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Recycling of Reclaimed Asphalt Pavement in Portland Cement Concrete

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إعادة تدوير الرصف الاسفلتي المسترجع في الخرسانة الاسمنتية

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الخلاصة: ينتج الرصف الإسفلتي المسترجع من عملية إزالة طبقات الأسفلت من الطرق. وتتم عملية الإزالة لأغراض إعادة الإنشاء أو لإعادة تغطية السطح أو للوصول للمرافق الخدمية المدفونة تحت الطرق. وغالبا ما يحتوي الرصف الإسفلتي المسترجع على ركام عالى الجودة مغطى بالأسفلت، ويمثل التخلص من هذه المواد هدرا لمصدر من مصادر الركام العالي الجودة, يتناول هذا البحث دراسة خصائص الخرسانة المصنوعة من ركام الرصف الإسفلتي المسترجع، وذلك بتصميم مجموعتين من الخلطات الخرسانية تكون نسبة الماء الى االاسمنت في الاولى منها ٤٥٪ وفي المجموعة الثانية ٥٠٪، كما ان نسبة ركام الرصف الاسفلتي المسترجع الىالركام العادي في كل منها كانت صفر في المائة ، و ٢٥٪ و ٥٠٪ و ٧٥٪ و ١٠٠٪ . وبإختبار الخلطات ، وجد أن الخلطات التي لا تحتوي على ركام الرصف الاسفلتي المسترجع (صفر في المائة) قد بلغ إجهاد الانظغاط بها بعد ٢٨ يوما ٥٠ ميجا باكسل للاولى و٣٣ ميجا باسكال للثانية . وقد اجريت عدة اختبارات على الخلطات العشر تضمنت اختبار الهبوط ، واجهاد الانظغاط ، واجهاد الانحناء ، ومعامل المرونة، كما تم تقييم ديمومة هذه الخلطات بوتسطة الامتصاص السطحي.

االمفردات المفتاحية: الرصف ألاسفلتي المسترجع، الخرسانة، قوة الإنضغاط، معامل المرونة.

Abstract: Reclaimed Asphalt Pavement (RAP) is the result of removing old asphalt pavement material. RAP consists of high quality well-graded aggregate coated with asphalt cement. The removal of asphalt concrete is done for reconstruction purposes, resurfacing, or to obtain access to buried utilities. The disposal of RAP represents a large loss of valuable source of high quality aggregate. This research investigates the properties of concrete utilizing recycled reclaimed asphalt pavement (RAP). Two control mixes with normal aggregate were designed with water cement ratios of 0.45 and 0.5. The control mixes resulted in compressive strengths of 50 and 33 MPa after 28 days of curing. The coarse fraction of RAP was used to replace the coarse aggregate with 25, 50, 75, and 100% for both mixtures. In addition to the control mix (0%), the mixes containing RAP were evaluated for slump, compressive strength, flexural strength, and modulus of elasticity. Durability was evaluated using surface absorption test.

Keywords: Reclaimed asphalt pavement, Concrete, Compressive strength, Elastic moduli

1. Introduction

Reclaimed asphalt pavement (RAP) is the result of removing old asphalt pavement material. RAP consists of high quality well-graded aggregate coated with aged asphalt cement. The removal of asphalt concrete is done for reconstruction purposes, resurfacing, or to obtain access to buried utilities. The disposal of RAP represents a large loss of valuable source of high quality aggregate.

Supplies of natural high quality aggregate are depleting in some areas in the world, or can be costly to transport to the construction site. Existing portland cement concrete and asphalt concrete pavements provide a source of high quality aggregate that can be recycled. Recycling can contribute to the waste disposal and to the conservation of natural resources (Yrjanson, 1989 and Kenai, *et al*. 2002).

Kenai, *et al*. 2002, conducted a study on the use of recycled concrete and bricks as an aggregate in concrete. The study used either fine aggregate replacement or coarse aggregate replacement or both. Percentages of replacement were 25, 50, 75, and 100% of the aggregate. The study recommended limiting the amount of recycled aggregate to 75% and 50% for the coarse and fine aggregate, respectively. A reduction in compressive strength was reported with the increase in recycled aggregate replacement. The study found that the relationships between tensile and compressive strength for natural aggregate concrete can be used for the recycled aggregate concrete.

Murshed, *et al*. 1997, investigated the use of combinations of coarse and fine RAP aggregate in normal concrete mixes and compared the results of compressive strength to conventional mixes with 0.4 and 0.5 water cement ratios. Compressive strength values were found to decrease with the increase in RAP content. The study concluded that the concrete mixes containing RAP can qualify for concrete applications such as sidewalks, driveways, curbs, and gutters.

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Table 1. Aggregate and RAP physical properties

Aggregate	Coarse Agg.	Fine Agg.	Coarse RAP	Fine RAP
Bulk SG	2.78	2.57	2.35	2.40
Bulk SG (SSD)	2.81	2.65	2.40	2.45
Apparent SG	2.84	2.78	2.5	2.5
Absorption (%)	1.8	1.5	1.8	1.6
LA Abrasion (%)	19.5	-	26.4	-

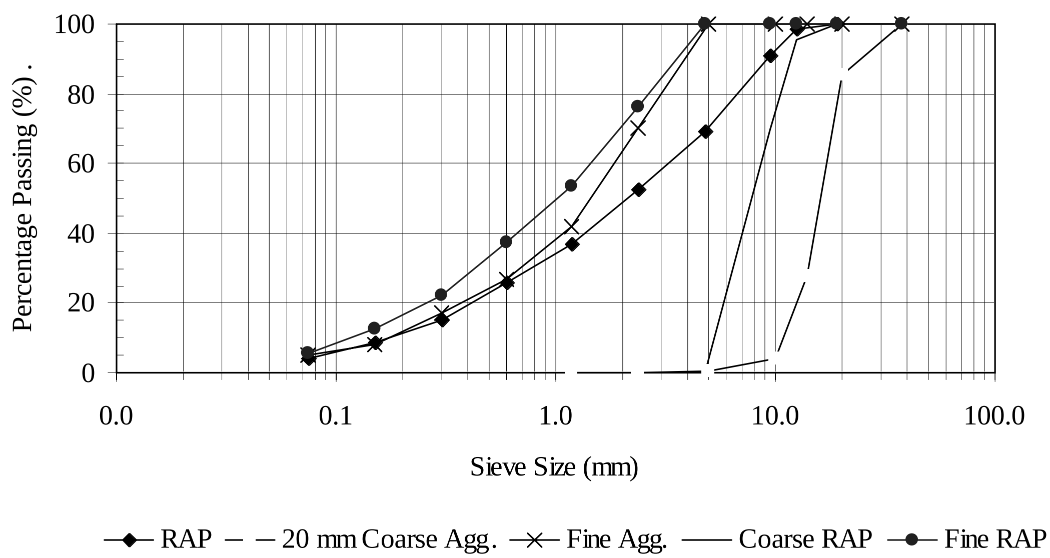

Figure 1. Grain size distribution for aggregate and RAP

Limbachiya, *et al*. 2000, used recycled concrete as an aggregate in high strength concrete. Results indicated that up to 30% of recycled concrete aggregate had no effect on strength. At higher percentages, there was a gradual reduction in strength. The study presented a method to adjust the water cement ratio to overcome this reduction in strength. The study concluded that the high strength concrete made with recycled concrete aggregate can have equivalent engineering and durability performance to normal high strength concrete.

Jankovic, 2002, in his study, compared the effect of polymer admixture with a percentage of 0, 4, and 8 % on concrete made with combinations of recycled brick and river sand. The study concluded that there is no effect of polymer on compressive and flexural strength. However, the polymer provided some improvement in water resistance and frost resistance. The study recommended using the concrete made from recycled blocks in thermal insulators, and in bearing walls for buildings.

This paper presents the results of a study conducted on the evaluation of using RAP in concrete mixes. Two mix grades are designed. Coarse aggregate is replaced with the coarse fraction of the RAP aggregate with various percentages including 0, 25, 50, and 75%. Mix properties including: slump, compressive and flexural strength, elastic modulus and surface absorption are presented.

2. Experimental Program

Aggregates used in the concrete mix consisted of 20 mm coarse aggregate (CA), fine aggregate (FA) and recycled asphalt concrete pavement (RAP). As a result of the cold milling operation, the RAP is in the form of loose particles coated with aged asphalt cement. RAP was separated by sieving on the 5 mm sieve size into coarse and fine RAP.

Normal portland cement type I was used. The aggregate and RAP gradation are shown in Fig. 1. The physical properties of aggregate and RAP are shown in Table 1.

Two normal portland cement concrete control mixes (with no RAP aggregate) were designed with ratios of 1: 1.9 : 2.9 : 0.5 and 1 : 1.7 : 2.5 : 0.45 for cement to fine aggregate to coarse aggregate to water. The cube compressive strength after 28 days of water curing resulted in 33 and 50 MPa for the two mixes, respectively. The mixes were referred to as Mix 30 and Mix 50.

The coarse aggregate was selected to be replaced with

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Table 2. Mix quantities

Mix	RAP %	Cement	Fine Agg.	Coarse Agg.	Coarse RAP	Water
		Quantity (kg/m^3)				
30	0	380.0	730.0	1100.0	0.0	190.0
	25	380.0	730.0	825.0	275.0	190.0
	50	380.0	730.0	550.0	550.0	190.0
	75	380.0	730.0	275.0	825.0	190.0
	100	380.0	730.0	0.0	1100.0	190.0
50	0	425.0	714.3	1070.0	0.0	191.4
	25	425.0	714.3	802.9	267.1	191.4
	50	425.0	714.3	535.7	534.3	191.4
	75	425.0	714.3	267.1	802.9	191.4
	100	425.0	714.3	0.0	1070.0	191.4

Table 3. Slump and unit weight for different RAP content mixes

Mix	Parameter	RAP Percentage				
		0	25	50	75	100
30	Slump, mm	163	95	90	85	20
	Unit Weight, kg/m^3	2458	2405	2392	2357	2323
50	Slump, mm	55	43	20	12	5
	Unit Weight, kg/m^3	2442	2458	2435	2389	2377

coarse RAP aggregate as it constitutes a higher percentage in the mix. The percentages of replacement were 0 (control), 25, 50, 75, and 100 %, by weight of the coarse aggregate. Table 2 shows the mix quantities for the two mixes. The aggregate weights are based on saturated surface dry (SSD) condition.

The fresh concrete mixes were tested for slump (ASTM C143-98) and unit weight (ASTM C138). Twelve 100 mm cubes, three 150 mm cubes, three 150 by 300 mm cylinders, and three 100 by 100 by 500 mm prisms were cast for each mix. All specimens were subjected to water curing. The 100 mm cube specimens were tested for compressive strength according to British standards (BS) (BS 1881-116) after 7, 14, 28, and 90 days of curing. The cylinders were tested for both modulus of elasticity (ASTM C469-94) and compressive strength (ASTM C873) after 28 days of curing. The prisms were tested for flexural strength (ASTM C78) after 28 days of curing. The 150 mm cubes were used to evaluate the durability of the mixes by the surface absorption test (BS 1881-208) after 56 days of curing.

3. Results and Discussion

3.1. Fresh Concrete Properties

Table 3 shows the slump and unit weight for the two mixes for different percentages of RAP replacement. The table indicates a reduction in the slump value from 163 to 20 mm for Mix 30 and from 55 to 5 mm for Mix 50 with the increase in the percentage of RAP replacement from 0 to 100%. In general, the unit weight shows the same trend for both mixes as it decreases with the increase in percentage of RAP content.

3.2. Compressive Strength

Figure 2 shows the results of the cube compressive strength (fcu) test after 7, 14, 28, and 90 days of curing for the different percentages of RAP replacement for Mix 30. The figure indicates the expected gain in strength with age. The figure also shows the reduction in strength with the increase in RAP content. Figure 3 shows the cube compressive strength (fcu) results for Mix 50. The figure also shows the gain in strength with curing and the reduction in strength with the addition of RAP for all mixes.

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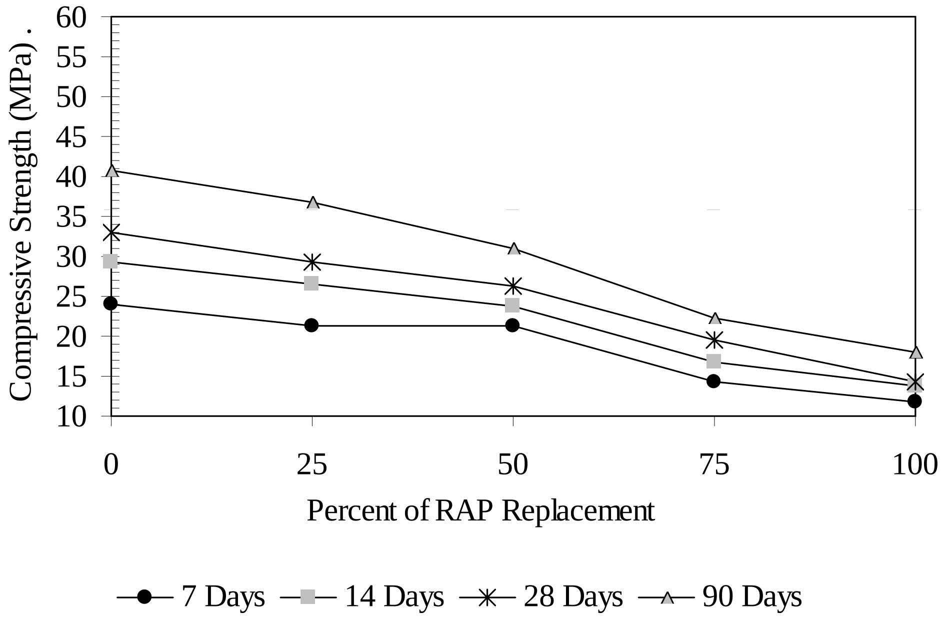

Figure 2. Compressive strength for Mix 30

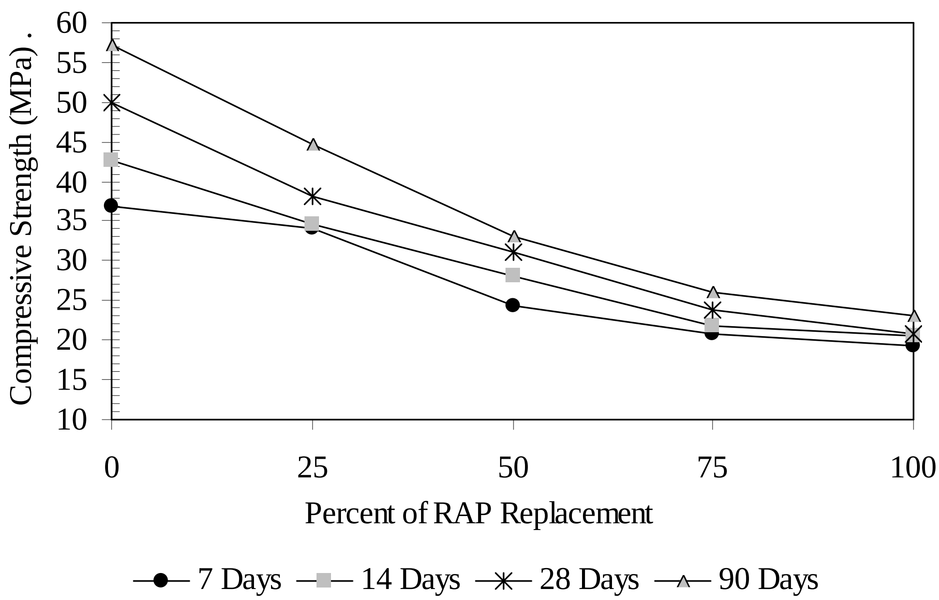

Figure 3. Compressive strength for Mix 50

For the 28 days compressive strength, the reduction in strength is indicated in Fig. 4 for both mixes. The figure indicates approximately 10% higher reduction in strength for Mix 50 compared with Mix 30. At 100% RAP replacement, the reduction is approximately 58 % for both mixes.

Figures 5 and 6 show the development of cube compressive strength at different curing periods for both mixes and different RAP percentage. The figures show the ratio of the compressive strength at different curing periods to the compressive strength at 28 days of curing (development ratio). The development of strength was generally the same for both mixes. The results are similar to the reported typical values for the gain in strength for normal concrete (Mehta and Monteiro, 1993; Neville, 1987).

The compressive strength for cylinders (fcyl) after 28 days of curing as well as the ratio of fcyl to fcu are shown in Table 4. The results indicate the reduction in strength with the increase in RAP content, which is consistent with the decrease in the case of cube specimens. The ratio of fcyl to fcu ranged from 0.77 to 0.89 for all specimens.

3.3. Flexural Strength

Table 5 shows the flexural strength (modulus of rupture) (f_r) results for the prisms after 28 days of curing. Predicted values based on the ACI Code equations (Mehta and Monterio, 1993) and the cylinder compressive strength (f_{cyl}) are also shown, in addition to the ratio of (f_r/f_{cyl}). A general trend of reduction in strength with the increase in RAP content can be seen. The modulus of rup-

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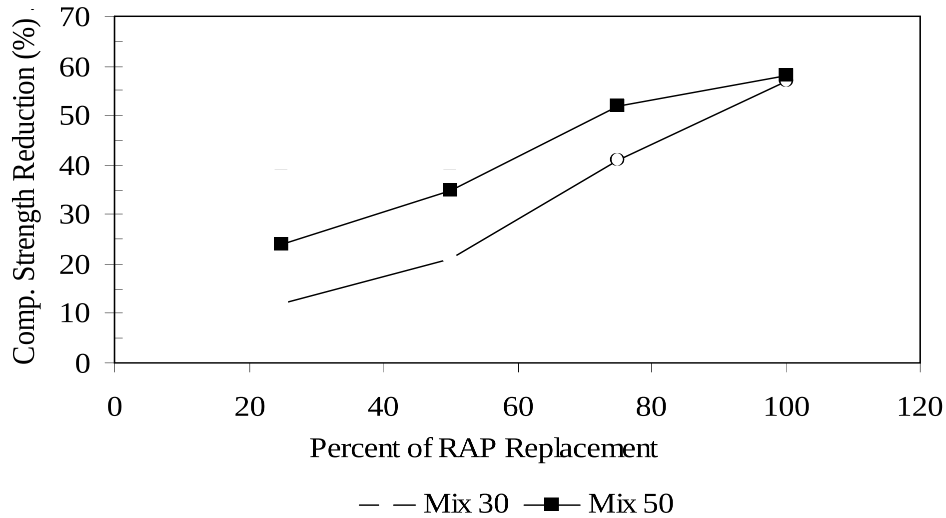

Figure 4. Percentage reduction in compressive strength

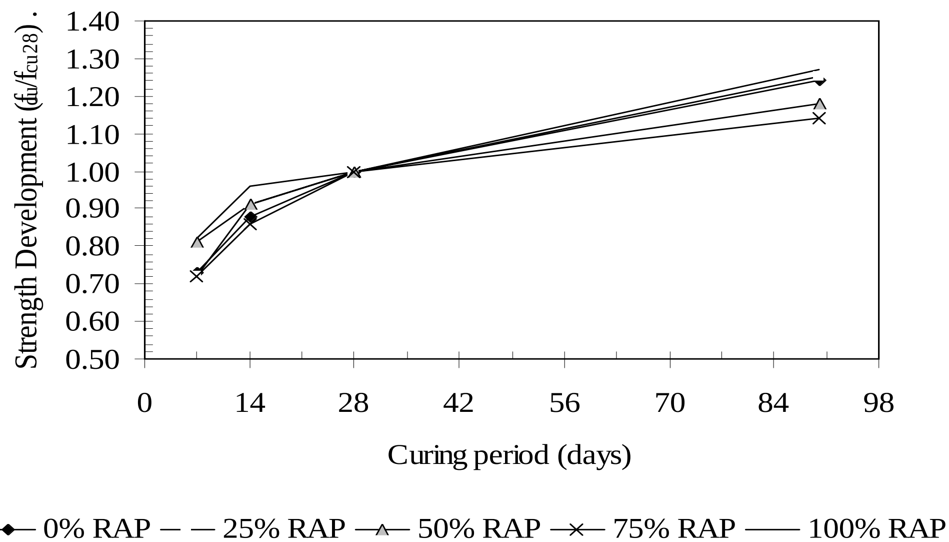

Figure 5. Strength development ratio for cube compressive strength (Mix 30)

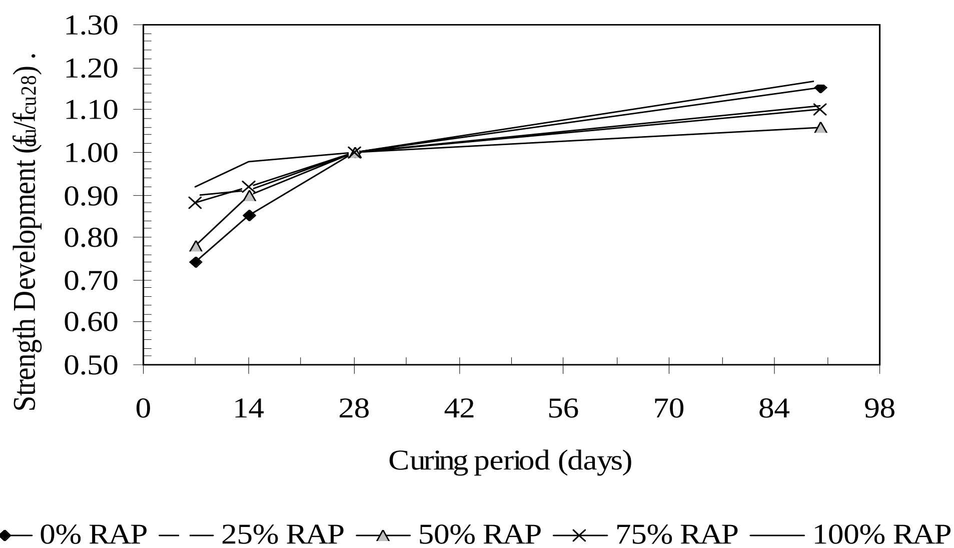

Figure 6. Strength development ratiofor cube compressive strength (Mix 50)

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Table 4. Cylinder compressive strength

Mix	Parameter	RAP Percentage				
		0	25	50	75	100
30	f_{cyl} [a]	29.4	23.8	20.9	15.9	12.4
	f_{cyl}/f_{cu} [b]	0.89	0.81	0.80	0.81	0.87
50	f_{cyl} [a]	39.5	30.3	24.0	19.8	16.9
	f_{cyl}/f_{cu} [b]	0.79	0.79	0.77	0.83	0.81

[a] f_{cyl} = cylinder compressive strength in MPa,

[b] f_{cyl}/f_{cu} = ratio of cube t o cylinder compressive strength

Table 5. Prism flexural strength (modulus of rupture)

Mix	Modulus of Rupture (f_r), MPa	RAP Percentage				
		0	25	50	75	100
30	Laboratory	4.0	4.30	3.3	3.1	2.7
	ACI Code [a]	3.6	3.2	3.0	2.6	2.3
	ACI Code [b]	5.4	4.9	4.6	4.0	3.5
	ACI Code [c]	3.4	3.0	2.8	2.5	2.2
	f_r/f_{cyl}	12	15	13	16	19
50	Laboratory	5.5	4.5	3.8	4.5	3.9
	ACI Code [a]	4.1	3.6	3.2	2.9	2.7
	ACI Code [b]	6.3	5.5	4.9	4.4	4.1
	ACI Code [c]	3.9	3.4	3.0	2.8	2.5
	f_r/f_{cyl}	11	12	12	19	19

[a] lower range = $0.66\sqrt{f_{cyl}}$, [b] upper range = $1.0\sqrt{f_{cyl}}$, and [c] recommended value = $0.62\sqrt{f_{cyl}}$.

ture decreased from 4.0 to 2.7 MPa for an increase in RAP replacement of 100% for Mix 30, about 33% reduction in strength. For the higher strength mix (Mix 50), the modulus of rupture decreased from 5.5 to 3.9 MPa for the 100% RAP replacement, which amounts to 29% reduction.

The modulus of rupture results obtained from the laboratory tests are shown to be in agreement with the range given by the ACI equations. Moreover, the ratio of (f_r/f_{cyl}) for both mixes and for the different percentages of RAP replacement agrees with typical reported values for normal concrete (Mehta and Monterio, 1993).

3.4. Modulus of Elasticity

The modulus of elasticity was determined according to ASTM C469-94 on the cylinder specimens before crushing them. The results are shown in Figs. 7 and 8 for Mix 30 and 50, respectively. For comparison, the ACI building code 318-83 gives the following expression for the static modulus of for normal weight concrete (Neville, 1987).

$$E_c = 4.70\sqrt{f_{cyl}} \qquad (1)$$

where, E_c = the modulus of elasticity in GPa and f_{cyl} = the 28 days cylinder strength in MPa. The British Standards for the structural use of concrete BS 8110: Part 2: 1985 tabulates typical values of the static modulus of elasticity based on the 28 days cube strength. An expression is proposed by Neville, 1987 based on the BS standards as follows:

$$E_c = 9.1\, f_{cu}^{0.33} \qquad (2)$$

where, E_C = the modulus of elasticity in GPa and f_{cu} = the 28 days cube strength in MPa.

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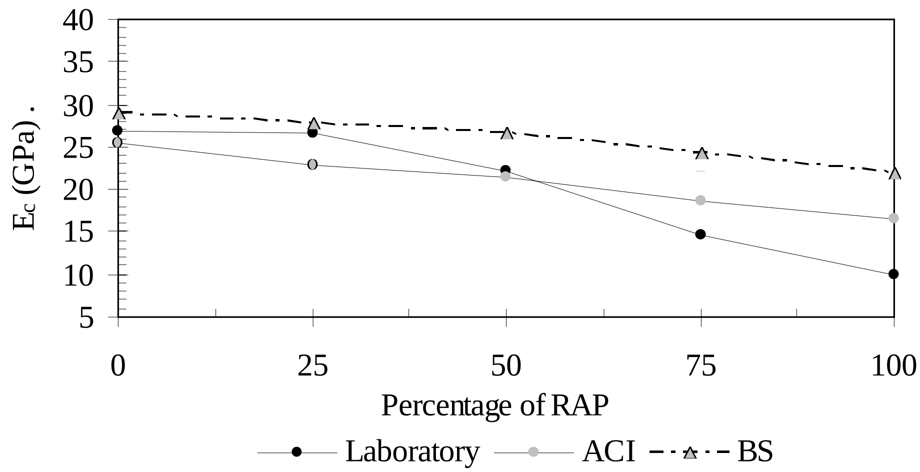

Figure 7. Modulus of elasticity for Mix 30

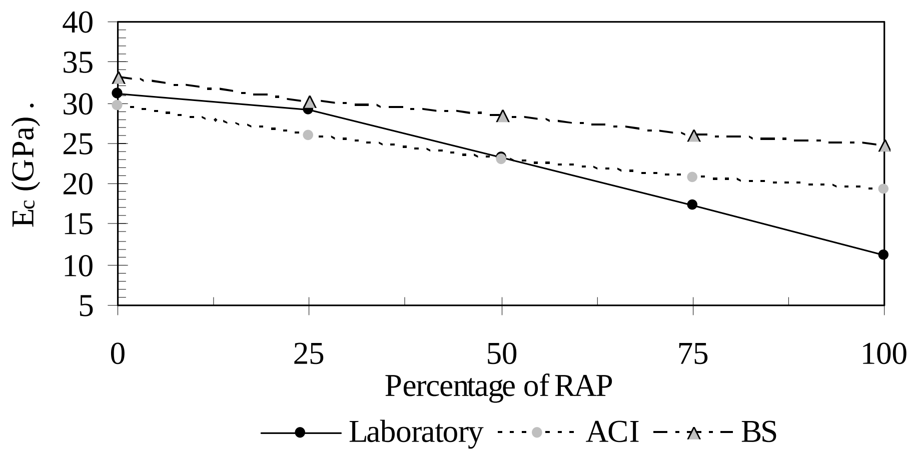

Figure 8. Modulus of elasticity for Mix 50

Both expressions 1 and 2 were used as shown in Figs. 7 and 8. The results indicate a decrease in the modulus as RAP percentage is increased. The results also indicate that the obtained results fall between the values predicted from both equations up to 50% RAP replacement. For higher percentages of RAP, the modulus is lower than that given by both equations. A regression analysis was performed on the ten mixes to obtain equations similar to Eqs. 1 and 2, the resulting equations were as follows:

$$E_c = 0.65\, f_{cyl}^{1.1} \quad (R^2 = 0.85,\ R^2_{adj} = 0.87) \tag{3}$$

$$E_c = 0.61\, f_{cu}^{1.05} \quad (R^2 = 0.85,\ R^2_{adj} = 0.87) \tag{4}$$

where, E_c, f_{cyl} and f_{cu} are as defined before; and R^2 and R^2_{adj} are the coefficient and adjusted coefficient of determination, respectively.

3.5. Durability

The initial surface absorption test (BS 1881-208) was performed as an indicator for the durability of the mixes. The test gives the water flow (in ml/m²/sec) into the surface of a dry cube specimen subjected to a head of 200 mm. Water is allowed to penetrate the surface for periods of 10, 30, 60 and 120 minutes. At the end of each period, flow measurements were made.

Figure 9 shows the results for Mix 30. The figure indicates a reduction in surface absorption with time. The same observations apply to Fig. 10 (Mix 50). The flow at 120 minutes for Mix 30 was in the range of 0.057 to 0.093 ml/m²/sec. Lower flow values were obtained for mix 50 with values in the range of 0.043 to 0.063 ml/m²/sec. The results did not indicate a significant difference in the absorption with the increase in RAP content for both mixes. However, a lower flow was obtained for the stronger mix (mix 50) which should be anticipated.

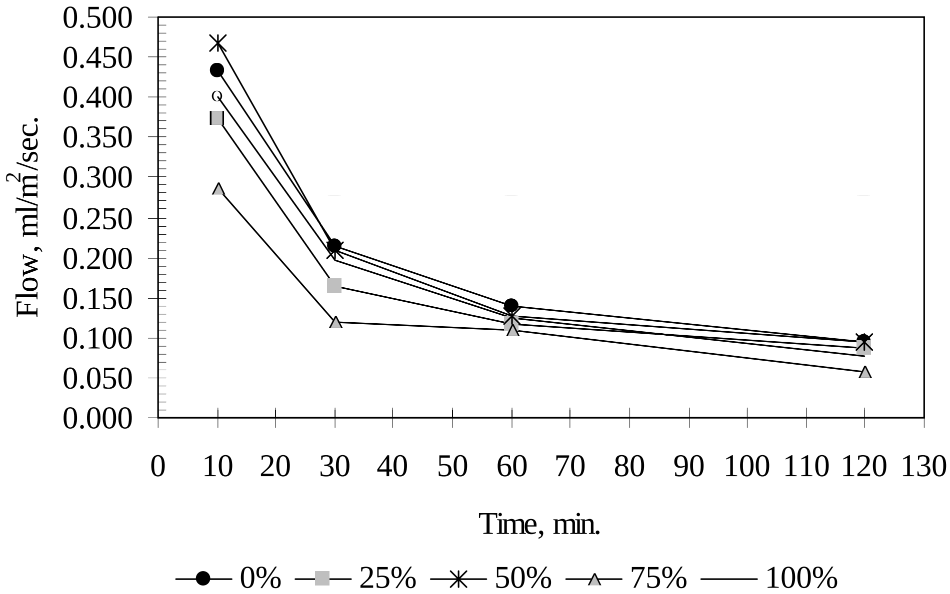

Figure 9. Initial surface absorption for Mix 30

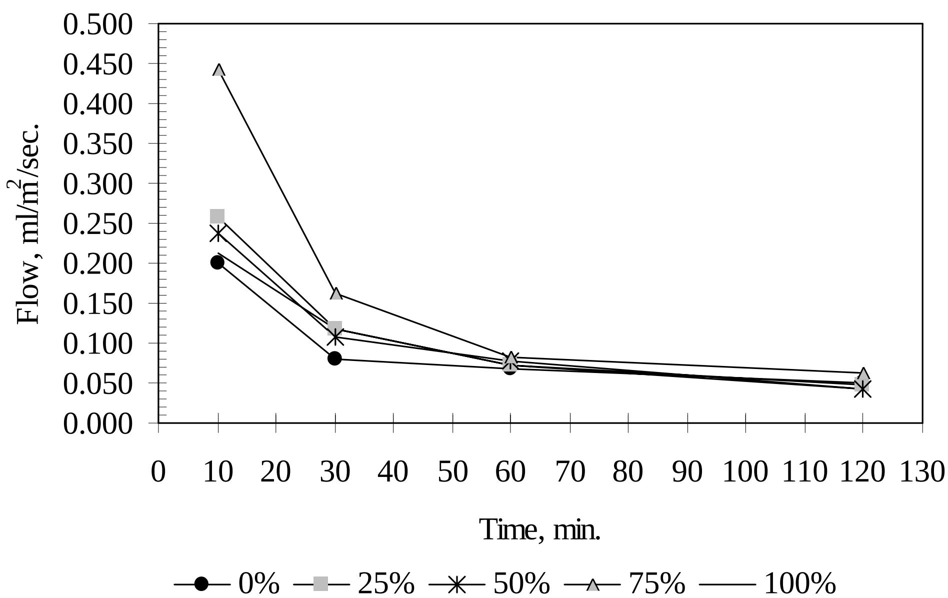

Figure 10. Initial surface absorption for Mix 50

4. Conclusions

Reclaimed asphalt pavement was used as a coarse aggregate substitute in two different normal concrete mixes having 28 days cube compressive strengths of 33 and 50 MPa. RAP was used with 25, 50, 75, 100% replacement of coarse aggregate. The slump decreased with the increase in RAP content. The compressive and flexural strength decreased as well with the increase in RAP content. The general trend of strength development, as well as the relations between flexural strength, elastic modulus and compressive strength for the RAP mixes agreed well with that for normal concrete. The surface absorption was not significantly affected by the addition of RAP. The results indicated the viability of RAP as an aggregate in non-structural concrete applications. The percentage of RAP should be limited according to the application. Low slump should also be considered when utilizing RAP in the mixes.

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