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TECHNICAL PAPER

Recent Development of Recycled Asphalt Pavement (RAP) Bases Treated for Roadway Applications

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Abstract Recycled asphalt pavement (RAP) has increasingly been used as a base material for highway construction as a sustainable solution. Due to the existence of asphalt, 100 % RAP typically has low strength and high potential of creep and permanent deformations. RAP can be blended with virgin aggregate, stabilized by cement and fly ash, or confined by geocell to increase its strength and reduce its creep and permanent deformations. This paper examines several recent experimental studies on treated RAP bases (blended RAP aggregate, cement and fly ash-stabilized RAP, and geocell-confined RAP) and discusses the key findings from these studies including the proportion of RAP to virgin aggregate, type and percent of stabilizing agent, strength, modulus, and creep deformation of treated RAP under static loading, and permanent deformation of treated RAP under cyclic loading.

Keywords RAP · Virgin aggregate · Blend · Stabilizing agent · Geocell · Strength · Modulus · Deformation

Introduction

Asphalt pavements which have reached the end of their service life are frequently rehabilitated by milling the existing pavement surfaces and replacing the milled portion with new hot mix asphalt (HMA). A large amount of recycled asphalt pavement (RAP) is generated every year because of this practice. The use of RAP has been in practice since 1930s and is necessary to reduce the cost of construction materials, to reduce the use of petroleum-based products, and to conserve natural resources by requiring less virgin aggregate and asphalt in road construction projects. The US Federal Highway

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Administration (FHWA) estimated that 100.1 million tons of asphalt pavements are milled off each year during resurfacing and widening projects [21]. Of that, 80.3 million tons are reclaimed and reused for roadbeds, shoulders, and embankments [21]. More than 73 million tons of RAPs are processed each year in the USA with much of them reused in pavement construction [18]. RAP can be used as a granular base material in paved and unpaved roadways, parking areas, bicycle paths, gravel road rehabilitation, shoulders, residential driveways, trench backfill, engineered fill, and culvert backfill [32].

Currently, great emphasis is placed on sustainable construction and infrastructure because the demand for sustainable and environmental friendly roads is increasing. More green technologies for sustainable roadway construction are needed. One way to construct environmentally sound roads is through the use of RAP materials. Historically, RAP has been used with new bituminous materials by either a hot-mix or cold-mix recycling process. However, a large quantity of RAP materials remains unused. Recent investigations [8, 21] have shown that the waste problems can be reduced by using RAP as base and subbase aggregate materials. Using RAP as a base course material would preserve non-renewable aggregate as well as reduce the amount of space needed to store millions of tons of RAP created each year. Peter Stephanos, the director of the FHWA Office of Pavement Technology, stated that recently, most State DOTs are seriously considering the economic and environmental benefits of using RAP in greater proportions and facing challenges to maintain high-quality pavement infrastructures [8].

Literature indicates that 100 % RAP could not produce base course of high quality due to its significant rate dependency and high deformation and creep [11]. Several researchers [12, 15, 17, 20, 22, 23, 25–28, 33, 35] have suggested that high-quality base courses could be obtained by blending RAP with virgin aggregates, stabilizing RAP with chemical additives such as cement, lime, fly ash, etc., and confining RAP with geocell. Fly ash is a fine, glass-like powder material recovered from gases created by coal-fired electric power generation. Millions of tons of fly ash were produced by US power plants annually. Stabilizing RAP with fly ash is an attractive and sustainable solution because fly ash traditionally has been disposed in landfills. Geocells are three-dimensional interconnected honeycomb type of geosynthetics used to reinforce weak soils and base courses of roads and are ideal for soil confinement. Geocell improves the performance of base course materials by providing lateral confinement to the infill materials [15, 25–30]. Han and Thakur [16] discussed the use of geosynthetics with recycled aggregates for sustainable roadway construction. This paper provides the state-of-the art review of past research work on treated RAP bases (blended RAP aggregate, chemically treated RAP, and geocell-confined RAP) and summarizes the key findings from these studies including the proportion of RAP to virgin aggregate, type and percent of stabilizing agent, strength, modulus, and creep deformation of treated RAP under static loading, and permanent deformation of treated RAP under dynamic loading.

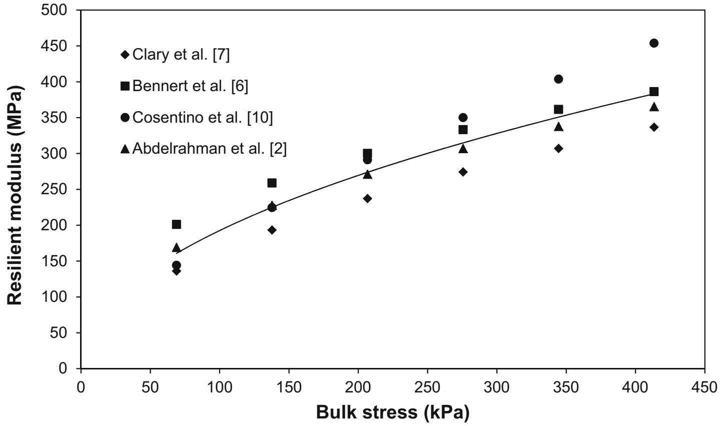
Extensive literature review was conducted in this study on blended RAP aggregate, chemically-stabilized RAP-aggregate blends, and geocell-reinforced RAP bases. The effects of blending, chemical stabilization, and geocell reinforcement on resilient modulus (M_R), California Bearing Ratio (CBR), shear strength, unconfined compressive strength (UCS), permanent deformation, and creep deformation properties of these bases are discussed in the following sections.

Resilient Modulus

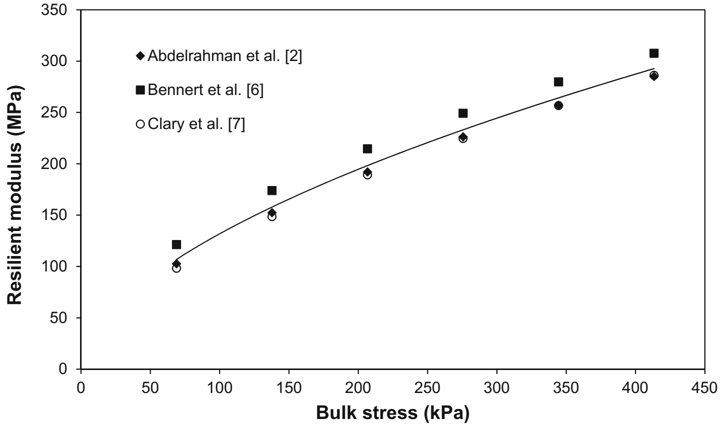
M_R is a fundamental material property used to characterize unbound pavement materials. It is a measure of material stiffness and provides a mean to analyze stiffness of materials under different conditions, such as moisture, density, stress level, etc. The 1993 American Association of State Highway and Transportation Officials (AASHTO) flexible pavement design method and the current Mechanistic-Empirical Pavement Design Guide (MEPDG) use M_R to define subgrade and base stiffness for a flexible pavement [1]. The M_R is an elastic modulus under repeated loads obtained through laboratory testing by dividing an applied deviator stress (σ_d) with a recoverable or resilient strain (ϵ_r). Literature shows M_R of blended RAP aggregate or chemically stabilized RAP aggregate base depends on several factors, such as moisture content, density, stress history, aggregate type, RAP type, gradation, temperature, fineness modulus, asphalt content in RAP, type of stabilizing agent, curing time for chemically stabilized RAP, etc. However, this paper only discusses the effects of RAP content, type of blending aggregate, type and amount of stabilizing agent, stress, curing time on M_R of blended RAP aggregate, or chemically stabilized RAP aggregate base.

Clary et al. [7], Bennert et al. [6], Cosentino et al. [10], and Abdelrahman et al. [2] reported the M_R tests conducted on blends of RAP and aggregates commonly used for base course applications. The M_R of RAP was found higher than the virgin aggregate base materials in these investigations, and the M_R of RAP-aggregate blends increased with an increase in the bulk stress and the RAP content in the blends as shown in Figs. 1a–c and 2. These researchers proposed the bulk stress (θ) model $M_R=K_1*\theta^{K2}$ to predict M_R of different blends by determining the model parameters (K_1 and K_2) based on the M_R test results. The K_1 and K_2 values were modified from Clary et al. [7], Cosentino et al. [10], and Abdelrahman et al. [2] to keep consistency with the units. New values for the model parameters are proposed to include different types of RAP and aggregate based on the M_R test results from these studies using the regression technique as shown in Fig. 1a–c. The values of the model parameters (K_1 and K_2) proposed by different researchers and in this study are shown in Table 1. The K_1 values range from 4.39 to 43.1 while the K_2 values range from 0.36 to 0.66. The M_R and θ used in this model should be in units of megapascal and kilopascal, respectively. The M_R values of the blends at the bulk stress of 345 kPa from these studies are shown in Fig. 2 to demonstrate the effect of the RAP content on M_R. The M_R values increase approximately linearly with an increase in the RAP content as shown in Fig. 2. The equation ($M_R=A$*RAP content$+B$) was developed based on the test results obtained by different authors. The values of the parameters A and B proposed by different researchers and in this study are shown in Table 2. The values of A range from 0.98 to 1.64 while those of B range from 182 to 209. The M_R value obtained using this equation should be in a unit of megapascal at a bulk stress of 345 kPa.

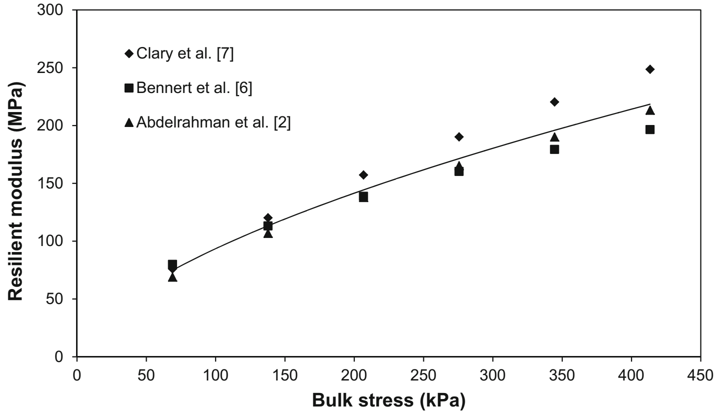
Potturi [22] conducted M_R tests on 7-day-cured cement-stabilized and cement-fiber-stabilized RAP specimens. The cement contents were controlled at 0, 2, and 4 % for cement-stabilized specimens and 2, 4, and 6 % for cement-fiber-stabilized specimens. The fibrillated polypropylene fiber content was kept at 0.15 %. It was found that the M_R increased with an increase in the bulk stress and the cement content, and the cement-fiber-stabilized RAP specimens had higher M_R than the cement-stabilized RAP specimens as shown in Fig. 3a. The bulk stress (θ) model was proposed based on the test



(a) *100% RAP- 0% aggregate blends*



(b) *50% RAP – 50% aggregate blends*



(c) *0% RAP – 100% aggregate blends*

Fig. 1 Resilient modulus versus bulk stress for the RAP-aggregate blends: *a* 100 % RAP–0 % aggregate blends, *b* 50 % RAP–50 % aggregate blends, *c* 0 % RAP–100 % aggregate blends

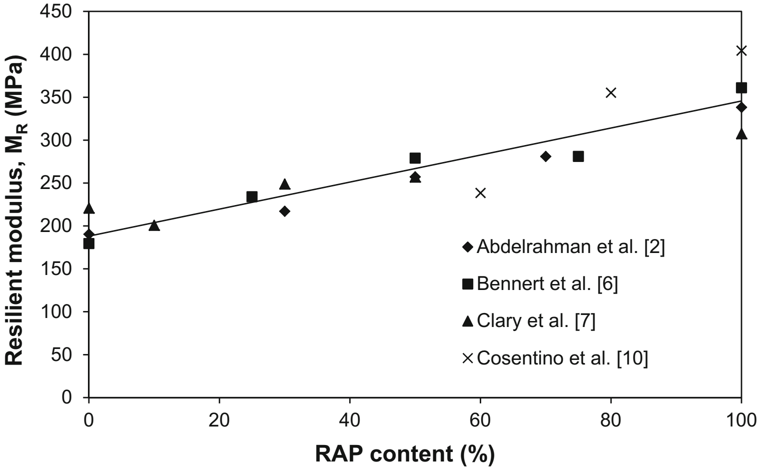


Fig. 2 Resilient modulus versus RAP content for the RAP-aggregate blends at bulk stress of 345 kPa

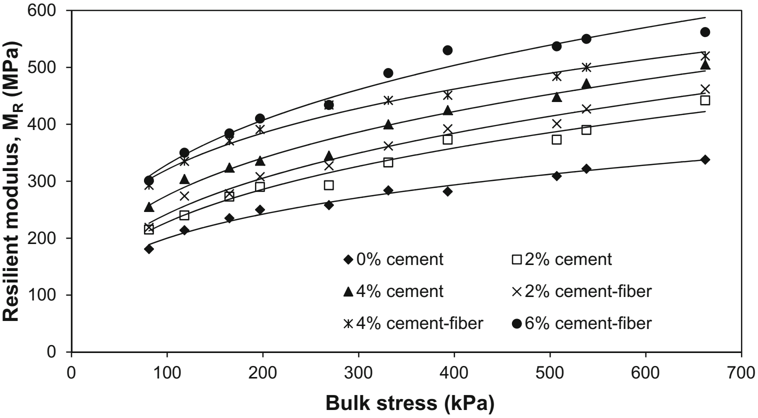
Table 1 Bulk stress (θ) model parameters for prediction of M_R of the RAP-aggregate blends ($M_R = K_1 * \theta^{K2}$)

Reference	M_R test method	RAP content (%) in blend of RAP aggregate	Model parameters		R^2
			K_1	K_2	
Modified from Clary et al. [7]	AASHTO T 294-94	0	4.64	0.66	0.88
		10	4.39	0.65	0.97
		30	5.67	0.65	0.97
		50	7.84	0.6	0.97
		100	16.07	0.51	0.93
Bennert et al. [6]	AASHTO TP 46-94	0	9.55	0.5	NA
		25	17.35	0.45	
		50	13.49	0.52	
		75	19.49	0.46	
		100	43.1	0.36	
Modified from Cosentino et al. [10]	LTTP Protocol P46	60	7.67	0.59	0.85
		80	10.78	0.6	0.95
		100	9.6	0.64	0.98
Modified from Abdelrahman et al. [2]	LTTP Protocol P46	0	4.79	0.63	0.96
		30	4.59	0.66	0.99
		50	9.2	0.57	0.97
		70	19.09	0.46	0.94
		100	27.39	0.43	0.85
Proposed in this study	NA	0	5.96	0.6	0.96
		50	9.91	0.56	0.97
		100	20.66	0.48	0.88

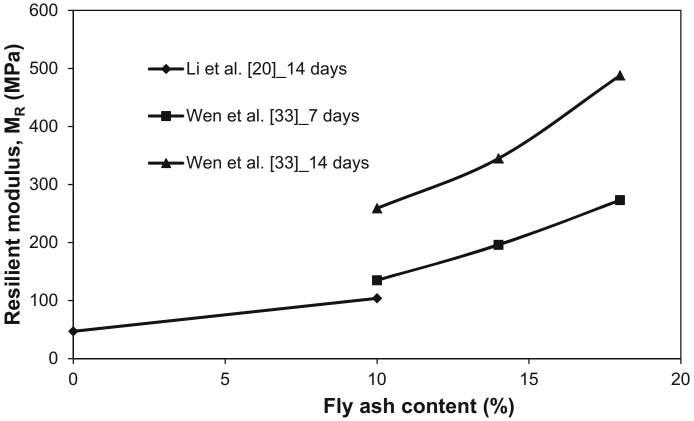
Table 2 Model parameters for prediction of M_R of the RAP-aggregate blends at a bulk stress of 345 kPa (M_R (MPa) = A*RAP content (%) + B)

Reference	A	B	R^2
Modified from Clary et al. [7]	0.98	209	0.91
Modified from Bennert et al. [6]	1.64	184	0.94
Modified from Abdelrahman et al. [2]	1.49	182	0.98
Proposed in this study	1.59	189	0.85

results obtained from Potturi [22]. The values for the model parameters (K_1 and K_2) are presented in Table 3. Li et al. [20] conducted M_R tests at a deviatoric stress of 21 kPa on a 14-day-cured fly ash-stabilized RAP specimens while Wen et al. [33] conducted M_R



(a) *Cement or cement-fiber stabilized RAP specimens (modified from Potturi [22])*



(b) *Fly ash stabilized RAP specimens*

Fig. 3 Effect of bulk stress, percentage of stabilizing agent, and curing time on M_R of the chemically stabilized RAP specimen

Table 3 Bulk stress (θ) model parameters for prediction of M_R of the cement and cement-fiber stabilized RAP ($M_R = K_1 * \theta^{K2}$)

Reference	M_R test method	Type and percentage of stabilizing agent	Model Parameters		R^2
			K_1	K_2	
			K_1	K_2	
Modified from Potturi [22]	AASHTO 307-99	0 % cement	55.91	0.28	0.98
		2 % cement	50.78	0.33	0.98
		4 % cement-fiber	66.08	0.31	0.98
		2 % cement-fiber	52.53	0.33	0.98
		4 % cement-fiber	95.31	0.26	0.99
		6 % cement-fiber	80.45	0.31	0.98

tests at a bulk stress of 83 kPa on 7- and 14-day-cured fly ash-stabilized RAP specimens. They found that the M_R increased with an increase in the fly ash content and the curing period as shown in Fig. 3b. In Fig. 3b, Li et al. [20]_14 days, Wen et al. [33]_7 days, and Wen et al. [33]_14 days stand for 14-, 7-, and 14-day-cured fly ash-stabilized RAP specimens, respectively. The variations in the properties of RAP, aggregate, and stabilizing agent may be the reason for the difference in the M_R values determined by different researchers under similar conditions of stress, RAP content, and stabilizing agent content.

California Bearing Ratio

The California Bearing Ratio (CBR) of base material is an indication of its bearing capacity under traffic loading and is determined as the ratio of the penetration resistance of the base material to that of a standard crushed stone. The CBR has been used by pavement engineers to characterize the strength of materials for designing pavements. However, its use for pavement design has been limited as the pavement engineers have recently found that the CBR is not a true mechanistic property and suggested that CBR can only be used for guidance of material selection [5].

Cosentino et al. [10], Bennert and Maher [5], Taha et al. [24], Guthrie et al. [14], and Cosentino et al. [9] conducted CBR tests on blended RAP aggregate specimens. They, except Cosentino et al. [10], found that the CBR of blends decreased with an increase in the RAP content as shown in Fig. 4. However, this result shows a different trend as that of the M_R test result. This difference may be because of the difference in the nature of these two tests. Cosentino et al. [10] found that the CBR of blends increased with an increase in the RAP content up to a certain level and then started decreasing. These investigations showed that the CBR values of 100 % RAP ranged from 11 to 33 %. The difference in the test results obtained by different researchers may be due to the difference in type of RAP, aggregate, and moisture content used for the blends.

Li et al. [20] conducted the CBR tests on RAP and fly-ash-stabilized RAP (SRAP) mixed in the field and laboratory to investigate the effects of fly ash on strength improvement. Ten percent of Class C fly ash was used to stabilize the RAP bases.

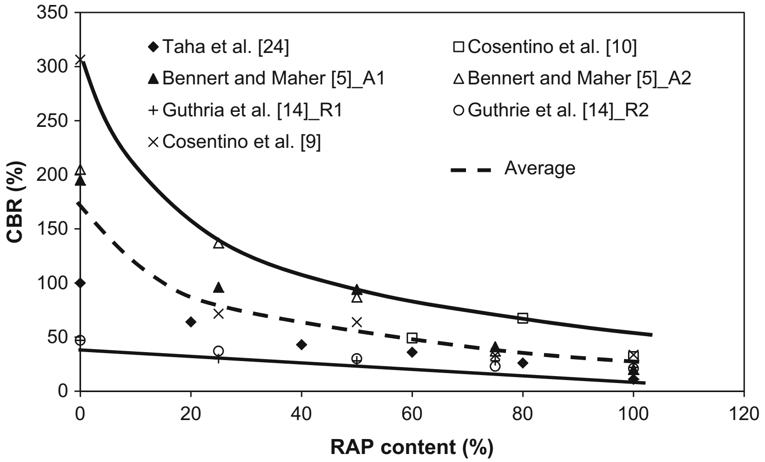
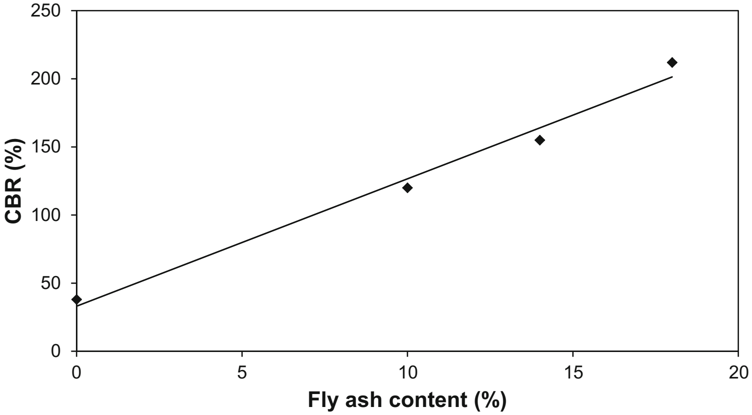


Fig. 4 CBR versus RAP content for the RAP-aggregate blends

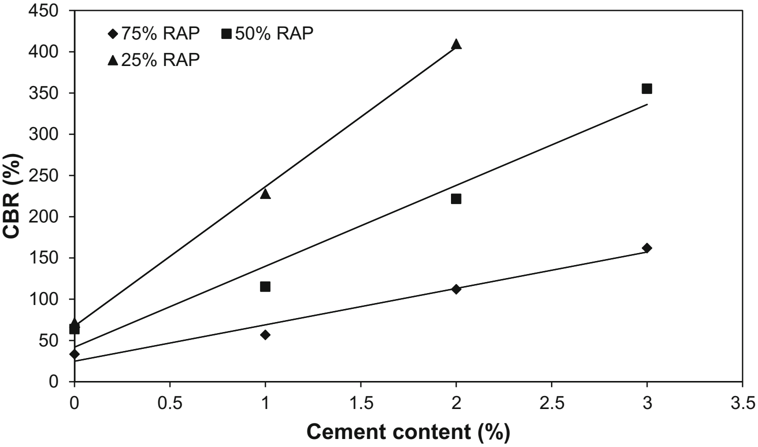
They found that SRAP had a significantly higher CBR than RAP. The CBR of RAP ranged from 3 to 17 % (mean=9 %), the CBR of the laboratory-mixed SRAP ranged from 70 to 95 % (mean=84 %), and the CBR of the field-mixed SRAP ranged from 13 to 53 % (mean=29 %). Wen et al. [33] conducted the CBR tests on 7-day-cured fly ash-stabilized RAP and found that the CBR of RAP increased linearly with an increase in fly ash content as shown in Fig. 5a. Cosentino et al. [9] conducted the CBR tests on 7-day-cured cement-stabilized RAP-aggregate blends and found that the CBR of RAP increased linearly with an increase in the fly ash content as shown in Fig. 5a. The equation, CBR (%)=A*stabilizing agent (%)+B, was proposed in this study to predict the CBR of chemical-stabilized RAP specimens based on the test results obtained by Wen et al. [33] and Cosentino et al. [9]. The values of the parameters A and B obtained in this study are presented in Table 4.

Shear Strength

Shear strength is the maximum shear stress that a soil can sustain. Attia [3] identified shear strength as an important property especially for unbound materials used under a thin HMA layer subjected to high shear stresses. Shear strength is a function of normal or confining stress, friction angle, and cohesion for a particular material. Cosentino et al. [10], Bennert and Maher [5], Attia [3], Bejarano [4], Garg and Thompson [13], and Kim and Labuz [19] evaluated shear-strength parameters (friction angle and cohesion) of the RAP-blended aggregate specimens, and the test results are shown in Fig. 6a, b. These investigations found that the friction angle and the cohesion of 100 % RAP specimen varied from 44° to 52 and 0 to 131 kPa, respectively. The large variation in the cohesion of RAP may result from the variation in the asphalt binder content of the RAP used by different researchers. Even though there are wide variations, the general trend is that the friction angle increases with the percent of RAP while the cohesion decreases with the percent of RAP. The blend with a higher friction angle had lower cohesion and vise versa.



(a) *CBR versus fly ash content (redrawn and modified from Wen et al. [33])*

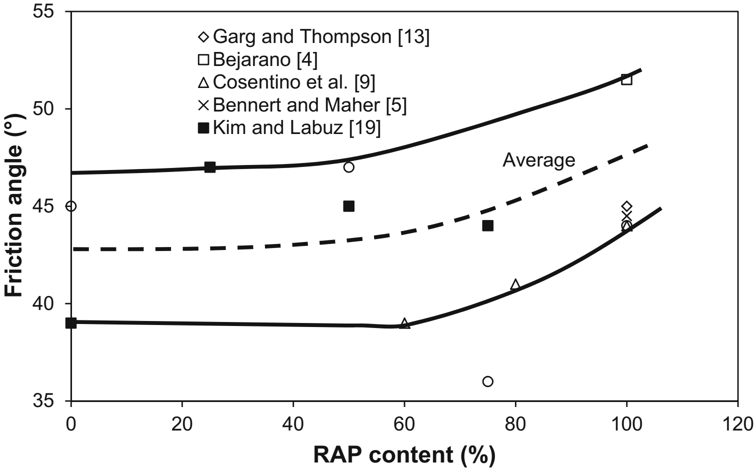


(b) *CBR versus cement content (redrawn and modified from Cosentino et al. [9])*

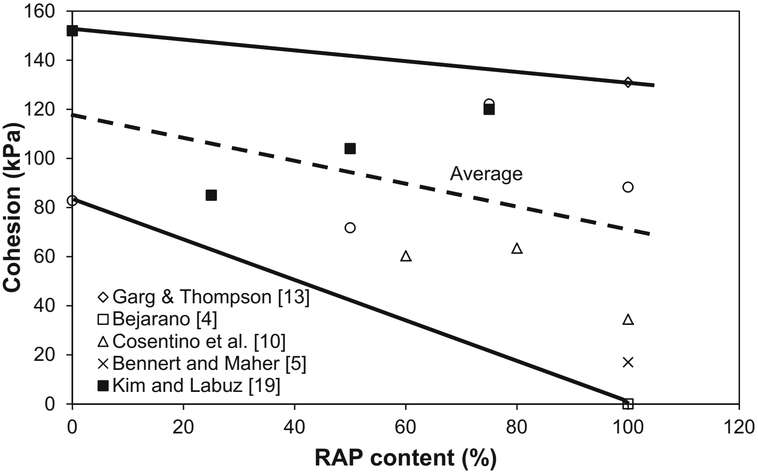
Fig. 5 Effect of stabilizing agent on CBR of the chemically stabilized RAP specimen

Table 4 Model parameters for CBR prediction of the chemically stabilized RAP-aggregate blends (CBR (%) = A*SA (%) + B)

Reference	RAP content (%)	Type of stabilizing agent (SA)	Model parameters		R^2
			A	B	
Modified from Wen et al. [33]	100	Fly ash	9.35	33.08	0.98
Modified from Cosentino et al. [9]	75	Cement	44.11	24.87	0.98
	50	Cement	98.07	41.83	0.97
	25	Cement	169	67.4	1



(a) *Friction angle versus RAP content*



(b) *Cohesion versus RAP content*

Fig. 6 Effect of RAP content on shear strength parameters of the RAP-aggregate blends

Unconfined Compressive Strength

The compressive stress at which an unconfined specimen fails in an axial compression test is termed as unconfined compressive strength of the specimen. Literature suggests that UCS of RAP can be increased by blending it with virgin aggregates or stabilizing it with chemical agents such as cement, fly ash, etc. Portland Cement Association (PCA) has suggested that the UCS of 7-day-cured chemically stabilized base course materials should be in the range of 2070 to 2760 kPa [14]. Guthrie et al. [14], Taha et al. [23], Ganne [12], Yuan et al. [35], and Hoyos et al. [17] evaluated the UCS of 7-day-cured cement-stabilized blends of RAP and aggregates commonly used for base course applications. All the above researchers, except Guthrie et al. [14] and Ganne [12] found that the UCS of blends decreased with an increase in the RAP content as shown in Figs. 7 and 8a–c. However, Guthrie et al. [14] found that the virgin aggregate samples had lower UCS than the blends containing 25 and 50 % RAP. Ganne [12] used three different types of RAP (R1, R2, and R3) to investigate the effect of RAP type on the UCS of RAP-aggregate blends. R1 was finest in the grain size, followed by R2 and R3. Ganne [12] found that blends containing 60 % RAP (R1) had the highest UCS, followed by the blends containing 75 and 50 % RAP. The blends containing the coarse RAP aggregates had a slightly higher UCS than those containing the fine aggregates. In Figs. 7 and 8a–c, Ganne [12]_R1, Ganne [12]_ R2, and Ganne [12]_ R3 stand for the blends containing R1, R2, and R3 types of RAP, respectively. The UCS of cement-stabilized blends increased with an increase in the cement content as shown in Fig. 8a–c.

Wen et al. [33] conducted UCS tests on 7- and 14-day-cured fly ash-stabilized RAP specimens and Taha et al. [23] conducted UCS tests on 3-, 7-, and 28-day-cured cement-stabilized RAP specimens. They found that the UCS increased with an increase in the stabilizing agent (cement or fly ash) content and the curing period as shown in Fig. 9. In Fig. 9, Wen et al. [33]_FA-7, Wen et al. [33]_FA-14, Taha et al. [23]_C-3, Taha et al. [23]_C-7, and Taha et al. [23]_C-28 stand for 7-day-cured fly ash-stabilized, 14-day-cured fly ash-stabilized, 3-day-cured cement-stabilized, 7-day-cured cement-stabilized, and 28-day-cured cement-stabilized RAP bases, respectively. The variations in the properties of RAP, aggregate, and stabilizing agent may be the reason for the difference in the UCS values determined by different researchers under the same RAP and stabilizing agent content.

Permanent Deformation

Thompson and Smith [31] identified permanent deformation as a key factor for the failure of pavements, so it is considered as an important characteristic to determine

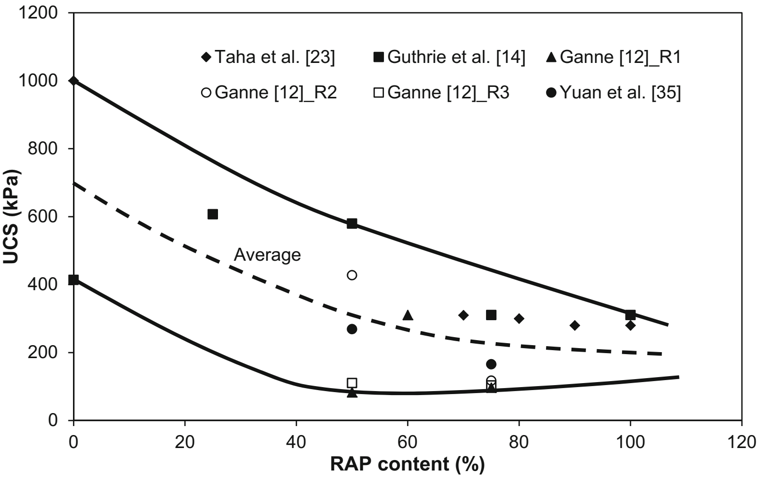
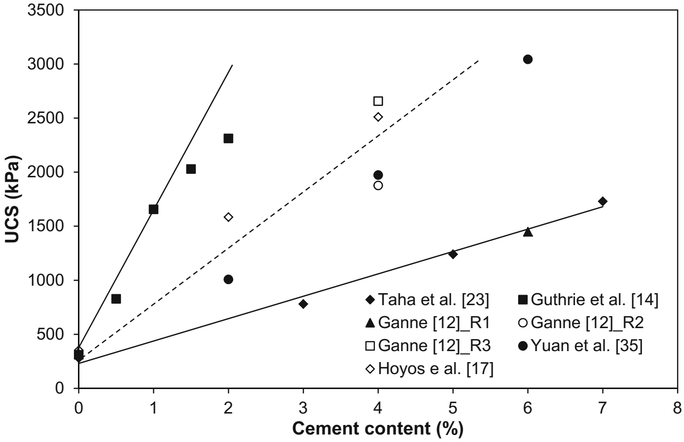
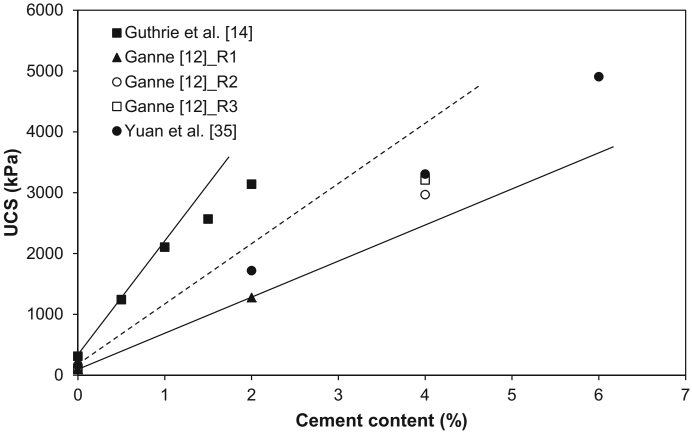


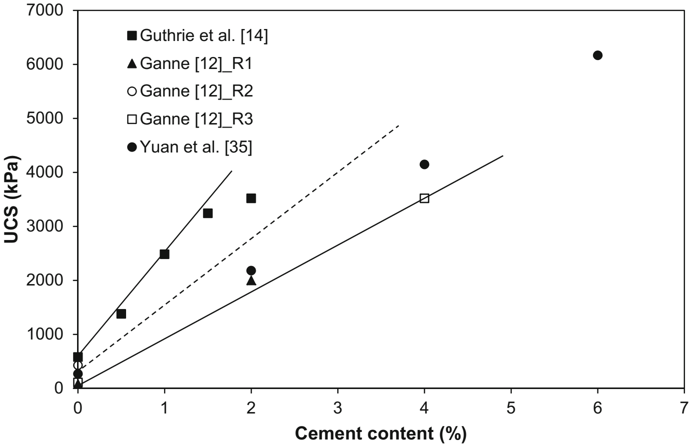
Fig. 7 Effect of RAP content on UCS of the RAP-aggregate blends



(a) *100% RAP – 0% aggregate blends*



(b) *75% RAP – 25% aggregate blends*



(c) *50% RAP – 50% aggregate blends*

Fig. 8 Effect of cement content on UCS of the RAP-aggregate blends

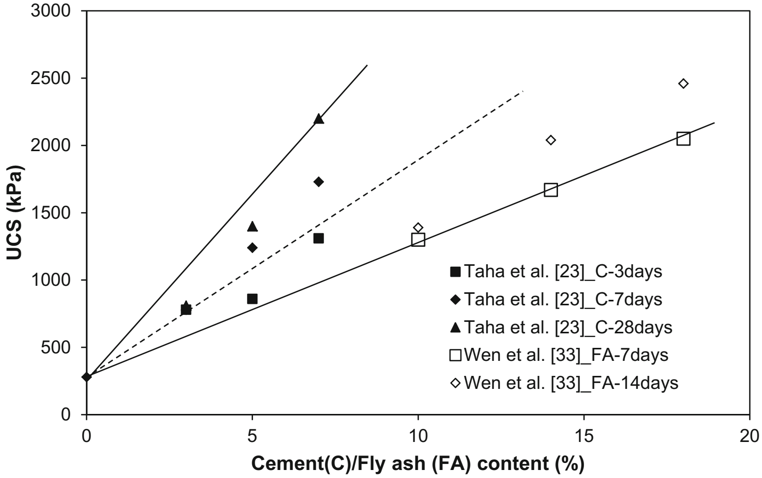


Fig. 9 Effect of curing time and stabilizing agent on UCS of the chemically stabilized RAP specimens

performance of pavements. Bennert et al. [6], Attia [3], Garg and Thompson [13], Kim and Labuz [19], and Wen and Wu [34] evaluated permanent deformations of blended RAP aggregate specimens and found that the permanent deformations of the blends increased with an increase in the RAP content as shown in Fig. 10. The permanent strains (ε_p) of the blends containing 50 % RAP and 100 % RAP versus the number of loading cycles (*N*) are shown in Fig. 11a, b, respectively. It can be seen that the permanent strain increased with the number of loading cycles.

Wen et al. [33] evaluated the permanent deformations of fly ash (FA)-stabilized RAP specimens and found that the permanent strains of blends decreased with an increase in the fly ash content in the blends as shown in Fig. 12. The equation $\varepsilon_p = 0.91 * e^{-0.9*FA}$ (FA is the fly ash content) was obtained in this study, which can predict the permanent strains of fly ash-stabilized RAP bases based on the test results of Wen et al. [33].

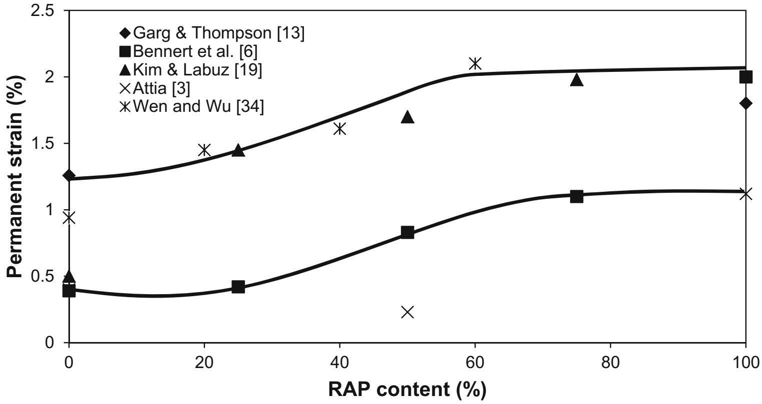
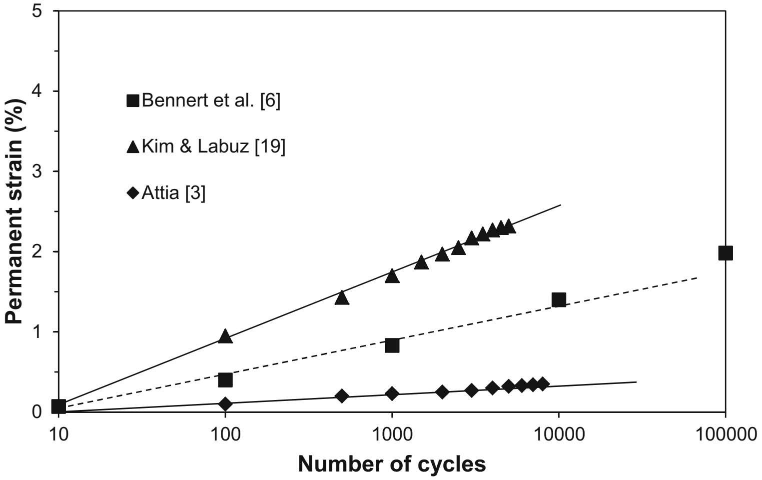
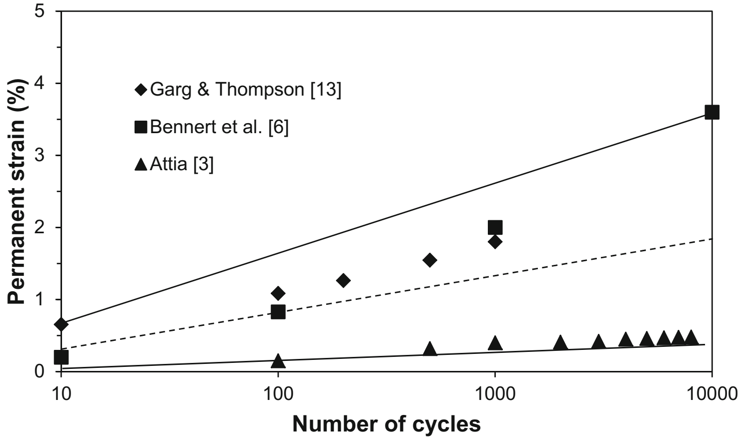


Fig. 10 Effect of RAP content on the permanent deformation of the RAP-aggregate blend



(a) *50% RAP – 50% aggregate blends*



(b) *100% RAP – 0% aggregate blends*

Fig. 11 Permanent strains versus the number of loading cycles for the RAP-aggregate blends

Thakur [25, 26] conducted large scale cyclic plate loading tests on unreinforced RAP bases and geocell-reinforced RAP bases over soft (target CBR=2 %) and firm (target CBR=5 %) subgrades to evaluate their performances. The bases had thicknesses of 0.15, 0.23, and 0.30 m. For a demonstration purpose, only the permanent deformations of the 0.15- and 0.30-m thick bases are shown in Fig. 13. In this figure, UR_soft and UR_firm stand for unreinforced bases over soft and firm subgrade respectively while R_soft and R_firm stand for geocell-reinforced bases over soft and firm subgrade. The permanent deformation increased with the number of loading cycles. The rate of the increase in the permanent deformation decreased with an increase of the loading cycles. The permanent deformation of the RAP base decreased with an increase in the subgrade strength, the base thickness, and the geocell confinement. The amount of the permanent deformation increased rapidly during the first few loading cycles and

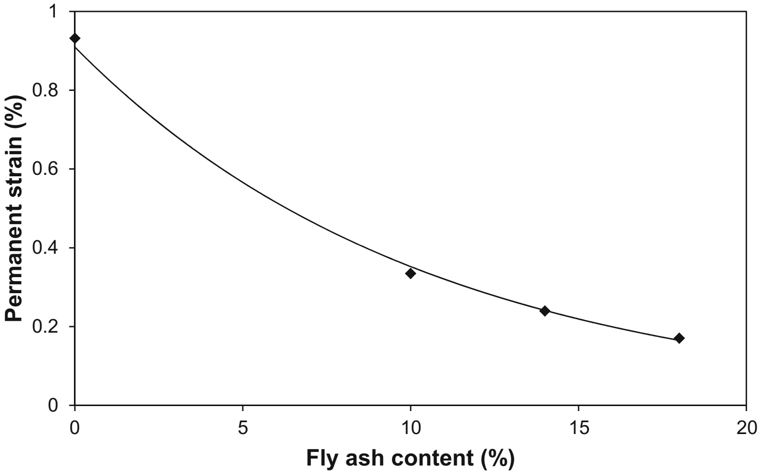


Fig. 12 Permanent strains versus fly ash content for the fly ash-stabilized RAP specimen (redrawn and modified from Wen et al. [33])

then increased at a reduced rate for the reinforced bases. Therefore, the reinforced bases showed a stabilizing response with a reduced rate of plastic deformation.

Creep Deformation

Creep is a time-dependent deformation of a material under a constant static load that is lower than its maximum load capacity. Granular materials (such as sand and aggregate) used as construction materials typically have low creep potential. Since RAP has asphalt binder, it is expected to have higher creep potential. Creep behavior of RAP under a constant stress may vary depending upon the level of applied stress. Cosentino

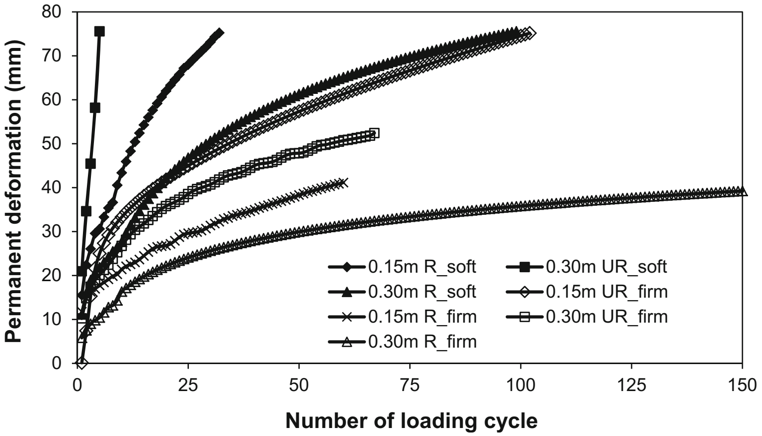


Fig. 13 Permanent deformation versus the number of loading cycles for the geocell-reinforced RAP bases (redrawn and modified from Thakur [25])

et al. [10] conducted creep tests on blended RAP-soil specimens under a fully confined condition at two vertical static stresses using the Brainard Kilman Terraload Consolidation Load Frame and confirmed that RAP crept under static loading. The creep deformation behavior is shown in Fig. 14. In this figure, RAP0 stands for the 0 % RAP or 100 % soil sample tested under an applied vertical stress of 231 or 462 kPa, RAP80 stands for the RAP-soil (80–20 %) blended sample tested, and RAP100 stands for the 100 % RAP sample tested. The soil used for blending with RAP was weak organic soil. The 100 % soil sample had most strain, followed by the blends containing 100 and 80 % RAP. They found that the creep deformations of the samples increased with an increase in the applied vertical stress and the RAP content. The rate of the increase in the creep deformation decreased with time.

Thakur et al. [26] conducted static plate loading tests in a test box and a compaction mold to investigate the effects of confinement, stress, and cover on creep deformations of unreinforced and geocell-reinforced RAP bases. They evaluated the creep deformation behavior of the following RAP specimens under two applied vertical stresses (276 and 552 kPa): unreinforced base (a RAP base prepared in a test box without geocell), single geocell-confined sample (a RAP sample prepared by placing RAP into the single geocell pocket), single geocell-confined base (a RAP base prepared by placing RAP into the single geocell pocket and the test box), multi-geocell-confined base (a RAP base prepared by placing RAP into the multi-geocell pockets and the test box), and fully confined sample (a RAP sample prepared by placing RAP into the modified Proctor compaction mold). The axial creep strain versus time curves for the RAP at five confining conditions at the applied vertical stresses of 276 and 552 kPa are shown in Fig. 15. The geocell reduced the immediate deformations of the geocell-reinforced RAP samples or bases by 18 to 73 % as compared with the unreinforced RAP base. The fully confined sample had 81 to 86 % lower creep deformation than the unreinforced base. The RAP samples or bases at 552 kPa crept more as compared with those at 276 kPa under the same confining conditions. It can be concluded that RAP crept more at the higher vertical stress and lower degree of confinement and vice versa.

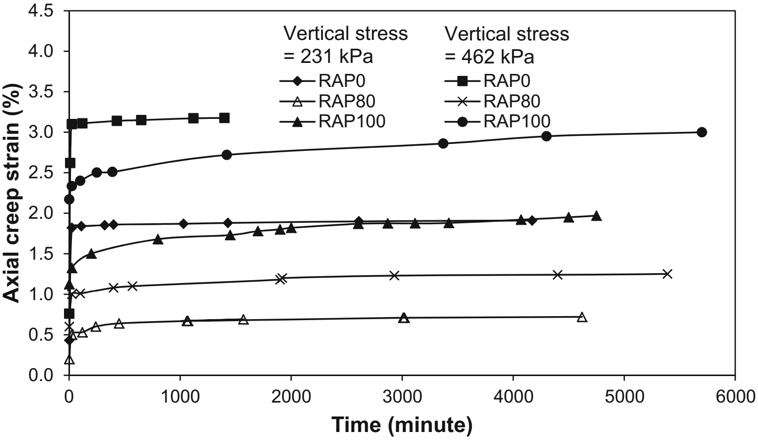


Fig. 14 Effect of RAP content and vertical stress on the creep behavior of the RAP-soil blends (redrawn and modified from Cosentino et al. [10])

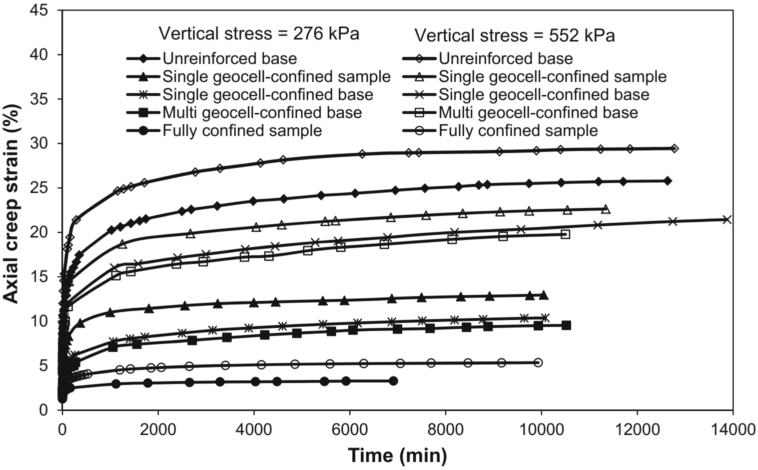


Fig. 15 Effect of confinement and vertical stress on the creep behavior of the geocell-reinforced RAP bases (redrawn and modified from Thakur et al. [30])

Conclusions

Extensive literature review was conducted on blended RAP aggregate, chemically stabilized RAP-aggregate blends, and geocell-reinforced RAP bases. The effects of blending, chemical stabilization, and geocell reinforcement on resilient modulus (M_R), California Bearing Ratio (CBR), shear strength, unconfined compressive strength (UCS), permanent deformation, and creep deformation of these bases were discussed. Based on the analyses of data presented in this paper, the following conclusions can be drawn:

1. The resilient modulus of the blended RAP aggregate base increased with an increase in the RAP content and the bulk stress and M_R of chemically stabilized RAP increased with an increase in the stabilizing agent content, the curing time of a sample, and the bulk stress.
2. The CBR of the blended RAP aggregate base decreased with an increase in RAP and the CBR of the chemically stabilized RAP base increased with an increase in the stabilizing agent content.
3. With large variations, the friction angle of the blended RAP aggregate increased with the percent of RAP while the cohesion of the blended RAP aggregate decreased with the percent of RAP.
4. The unconfined compressive strength of the blended RAP aggregate decreased with an increase in the RAP aggregate while that of the chemically stabilized RAP sample increased with an increase in the stabilizing agent content and the curing period.
5. The permanent deformations of the blended RAP aggregate and the geocell-reinforced RAP bases increased with the number of loading cycles. The permanent deformation of the blended RAP aggregate increased with an increase in the RAP content. The permanent deformation of the chemically stabilized RAP decreased with an increase in the stabilizing agent content. The rate of permanent deformation decreased with the number of loading cycles. The blending, chemical stabilization, and geocell confinement improved the performance of the RAP bases.

6. RAP crept more at a higher vertical stress and a lower degree of confinement. Blending and geocell confinement reduced the creep deformations of the RAP bases.

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