Chapter

Applications of Cement in Pavement Engineering

Sarella Chakravarthi, Galipelli Raj Kumar and Sabavath Shankar

Abstract

Recycled materials primarily Reclaimed Asphalt Pavement (RAP), and Recycled Concrete Aggregate (RCA) are produced from pavement rehabilitation and construction-demolition activities. Generally, these materials are utilized for landfills, parking lots, shoulders, and other places that are not environmentally friendly. The top layers of the pavement and concrete structures are constructed using superior qualities of aggregates that satisfy the specification. During their service life, the aggregates present in these structures undergo deterioration due to environmental and traffic factors. After reaching the end of their service life, the deteriorated structures are dismantled and considered as waste. Nevertheless, these recycled materials will have some retain value which can be used in different layers of the pavements in different percentages. The reuse of these materials in place of conventional aggregates preserves the environment and become a sustainable construction practice. Further, the direct utilization of these materials in the pavements may not satisfy the mechanical characteristics. To fulfill these gaps, cement stabilization of recycled materials is the best option. With this background, the proposed book chapter will highlight the usage of cement in pavement application, and a few types of research works carried in cement treated pavement layers will be discussed in a detailed and scientific manner.

Keywords: cement concrete pavement, granular layers, cement treated bases and performance of pavements

1. Introduction

Recycled materials primarily Reclaimed Asphalt Pavement (RAP), and Recycled Concrete Aggregate (RCA) are produced from pavement rehabilitation and construction-demolition activities. Generally, these materials are utilized for landfills, parking lots, shoulders, and other places that are not environmentally friendly. The top layers of the pavement and concrete structures are constructed using superior qualities of aggregates that satisfy the specification. During their service life, the aggregates present in these structures undergo deterioration due to environmental and traffic factors. After reaching the end of their service life, the deteriorated structures are dismantled and considered as waste. However, these recycled materials have some retain value which can be used in different layers of the pavements in different percentages. The reuse of these materials in place of conventional aggregates preserves the environment and become a sustainable construction practice. However, the direct utilization of these materials in the pavements may not achieve acceptable mechanical characteristics. To fulfill these mechanical properties with recycled materials, stabilization is the best option left to the engineers.

Several stabilization techniques are involved around the world to provide adequate strength to the weak bases or soil materials. The stabilizers include lime, asphalt emulsion, fly ash, and cement are widely used to improve the mechanical properties of recycled materials as a base or subbase courses in pavements. Cement stabilization is advantageous because of rapid gain in strength and its easy availability in the market. To understand the mechanical properties of the recycled materials with cement stabilization, a laboratory study is carried using RAP and RCA in different proportions with Natural Aggregates (NA). The compaction characteristics, Unconfined Compressive Strength (UCS), Indirect Tensile Strength (ITS), and Modulus of Elasticity (E) tests were conducted to assess the performance.

Apart from the recycled aggregates, several hazardous and industrial wastes from the production plants like Electrolyte Manganese Residue (EMR), Red mud, slag, and glass can be efficiently stabilized using cement and can be used in the pavements as a base. Zang et al. (2019) proved that the stabilization of the EMR and Red mud in the road bases achieved adequate strength and make it environmentally friendly [1]. The replacement of conventional aggregates with 50% steel slag stabilized with 4% cement content achieved maximum strength and stiffness along with other economic benefits [2]. At the same time, the use of cement treated recycled glass up to 30% along with the other recycled materials achieved required strength properties [3]. Besides, it is estimated from the study that 26-32% of cost savings with the cement stabilization of the recycled aggregates [4].

The usage of cement in pavement construction is considerable. There are several applications in the construction field that includes bridges, tunnels, safety barriers, pavements, and sound barriers. The benefits of cement-treated bases include high bearing capacity and increased stiffness, and lower deformation under loads. The following are the potential advantages of cement in various construction fields which are listed below.

- Airports for parking aprons, taxiway and runway take-off
- Parking areas for heavy vehicles
- Heavy-duty industrial floors
- Usage of cement and concrete in bridge decks
- Subgrade soil stabilization with cement
- Soil stabilization with lime and cement
- Recycling of pavement with treated and bases and subbases
- Construction of dry lean cement concrete layer
- Debonding layer over stabilized cemented bases
- Construction of concrete pavement
- Construction of interlocking bloc pavement s
- Cell filled pavements.

With this background, the application of the cement in the field of pavement engineering as a base and sub-base layer is presented. This includes evaluation in terms of mechanical properties at various cement stabilization levels and finally compared with the available specifications.

2. Literature review

The potential use of recycled aggregates in pavement bases is investigated around the world. Their utilization in the pavement is limited due to inferior physical and mechanical properties. Reclaimed asphalt pavement (RAP) materials used in the pavements has concerns with the reduction in the strength, more significant permanent deformation, poor distribution of stresses, and durability issues and recommended for stabilization [5, 6]. Besides, the use of recycled concrete aggregates (RCA) above the water table is recommended [7] due to the concerns of groundwater contamination and durability issues [8, 9]. Studies suggested that the properties of the recycled materials can be enhanced with the addition of additives or blending with superior quality materials [10]. The stiffness of the base increases with the cement stabilization, which reduces the deflections and increases the pavement life at higher traffic loads and serves better than NA bases [8, 9]. With this background, there is a stressing need for chemical stabilization of recycled materials to improve their mechanical properties. Some of the previous studies were presented in **Table 1**, which shows the benefits of the cement stabilization on various recycling materials.

Author, year	Conclusions
Arulrajah et al. 2020 [11]	Stabilization of construction and demolition wastes containing a little amount of polyethylene terephthalate with 3% cement satisfied the requirements of pavement base and subbases.
Kasu et al. 2020 [4]	Cement content in the mix has a significant influence on the mechanical and durability properties compared with recycled aggregate contents.
Arshad, 2020 [12]	Addition of cement content in the range of 1.5-4.5% improved the mechanical properties and reduced the strains in the recycled aggregate blends
Yan et al. 2020 [13]	The addition of recycled aggregate content from the construction and demolition waste into the stabilized bases improves the mechanical and durability properties. However, the residual strength is maximum at 30% of the recycled aggregate content in the mix.
Chakravarthi et al. 2019 [14]	Concluded that cement stabilization of the RCA is more pronounced than RAP and improvement in the mechanical properties is observed.
Faysal et al. 2016 [15]	Strength and stiffness characteristics are significantly improved with cement content.
LaHucik et al. 2016 [16]	Cement stabilization on a small scale for the bases with recycled materials like RAP and Quarry by-products is feasible for no freeze zones.
Behiry, 2013 [17]	Revealed that the performance of cement treated recycled materials depends on cement content, curing time and dry density.
Xuan et al. 2012 [18]	Stated that an increase in the cement content and decreasing the masonry content improves the strength and modulus of the bases.
Taha et al. 2002 [19]	Replacement of cement stabilization of RAP-virgin aggregate mixes in place of conventional bases considered a viable alternative.

Table 1.
Previous studies on cement stabilization of recycled bases.

3. Objectives and methodology of the study

The current study aims at laboratory evaluation of the cement stabilized bases consists of recycled materials like RAP and RCA as a partial and full replacement with natural Aggregates (VA) with the following goals.

- To determine the influence of the cement content and recycled aggregates content on the stabilized base mixes in terms of various mechanical properties.
- To optimize the cement content, recycled aggregates, and VA combination for road bases based according to the standard specifications.
- Stiffness characterization of the given recycled aggregates and VA combinations at different stabilization levels.

The required materials such as conventional aggregate, RAP, RCA, and ordinary Portland cement of 53 grade are collected locally. Aggregate gradations for the test mixtures were determined and compared with the requirements following the Ministry of Road Transport and Highways (MoRTH, 2013) specifications, Government of India (GoI) [20]. Initially, bitumen was extracted from the collected RAP material, followed by physical tests like Sieve analysis, impact test, Flakiness, and Elongation index were performed on RAP and RCA according to the standards as shown in **Figure 1**. From the physical properties, the flakiness and elongation index for RAP is higher than the specification limits, and the water absorption of the RCA is more than 2%. The flakiness and elongation index of RAP aggregates is due to the formation of fracture surfaces during its service life. The crushing process and the water absorption of the RCA are more compared with the VA because of the presence of cement mortar around its surface. Although the recycled materials did not satisfy the required specifications, they are used in the study. This is the main motivation of the study to improve their mechanical properties through the process of stabilization. After physical characterization, the materials are blended in the ratio of RAP/RCA and conventional aggregate content (0/100, 25/75, 50/50, 75/25) as shown in **Figure 2** with an increment of cement from 0%, 2%, 4%, 6%. The next step involves the determination of compaction characteristics of the mixes such as Optimum moisture content

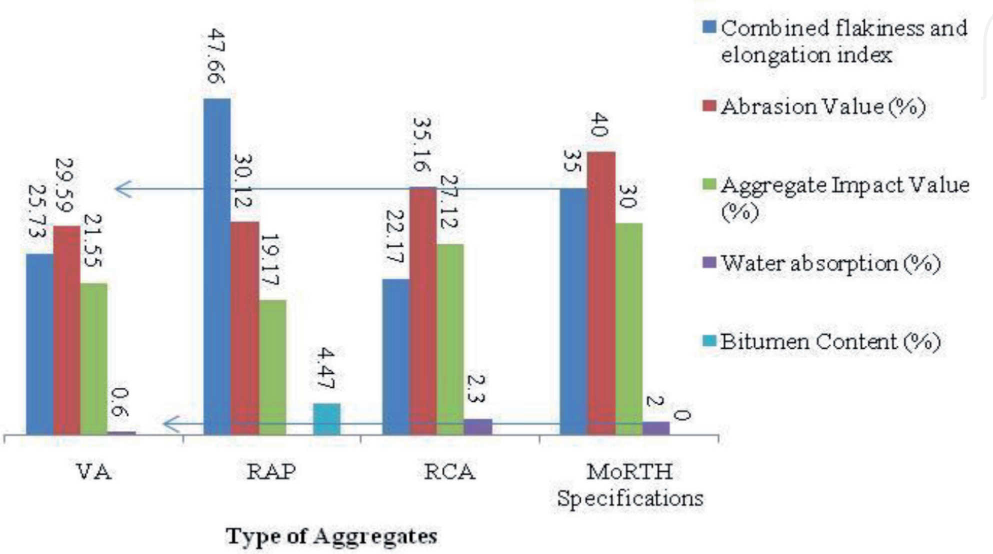

Figure 1.
Physical properties of aggregates.

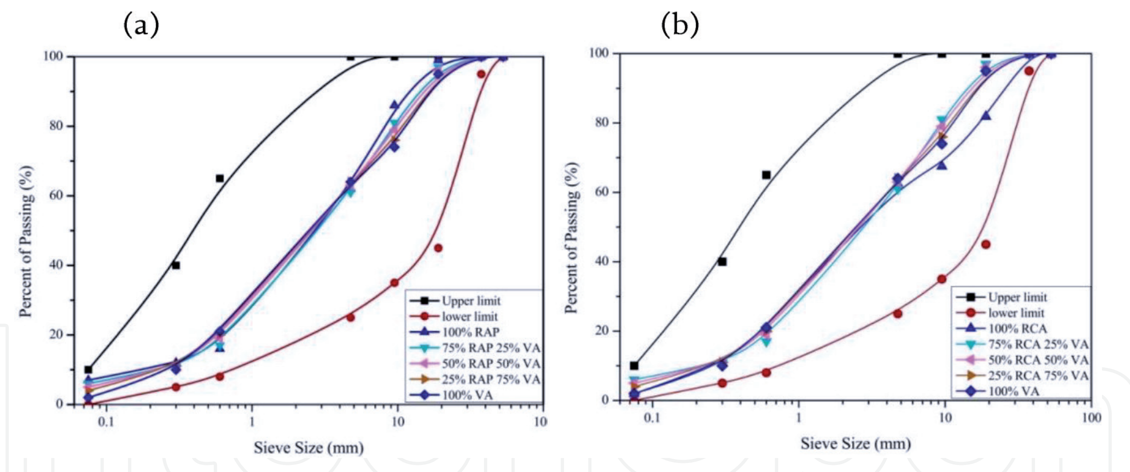

Figure 2.
(a) Gradation curve for RAP blends; (b) gradation curve for RCA blends.

(OMC) and maximum dry density (MDD) using the Modified Proctor Test. The obtained OMC values from the modified Proctor test are used in the preparation of the samples for further tests and cured for 7 days as suggested by the researchers. The strength parameters like UCS, ITS, and stiffness parameters like Modulus of elasticity and Resilient Modulus were evaluated for the specimens prepared at OMC.

4. Compaction characteristics

Modified Proctor's test was performed according to the Indian Standards (IS 2720-part 8-1985) on all the mixes proportions of RAP and RCA with VA. The test is repeated three times to check the repeatability and accuracy. Modified Proctor compaction is achieved using a hammer of weight 4.5 kg falling from a height of 457 mm in the mold of dimensions 102 mm in diameter and 127 mm in height. All particle sizes greater than 19 mm were replaced with the same amount of particles less than 19 mm from the mix as a mold correction.

The obtained OMC and MDD results for different blending mixes are shown in **Tables 2** and **3**. It is revealed that the required amount of OMC is reduced with the increase in the percentage of RAP due to the low moisture absorption capacity of bitumen coated RAP. While the MDD is low at 100% RAP and increases with VA content due to the low specific gravity of the RAP aggregates which agrees with the previous research study [21] and MDD increases with the cement content. The addition of the cement to the mix improves the compaction capacity due to good aggregate packing. In the case of RCA blends, there is no proper trend observed with the addition of RCA due to the indifferences in mortar on the surface of RCA. The same is verified by conducting a water absorption test on two samples of the

% of cement	100% RAP		75% RAP		50% RAP		25% RAP	
	OMC (%)	MDD (g/cc)	OMC (%)	MDD (g/cc)	OMC (%)	MDD (g/cc)	OMC (%)	MDD (g/cc)
0	7.06	1.93	7.44	2.03	7.61	2.13	7.16	2.20
2	7.13	2.08	7.52	2.08	7.72	2.14	7.38	2.22
4	7.24	2.11	7.64	2.10	7.89	2.15	7.67	2.22
6	7.45	2.21	7.88	2.11	7.95	2.16	8.09	2.23

Table 2.
Optimum moisture content and maximum dry density results for RAP blends.

% of cement	100% RCA		75% RCA		50% RCA		25% RCA	
	OMC (%)	MDD (g/cc)	OMC (%)	MDD (g/cc)	OMC (%)	MDD (g/cc)	OMC (%)	MDD (g/cc)
0	9.7	2.14	9.2	2.13	12.3	2.02	9.44	2.13
2	8.2	2.1	10.2	1.98	7.93	2.16	10.06	2.2
4	11.1	2.06	9.2	2.01	9.28	2.17	9.44	2.22
6	9.5	2.09	11.5	1.97	10.92	2.2	10.35	2.25

Table 3.
Optimum moisture content and maximum dry density results for RCA blends.

same gradation with the difference in the mortar presence. This variation of mortar percentage in the sample causes significant variations in the OMC and MDD at high percentages of RCA in the mix (100%RCA and 75% RCA). The MDD values of RAP and RCA blends ranges between 1.93 and 2.25 g/cc.

5. Unconfined compressive strength test (UCS) and elastic modulus

The Unconfined Compressive Strength (UCS) is used to determine the bonding strength or cohesion of a stabilized material. The samples are prepared at corresponding OMC according to ASTM D 1632. The dimensions of the cylindrical mold are of size 101.6 mm diameter, and 200 mm height is chosen. The samples are compacted and cured in closed plastic bags to prevent the escape of moisture. They tested at the end of the 7 days curing period. The UCS is calculated from the maximum load at the failure divided by the cross-sectional area of each specimen gives the compressive strength (**Figure 3**).

There is a surge in the UCS with cement content, as observed in **Figure 4**. Besides, the rate of increase in strength declines with the addition of recycled aggregates content. Higher RAP content slows down the rate of strength gain in the mixtures. For example, the mixes with increased recycled aggregates content have low strength at given cement content. The increase in asphalt coated surface area requires more amount of the stabilizing agent to form bonds with the other aggregates. Besides, the RCA stabilized bases do not show any particular trend with RCA content.

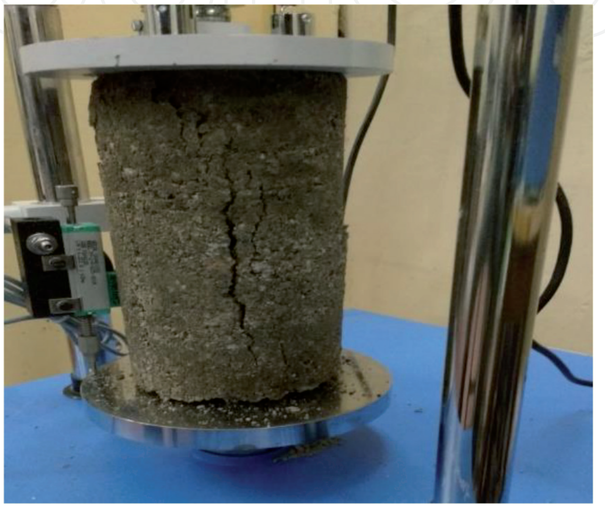

Figure 3.
Sample testing of UCS.

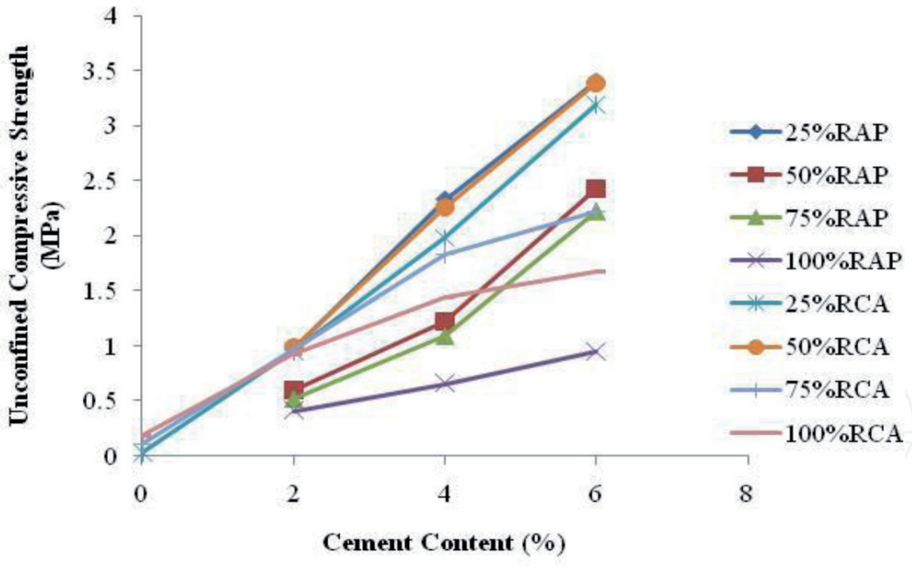

Figure 4.
Unconfined compressive strengths of RAP - VA and RCA - VA blends of varying cement percentages.

Further, 50% of RCA shows higher strength irrespective of the cement content; this is due to the better interlocking of RCA with the NA, which increases the strength. At 6% cement content, all the mixes exhibit higher strengths. The obtained results are compared with the low volume road standards for cement-treated bases, as shown in **Table 4**.

From the observations, the majority of the blends at 4% cement satisfied the specifications as a subbase layer for low volume roads. However, RAP/RCA blends with 25% RAP and 6% cement content have UCS of 3.4 MPa/3.19 MPa and 50% RCA with 6% cement with UCS of 3.37 MPa satisfied the Ministry of Rural Development (MoRD) specification, i.e., 2.76 MPa and can be used as a base layer for low volume roads and as a subbase layer for high volume roads. To extend their utilization as a base layer in the high-volume roads requires an increase in stabilization levels and curing period.

Further, RCA blends show more strength compared with RAP blends. For instance, at constant cement content, 100% RCA mix show almost double strength compared with 100% RAP mix. The reason behind this phenomenon is due to the existence of a strong bond between RCA, VA, and cement. Besides, the mortar which is coated with the RCA aggregates contributes to the development of strength. The RCA blends without stabilization exhibited retained strength at 7 days of curing. This clearly explains the self-cementing property of the RCA in agreement with the previous studies where the mortar present in the RCA helps in bonding [23].

Besides, the untreated RAP mixes are weak and collapsed while removing from the split mold, which represents the weak bonding between the aggregates. The strength development in the blends depends on the blended aggregate proportions, stabilization level, and the residual cement present in the existing RCA. However,

UCS (MPa)			
Low volume road (traffic <2 msa) [22]		High volume road (traffic >2 msa) [20]	
Sub-base	Base	Sub-base	Base
1.70	2.76	1.5-3.0	4.5-7.0

Table 4.
UCS as per Indian specifications.

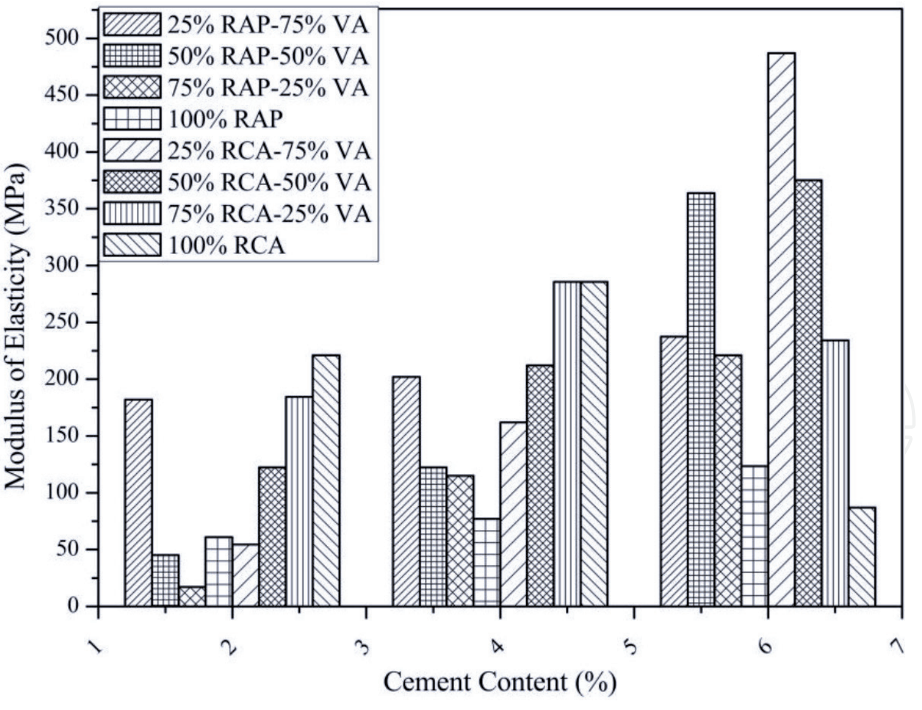

Figure 5.
Modulus of elasticity of RAP VA and RCAVA mixes at 7 days curing period.

RAP did not have a contribution to strength development [24]. A linear relationship is noticed between the UCS and the cement content irrespective of the type of mix. Out of which 25% RAP-75% VA and 50% RCA - 50% VA blends show a rapid gain in strength. This is due to the existence of the unhydrated mortar in RCA, less asphalt coated surface area, and presence of high-quality aggregates, and better interlocking between the aggregates along with the stabilization.

Elastic modulus is the ratio of applied stress to corresponding strain within the elastic limit. This property is used to characterize the materials and to analyze the stresses and strains in different pavement layers. With the continuous application of loads, the recoverable character of these materials will be declined, and the plastic deformation is accumulated. This repeated application of load property is measured using Resilient Modulus (M_R) (**Figure 5**).

The elastic modulus of RAP/VA and RCA/VA blends at different cement contents after 7 days of curing period is calculated. The elastic modulus of RCA blends ranges from 11.95 MPa at 100% RCA with 0% cement content to 486.96 MPa at 25% RCA at 6% cement content. In contrast, the elastic modulus of RAP blended mixes ranges from 60.99 MPa at 100% RAP at 2% cement content to 363.78 MPa at 50% RAP at 6% cement content.

There is a linear increase in the elastic modulus with an increase in the cement content in each mix. However, 100% RCA and 75% RCA-25% VA at 6% cement content there is a tremendous decrease. This is due to the overdosage of the cement to the mix in addition to the existing residual mortar surrounding the aggregates, which makes the material more brittle.

Blending with VA improved the modulus of all RAP mixes as the elastic modulus increased with the increase in the percentage of VA in the combination. The scenario is completely reverse in the case of RCA blends where the elastic modulus increases with the increase in the RCA. This trend is observed up to a smaller dosage of cement contents that is 4%. Whereas at 6% cement, the scenario is completely different for RCA mixes, further addition of the RCA to the mix lowers the modulus values. This clearly shows the effect of blending, in addition to the cement content, equally impacts the overall performance of the mix.

6. Indirect tensile strength test (ITS)

The tensile strength of the cement-treated bases is important as cement-treated materials generally weak in tensile. The developed tensile cracks extend to the top of the pavement layers and weaken the pavement structure makes it susceptible to moisture. Generally, the tensile strain at the bottom of the bituminous layer is considered for analysis which also represents the top of the cement-treated base. The higher the tensile strength represents is more resistance to the tensile stresses that cause in the base. To determine the tensile strength characteristics, the ITS test is carried out on RAP, and RCA blends at different cement contents curing for 7 days. The samples are compacted at the obtained OMC to reach the maximum density with dimensions of the internal diameter of 101.60 mm and 63.5 ± 2.5 mm in height and then extracted after 24 hours followed by curing for 7 days. Then cured samples are tested for ITS as per ASTM D6931 at a loading rate of 50.8 mm per minute, and the failure load is noted. The Indirect Tensile Strength is determined by using the following formula:

$$S_T = \frac{2000P}{\pi D t} \quad (1)$$

Here, S_T is the Indirect Tensile Strength in N/mm^2, D is the Diameter of the Specimen in mm, t is the thickness of the specimen in mm, and P is the Ultimate Failure Load in kN (**Figure 6**).

From **Figure 6**, it is observed that ITS value decreases as the RAP content increases with constant cement; this is due to weak bonding between the RAP and conventional aggregates. 25% RAP with 6% cement shows more ITS value and 50% RCA with 6% cement content have higher ITS in case of RCA blends. The ITS values

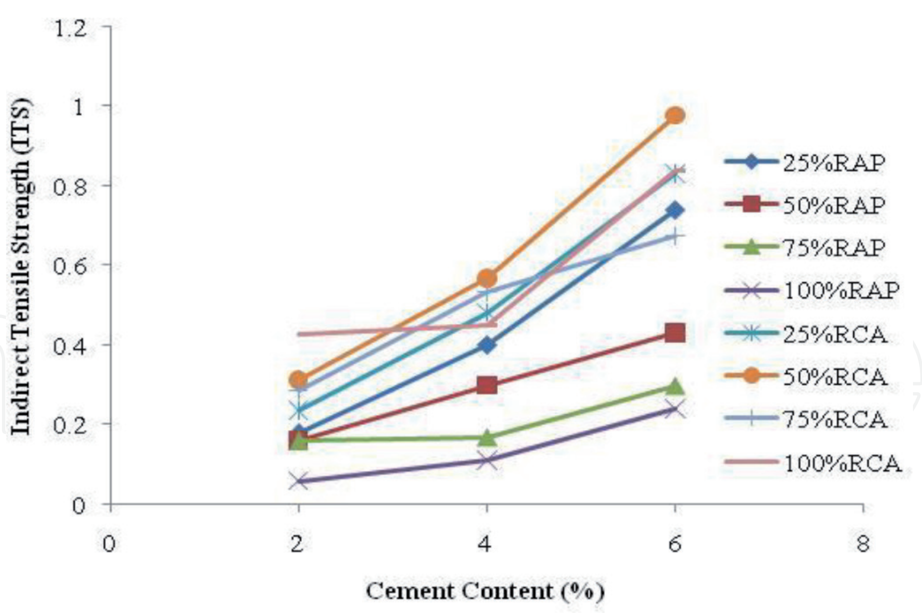

Figure 6.
Indirect tensile strengths of RAP-VA and RCA-VA blends of varying cement percentages [14].

Country/code	ITS (MPa)	
Italy [25]	0.32-0.60 (gyratory compaction) > 0.25 (proctor compaction)	
South Africa [25]	>0.25 for cement 1.5-3%	>0.20 for cement 3-5%

Table 5.
ITS of different countries specifications.

increase with the increase in the amount of cement. The RCA blends show more strength compared with RAP blends as observed in UCS. 50% RCA blends followed by 25% of RCA blends show higher strength compared with remaining blends. This is due to the existence of proper interlocking between RCA and VA and the self-cementing behavior of RCA. In contrast, the RAP blended mixes have a weak bond compared with RCA due to the existing bitumen coating. It is observed that at an average the ITS value is 0.2 times that of the UCS value of RAP treated bases and 0.32 times that of UCS value in case of RCA treated bases for a 7-day curing period.

The ITS value of the present study is compared with other country's specifications. Moreover, it is observed that the acceptable UCS is around 0.20 MPa from **Table 5**. All the recycled aggregate blends achieve this value except 100% RAP at 3% cement content. However, RCA blends achieved the required ITS at 2% cement content.

7. Resilient modulus

Resilient Modulus (M_R) is the ratio of deviator stress to the recoverable strain under the application of repeated loading. It is one of the important stiffness parameters and used as input in the pavement design by most of the transportation departments. The samples were prepared according to ASTM D 1632 and ASTM D 6926 using a cylindrical metal specimen with an interval diameter of 101.60 mm and 63.5 ± 2.5 mm in height. The repeated-load indirect tension test is used to determine the resilient modulus of the mixtures according to ASTM D 4123 by applying compressive loads with a waveform at 25°C temperature and 1 Hz for loading frequencies (the recommended load range can be 10 to 20% of the indirect tensile strength). The Poisson's ratio for the calculation of resilient modulus was assumed as 0.2. The resilient modulus is calculated using the following equation.

$$ERT = \frac{P(\mu + 0.27)}{\Delta H^{*} t} \quad (2)$$

where P is the repeated load, μ is the Poisson's ratio, ΔH is the horizontal deformation, and t is the thickness of the specimen.

Figure 7 shows that M_R value increases with the cement content and decreases with the RAP content. The maximum stiffness values were observed for 25% RAP mixes

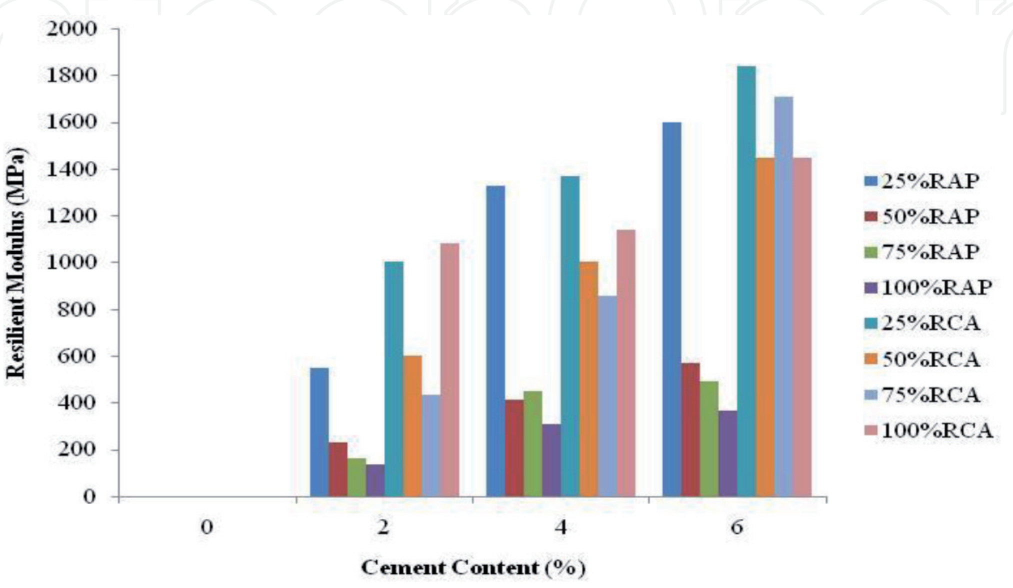

Figure 7.
Resilient Modulus of RAP-VA and RCA-VA mix at 7 days curing period.

and 75% RCA as well. However, there is no appropriate trend that is observed in the RCA blends. However, there is an increase in the stiffness of the mixture independent of the RCA content. As the test is conducted at 7 days of the curing period, more curing periods might be required to gain sufficient stiffness for the cement-treated RAP bases.

8. Applications of the cement-treated recycled bases

The motive of the utilization of the cement-treated recycled bases is to improve the bearing capacity of the base layer with already used aggregates which is a conservative method. It is one of the sustainable construction practices and economical. The selection of the optimum amount of the cement stabilizer is necessary to detrimental overdosage effects like shrinkage. Besides, there is an increase in carbon footprints with a high amount of cement content. The cement-treated recycled bases can be served as a base and subbase layer in the low volume and high-volume roads as well. The Full-depth reclamation, along with cement stabilization, is advantageous when the pavement condition Index is low with poor hydro planning. It will create a strong base layer that can be covered with a thin asphalt layer. Further, the RCA can be used in the base and subbase layers, which is a locally available source. Stabilization of RCA leads good results in decreasing the leachate problems and to improve the mechanical properties.

9. Conclusions

After a thorough investigation of the strength and stiffness properties of the cement-treated recycled materials, the following conclusions are drawn:

- Cement Stabilization of the recycled materials improved the strength and stiffness of the mixes. However, the recycled material content in the mix plays a critical role in the strength development for RAP mixes.

- Maximum strength is achieved at 50% RCA and 25%RAP blended mixes which are measured in terms of ITS and UCS.

- The relation between the ITS and UCS of the cement-treated based is established. On average, the ITS value is 0.2 times that of the UCS value for RAP treated bases and 0.32 times that of UCS value in the case of RCA treated bases at 7 days of curing period.

- Cement stabilization of RCA blends is more effective compared with RAP blends in terms of mechanical properties.

- Based on the experimental results, cement stabilized recycled materials require more curing period to achieve adequate strength and stiffness. All the stabilized bases achieved the target strength at 6% cement content for low volume roads subbases except 100% RAP mix.

Author details

Sarella Chakravarthi, Galipelli Raj Kumar and Sabavath Shankar*
Department of Civil Engineering, National Institute of Technology, Warangal, India

*Address all correspondence to: ss@nitw.ac.in

References

[1] Zhang Y, Liu X, Xu Y, Tang B, Wang Y, Mukiza E. Preparation and characterization of cement-treated road base material utilizing electrolytic manganese residue. Journal of Cleaner Production. 2019; 232:980-92.

[2] Liu J, Yu B, Wang Q. Application of steel slag in cement-treated aggregate base course. Journal of Cleaner Production. 2020:121733.

[3] Arulrajah A, Disfani MM, Haghighi H, Mohammadinia A, Horpibulsuk S. Modulus of rupture evaluation of cement stabilized recycled glass/recycled concrete aggregate blends. Construction and Building Materials. 2015; 84:146-55.

[4] Kasu SR, Manupati K, Muppireddy AR. Investigations on design and durability characteristics of cement-treated reclaimed asphalt for base and subbase layers. Construction and Building Materials. 2020; 252:119102.

[5] Guthrie, W. Spencer, Dane Cooley, and Dennis L. Eggett. Effects of reclaimed asphalt pavement on mechanical properties of base materials. Transportation Research Record. 2005; 1: 44-52.DOI: 10.3141/2005-06

[6] Puppala, Anand J., Laureano R. Hoyos, and Ajay K. Potturi. Resilient moduli response of moderately cement-treated reclaimed asphalt pavement aggregates. Journal of Materials in Civil Engineering. 2011; 23(7): 990-998.DOI: 10.1061/(ASCE)mt.1943-5533.0000268

[7] Murray Reid, J., Khaled E. Hassan, Okan Sirin, and Ramzi A. Taha. Demonstrating the Worth of Recycled Aggregates—A Case Study from Qatar. In Geo-Chicago 2016. p. 534-545. DOI: 10.1061/9780784480137.051

[8] Pérez, Pablo, Francisco Agrela, Rosario Herrador, and Javier Ordoñez. Application of cement-treated recycled materials in the construction of a section of road in Malaga, Spain. Construction and Building Materials. 2013; 44: 593-599. DOI: 10.1016/j.conbuildmat.2013.02.034

[9] Eren, Ş. and Filiz, M. Comparing the conventional soil stabilization methods to the consolid system used as an alternative admixture matter in IspartaDarıdere material. Construction and Building Materials. 2009; 23 (7): 2473-2480.DOI: 10.1016/j.conbuildmat.2009.01.002. Available from: http://www.sciencedirect.com/science/article/pii/S0950061809000038.

[10] Arulrajah, A., Piratheepan, J., Disfani, M. M., & Bo, M. W. Geotechnical and environmental properties of recycled construction and demolition materials in pavement subbase applications. Journal of Materials in Civil Engineering. 2013; 25(8), 1077-1088.DOI: 10.1061/(ASCE)MT.1943-5533.0000652

[11] Arulrajah, Arul, SahanPerera, Yat Choy Wong, SuksunHorpibulsuk, and FarshidMaghool. Stiffness and flexural strength evaluation of cement stabilized PET blends with demolition wastes. Construction and Building Materials. 2020; 239: 117819.DOI: 10.1016/j.conbuildmat.2019.117819

[12] Arshad M. Laboratory investigations on the mechanical properties of cement-treated RAP-natural aggregate blends used in base/subbase layers of pavements. Construction and Building Materials. 2020; 254:119234.

[13] Yan K, Li G, You L, Zhou Y, Wu S. Performance assessments of open-graded cement stabilized macadam containing recycled aggregate. Construction and Building Materials. 2020; 233:117326.

[14] Chakravarthi, S., Anusha Boyina, Arun Kumar Singh, and S. Shankar. Evaluation of cement-treated reclaimed asphalt pavement and recycled concrete pavement bases. International Journal of Pavement Research and Technology. 2019; 12 (6): 581-588.DOI: 10.1007/s42947-019-0069-1

[15] Faysal, M., Mahedi, M., Aramoon, A., Thian, B., Hossain, M. S., Khan, M. A., & Khan, M. S. Determination of the structural coefficient of different combinations of cement-treated/untreated recycled base materials. In Geotechnical and Structural Engineering Congress; 2016. p. 1198-1208. DOI: 10.1061/9780784479742.100

[16] LaHucik, Jeffrey, Scott Schmidt, Erol Tutumluer, and Jeffery Roesler. Cement-treated bases containing reclaimed asphalt pavement, quarry by-products, and fibers. Transportation Research Record, 2580. 2016; (1): 10-17. DOI: 10.3141/2580-02

[17] Behiry, Ahmed Ebrahim Abu El-Maaty. Utilization of cement treated recycled concrete aggregates as base or subbase layer in Egypt. Ain Shams Engineering Journal. 2013; 4 (4): 661-673.DOI: 10.1016/j.asej.2013.02.005

[18] Xuan, D. X., L. J. M. Houben, A. A. A. Molenaar, and Z. H. Shui. Mixture optimization of cement treated demolition waste with recycled masonry and concrete. Materials and structures 45. 2012; 1-2: 143-151.DOI: 10.1617/s11527-011-9756-3

[19] Taha, Ramzi, Ali Al-Harthy, Khalid Al-Shamsi, and Muamer Al-Zubeidi. "Cement stabilization of reclaimed asphalt pavement aggregate for road bases and subbases." Journal of materials in civil engineering 14, no. 3 (2002): 239-245.DOI: 10.1061/(asce)0899-1561(2002)14:3(239)

[20] Ministry of Road Transport and Highways, Specifications for Road and Bridgeworks, Fifth Revision, Ministry of Road Transport and Highways, New Delhi, 2013.

[21] Guthrie WS, Brown AV, Eggett DL. Cement stabilization of aggregate base material blended with reclaimed asphalt pavement. Transportation Research Record. 2007; 2026(1): 47-53. DOI: 10.3141/2026-06

[22] MORD. Ministry of Rural Development: Specifications for Rural Roads. New Delhi: The Indian Roads Congress, 2014.

[23] Poon CS, Chan D. Feasible use of recycled concrete aggregates and crushed clay brick as unbound road sub-base. Construction and building materials. 2006; 20(8): 578-585. DOI: 10.1016/j.conbuildmat.2005.01.045

[24] Yuan D, Nazarian S, Hoyos LR, Puppala AJ. Evaluation and mix design of cement-treated base materials with a high content of reclaimed asphalt pavement. Transportation Research Record. 2011; 2212 (1):110-119.DOI: 10.3141/2212-12

[25] Autelitano, F., & Giuliani, F. Electric arc furnace slags in cement-treated materials for road construction: Mechanical and durability properties. Construction and Building Materials. 2016; 113: 280-289.DOI: 10.1016/j.conbuildmat.2016.03.054