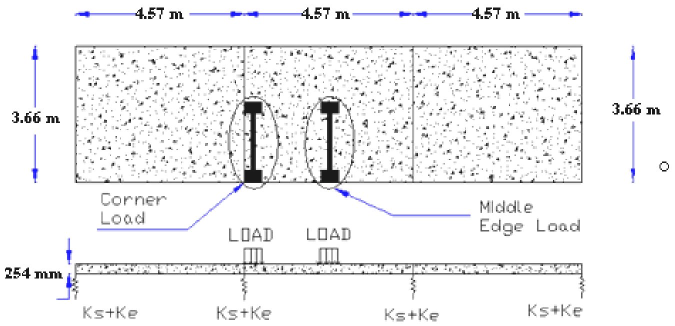


Fig. 7. The *98kN* Axle Wheel Load at Slab Corner and Middle Edge.

of Florida for Florida Department of Transportation (FDOT) for the analysis of PCC pavements subjected to load and thermal effects and has demonstrated to be a fairly effective and reliable tool for this type of analysis.

Fig. 6 shows the finite element model used to perform the stress analysis.

The following parameters were used to model the concrete pavement:

1) Slab thickness = *254mm.*; slab length = 4.57*m.*; slab width = 3.66*m*;
2) Subgrade modulus, k_s = *82MN/m³*; edge stiffness, k_e = *207MN/m²*; and
3) Joint linear stiffness, k_l = *3447MN/m²*; joint torsion stiffness k_t = 4.4 MN- *m/m.*

The two loading positions of the 98*kN* single-axle load used in the analysis are shown in Fig. 7. The middle of the slab edge is the most critical loading position during the day when the temperature differential in the slab is positive, while the slab corner is the most critical loading position at night when the temperature differential is negative.

Tables 18 and 19 show the computed maximum stresses and maximum stress to flexural strength ratios, using properties of concrete containing different RAP-1 contents for the conditions when a 98*kN* axle load is applied at the slab corner and mid edge, respectively. It can be seen from the computed values in Tables 18 and 19 that the most critical condition occurs when there is a positive temperature differential in the concrete slab and the load is applied at the mid edge of the slab. Thus, this critical temperature-load condition is used to evaluate the effects of RAP on the potential performance of concrete pavement. At this critical condition, it can be seen (from Table 19) that the maximum stress to strength ratio generally decreases as the RAP-1 content increases. Tables 20 and 21 show the computed maximum stresses and stress to strength ratios for this same critical loading condition using properties of concrete with different RAP-2 contents at curing times of 14 and 28 days, respectively. It can be seen that the maximum stress to strength ratio generally decreases as the RAP-2 content increases, with the exception for the case of *w/c* of 0.48 and a curing time of 28 days.

This stress-strength ratio is related to the number of stress cycles to fatigue failure. A lower stress-strength ratio means a higher number of stress cycles to failure as well as a better performing concrete. It can be seen that stress-strength ratio decreases as the

Table 18. Computed Maximum Stresses and Stress-strength Ratios in a Typical Concrete Pavement Subjected to a 98*kN* Axle Load at Slab Corner Using Properties of Concrete with Different RAP-1 Contents.

% RAP	Elastic Modulus (*GPa*)	Stress (*MPa*) (+11ºC Temp Differential)	Stress (*MPa*) (–11ºC Temp Differential)	Flexural Strength (*MPa*)	Stress Ratio (+11ºC Temp Differential)	Stress Ratio (–11ºC Temp Differential)
14-day Curing						
0	30.61	2.66	2.13	6.08	0.44	0.35
10	26.33	2.55	1.83	5.56	0.46	0.33
20	23.09	2.44	1.71	5.71	0.43	0.30
40	15.92	2.04	1.25	4.92	0.41	0.25
28-day Curing						
0	32.95	2.74	2.26	6.48	0.42	0.35
10	27.57	2.57	1.97	6.48	0.39	0.30
20	23.44	2.45	1.73	5.17	0.47	0.33
40	16.20	2.05	1.27	3.93	0.52	0.32
90-day Curing						
0	32.54	2.73	2.23	6.72	0.41	0.33
10	28.47	2.59	2.02	5.82	0.44	0.35
20	24.61	2.49	1.80	5.21	0.48	0.35
40	17.23	2.11	1.34	4.66	0.45	0.29

Table 19. Computed Maximum Stresses and Stress-strength Ratios in a Typical Concrete Pavement Subjected to a 98*kN* Axle Load at Mid Edge Using Properties of Concrete with Different RAP-1 Contents.

% RAP	Elastic Modulus (*GPa*)	Stress (*MPa*) (+11ºC Temp Differential)	Stress (*MPa*) (–11ºC Temp Differential)	Flexural Strength (*MPa*)	Stress Ratio (+11ºC Temp Differential)	Stress Ratio (–11ºC Temp Differential)
14-day Curing						
0	30.61	3.10	2.01	6.08	0.51	0.33
10	26.33	2.81	1.79	5.56	0.50	0.32
20	23.09	2.59	1.61	5.71	0.45	0.28
40	15.92	2.04	1.19	4.92	0.41	0.24
28-day Curing						
0	32.95	3.24	2.12	6.48	0.50	0.33
10	27.57	2.90	1.85	6.48	0.45	0.28
20	23.44	2.62	1.63	5.17	0.51	0.32
40	16.20	2.06	1.21	4.32	0.48	0.28
90-day Curing						
0	32.54	3.21	2.10	6.72	0.48	0.31
10	28.47	2.95	1.90	5.82	0.51	0.33
20	24.61	2.70	1.69	5.21	0.52	0.32
40	17.23	2.14	1.26	4.66	0.46	0.27

Table 20. Computed Maximum Stresses and Stress-strength Ratios in a Typical Concrete Pavement Subjected to a 98*kN* Axle Load at Middle Edge Using Properties of Concrete with Different RAP-2 Contents at 14 Days Cure.

Water Cement Ratio	% RAP	Elastic Modulus(*GPa*)	Stress (*MPa*) (+11ºC Temp Differential)	Flexural Strength(*MPa*)	Stress Ratio (+11ºC Temp Differential)
14-day Curing					
0.43	0	28.64	2.72	5.25	0.52
0.43	20	19.23	2.13	4.21	0.50
0.43	40	12.20	1.60	3.17	0.50
0.43	40	16.13	1.90	3.86	0.49
0.48	0	27.09	2.63	4.98	0.53
0.48	20	20.39	2.20	4.08	0.54
0.48	40	14.63	1.79	3.48	0.51
0.53	0	23.85	2.43	4.64	0.52
0.53	20	19.65	2.15	3.97	0.54
0.53	40	12.82	1.66	3.20	0.52

Table 21. Computed Maximum Stresses and Stress-strength Ratios in a Typical Concrete Pavement Subjected to a 98*kN* Axle Load at Middle Edge Using Properties of Concrete with Different RAP-2 Contents at 28 Days Cure.

Water Cement Ratio	% RAP	Elastic Modulus(*GPa*)	Stress (*MPa*) (+11ºC Temp Differential)	Flexural Strength(*MPa*)	Stress Ratio (+11ºC Temp Differential)
28-day Curing					
0.43	0	28.19	2.70	6.29	0.43
0.43	20	19.78	2.16	4.86	0.44
0.43	40	12.75	1.65	3.60	0.46
0.43	40	14.35	1.77	3.99	0.44
0.48	0	25.71	2.55	5.09	0.50
0.48	20	20.47	2.21	4.07	0.54
0.48	40	13.50	1.71	3.33	0.51
0.53	0	28.06	2.69	5.53	0.49
0.53	20	20.60	2.21	4.36	0.51
0.53	40	14.16	1.75	3.99	0.44

percentage of RAP increases. This means that the potential performance of concrete improves as the percentage of RAP in the concrete increases.

Conclusion

Results of the laboratory testing program indicate that compressive strength, splitting tensile strength, flexural strength, and elastic modulus of the concrete decreases as the percentage of RAP increases. The coefficient of thermal expansion and drying shrinkage do not appear to be significantly affected by RAP content. When a finite element analysis was performed to determine the maximum stresses in typical concrete pavements in Florida under critical temperature and load conditions, the resulting maximum stress to flexural strength ratio for the concrete was generally reduced as compared with that of a reference concrete with no RAP. This indicates that using a concrete containing RAP could possibly result in improvement in the performance of concrete pavements.

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