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Evaluation of Cement Treated Reclaimed Asphalt Pavement and Recycled Concrete Pavement bases

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Abstract

During rehabilitation and reconstruction activities a lot of recycling waste is created which is utilizing mainly for landfilling. Reclaimed Asphalt Pavement (RAP) and Recycled Concrete Aggregate (RCA) are the two important sources of recycled waste. This RAP and RCA has some retained value which can be used in the subbase and base applications, in turn, create a sustainable environment. However, their adaptability varies geographically due to the climatic, environmental and specifications. The usage of these materials in the bases is limited due to the limited research and specifications. Aiming at the maximum utilization of the recycled materials without compromising the specifications, laboratory investigation was carried out on cement stabilized RAP and RCA by replacing with Conventional Aggregate (VA) in the ratios of 25/75, 50/50, 75/25, and 100/0. The results show that the RAP and RCA aggregate blends need higher cement contents to satisfy the specifications for high volume roads. For low volume roads, 25% RAP-75% VA, 25% RCA-75% VA and 50% RCA-50% VA at 6% cement content satisfied the specifications of UCS 2.67 MPa. No particular trend is observed in the OMC and MDD for RCA blends due to the distribution of mortar non-homogeneously. RAP blends show low strength properties compared with RCA blends. The Elastic modulus of the RCA blended mixes declines with the increase in the cement content and RCA content. Overall, 25% RAP-75% VA with 6% cement content and 50% RCA-50% VA at 6% cement performed well and can be utilized in the low volume roads.

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Keywords:"RAP; RCA; VA; UCS; ITS; Modulus of Elasticity"

1. Introduction

Reclaimed Asphalt Pavement (RAP) and Recycled Concrete Aggregate (RCA) are two primary recycled materials which are generating from the pavement rehabilitation and construction industry. Most of these materials are used for landfilling, parking lots, shoulders and other places which are not environmental friendly.

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Generally, superior qualities of aggregates are used in the surface courses and construction industry. Although they deteriorated to some extent due to environmental and traffic factors, they have some service life which can be used in the lower layers of the pavement in which stress levels are less compared to the top layers. Recycling of these materials will conserve the natural resources, preserve the environment, and maintains existing geometrics. RAP or RCA does not satisfy all the properties of the specifications due to deterioration in which they exhibit low strength properties. Although research works carried out on RAP and RCA bases around the world to increase the usage of these materials in the bases and subbases, their adaptability varies with geographical locations. The traffic scenario, type of material, and the climatic conditions are different around the world. So, there is a need to explore the properties of the RAP and RCA materials in the bases and subbases and to bring the confidence of their adaptability in the Indian roads. So, a laboratory study is carried out on RAP and RCA bases stabilized with cement by replacing VA in the ratios of 25/75, 50/50, 75/25, and 100/0. The tests include the physical properties, compaction characteristics, unconfined compressive strength (UCS), Indirect Tensile Strength (ITS), and Modulus of Elasticity (E).

2. Background

Cement stabilization is widely used to increase the bearing capacity of poor soils or aggregate which provide sound base and will transfer stresses without excessive deformation to the underneath layers. Besides this process, the physical properties, type of material, environmental conditions have an impact on the strength characteristics Guthrie et al. (2005). Upon the extensive literature research on the cement stabilized bases, several important points were observed. The asphalt content present in the RAP does not have any contributions towards the strength of Cement-treated bases by Yuan et al. (2011). The replacement of 50 to 75% VA with RAP stabilized with 1% cement is suitable and economical to use in the bases by Guthrie et al. (2007). Replacement of 60% RAP with VA with 2% cement shows low plastic strain by Puppala et al. (2017). Up to 60% RAP with 6% cement satisfies all the strength requirements by Khay et al. (2015). Sebesta (2005) reported that stabilized bases with higher cement contents exhibit more cracking. The Strength of RAP blends increases with the addition of the crushed stone aggregate and the cement content by Saha and Mandal (2017). The compressive strength increases with the increase in the RCA RAP ratio at constant cement content. On the other hand, RCA is the marginal material widely available with higher water absorption. The CBR values of RCA aggregates blends with different base materials increases with RCA content and then decreases by Bestgen et al. (2016); Arisha et al. (2017); Bennert and Maher (2005); and Haider et al. (2014). Due to the weak bond between the RAP and other aggregates as the RAP material is coated with the aged bitumen, more cement is necessary to stabilize the RAP bases Khay et al. (2015). Although several studies were carried out on the RAP and RCA bases, their stabilization levels vary with source to source. Very limited research is carried out on cement treated bases in India. So, there is a need to study the adaptability, and maximum utilization of the RAP and RCA stabilized bases in the Indian context. In the current study, laboratory evaluation in terms of physical properties, compaction characteristics, Unconfined compressive strength, Indirect tensile strength, elastic modulus is carried out by replacing RAP/RCA with VA in the ratio of 25/75, 50/50, 75/25, and 100/0 stabilized with cement contents of 2, 4, and 6 percentages. The main aim of the study is to evaluate the adaptability of the RAP and RCA blends for Indian low volume roads. Physical characteristics, compaction characteristics and performance tests include UCS, ITS, and Modulus of Elasticity (E) are evaluated in the Indian context.

3. Study Objective and Methodology

The study aims at evaluating the strength characteristics of cement treated bases. Materials required for the work like Virgin aggregate, RAP, RCA and Ordinary Portland Cement of 53 grade were used. Aggregate gradations for the test mixtures were determined in accordance with the grading requirements as mentioned in MoRTH 5th revision (2013). 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 to know whether it satisfies the requirements. The materials were blended in the ratio of RAP/RCA and virgin aggregate content (0/100, 25/75, 50/50, 75/25) with an increment of cement from 0%, 2%, 4%, 6%. The next step involves the determination of Optimum moisture content (OMC) and Maximum dry density (MDD) using the Modified Proctor test. The OMC value obtained from the modified Proctor test was used in preparing the samples for further tests and cured for 7 days as suggested by many researchers. The strength parameters like UCS, ITS and stiffness parameter like Modulus of elasticity were evaluated for the specimens prepared at OMC.

4. Materials

Materials include RAP of age 7 years, RCA, VA and Ordinary Portland cement of Grade 53 are collected from nearby surroundings of Warangal. VA includes different maximum aggregate sizes 26mm, 19 mm and 4.75 mm.

5. Specimen Preparation

After the performance of necessary tests, compaction characteristics like OMC and MDD are determined. Compaction was performed using Modified proctor testing procedure AASHTO T180. The mould dimensions were 102 mm in diameter by 127 mm in height. The hammer weight was 4.5 kg, and it had a free-fall distance of 457 mm. All particle sizes greater than 19 mm were replaced with the same amount of particles less than 19 mm from the mix as a mould correction. At obtained OMC, samples were cast to evaluate for UCS, elastic modulus and ITS.

6. Unconfined Compressive Strength Test (UCS)

UCS samples were cast at OMC according to ASTM D 1632 in which the dimensions of the cylindrical mould are 101.6mm diameter and 200mm height. Samples were cured in closed plastic bags to prevent the escape of moisture. The maximum load taken by each specimen was then divided by the cross-sectional area of the specimen to obtain the compressive strength.

7. Indirect Tensile Strength Test(ITS)

The samples were prepared using a cylindrical specimen with an 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 the samples are tested for Indirect Tensile strength as per ASTM D6931 at a loading rate of 50.8 mm per minute. The Indirect Tensile Strength is determined by using the following formula:

$$S_T = \frac{2000P}{\pi D t} \tag{1}$$

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.

8. Analysis of Results

Initially, the physical properties of various aggregates VA, RCA and RAP are obtained. The percentage of bitumen from the RAP after extraction using n-Propyl Bromide is of 4.47%. After, sieve analysis, physical properties include flakiness and elongation index, abrasion value, aggregate impact value and water absorption were carried out on, RCA, VA, and bitumen free RAP aggregates and compared with Ministry of Road Transport and Highways (MoRTH, 2013) and tabulated in Table 1.

Table 1 Physical properties of RAP, RCA and VA

Property	VA	RAP	RCA	MoRTH Specifications
Combined flakiness and elongation index	25.73	47.66	22.17	35
Abrasion Value (%)	29.59	30.12	35.16	40
Aggregate Impact Value (%)	21.55	19.17	27.12	30
Water absorption (%)	0.6	-	2.3	2
Bitumen Content (%)	NA	4.47	NA	-

From the physical properties, water absorption of RCA is high compared with VA and RAP which has high flakiness index does not satisfy the specifications. The flakiness and elongation index of RAP is more than the specified limits; this is due to the breaking of aggregates along the fracture surface while crushing. These fracture surfaces are formed during the service of the aggregates or maybe during the process of reclamation. The strength and stiffness of compacted cement treated, RAP mixes are mainly determined by the gradation of the mix and the cement hydration rather than the properties and shape of aggregate according to Yuan et al. (2011). So, the RAP material is considered, although the combined flakiness and elongation index of RAP didn't satisfy the specifications. The gradation curves for the RAP-VA blends and RCA-VA blends are presented in Fig. 1. From the gradation chart, it is observed that the gradation of all the blends follows almost mid-gradation.

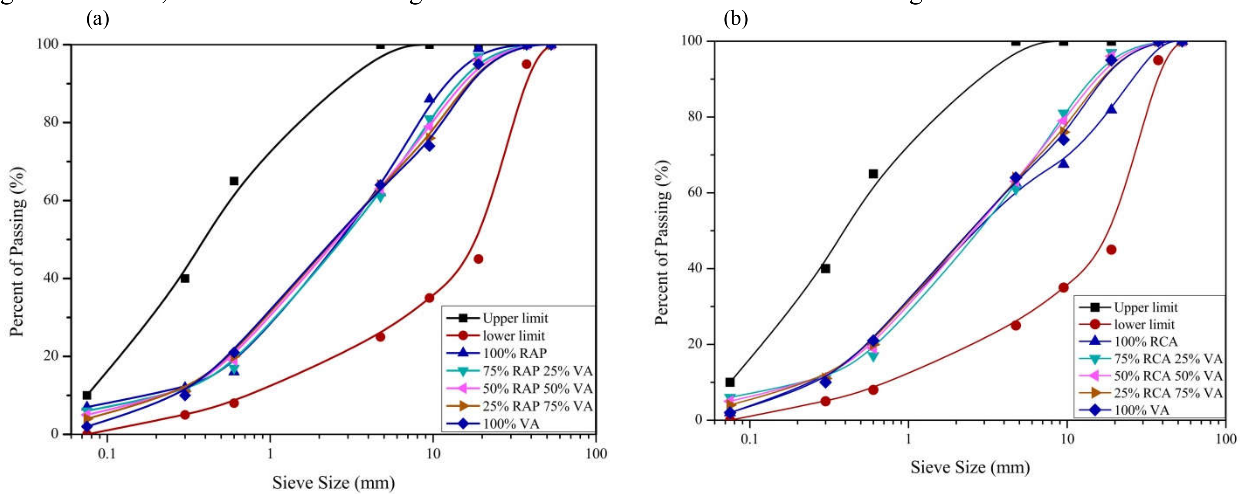

Fig. 1. (a) Gradation Curve for RAP blends; (b) Gradation Curve for RCA blends

8.1. Compaction Test

Modified Proctor's test was carried out as per IS: 2720 (part 8-1985). The compaction test is performed on all the mixes prepared with different proportions of RAP and RCA blends.

Table 2 Optimum Moisture Content and Maximum Dry Density Results for RAP Blends

% 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 3 Optimum Moisture Content and Maximum Dry Density Results for RCA 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

From the results of OMC and MDD obtained for different blending mixes are shown in Table 2 and 3, it is evidenced that relatively less water content is required at higher percentages of RAP which is due to less water absorption of RAP because of bitumen coating. MDD is low at 100% RAP and increases with VA content and cement content. This is because of the low specific gravity of the RAP aggregates. The MDD and OMC increase with the increase in the cement content. On the other hand, the RCA blends do not show any trend; this may be due to the presence of non-homogeneous material which means some samples may get more mortar surrounded by the aggregates and others surrounded less amount of mortar. More mortar presence leads to the high water absorption which increases the OMC. The same is verified by conducting water absorption test on two samples of the same gradation with the difference in the mortar presence. This variation of mortar percentage in the sample cause 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 to 2.23 g/cc and 1.97 to 2.25 g/cc. A relationship is established between the cement content - OMC and cement content - MDD. The results are shown in Table 4. A polynomial equation fitted for the RAP blends.

$$y = Ax^2 + Bx + C \tag{2}$$

where A, B, C are coefficients, y is OMC or MDD, and x is the percentage of cement content.

Table 4. Coefficients for OMC & MDD with respect to cement content

% RAP	100				75				50				25			
Description	Coefficients			R^2	Coefficients			R^2	Coefficients			R^2	Coefficients			R^2
	A	*B*	*C*		*A*	*B*	*C*		*A*	*B*	*C*		*A*	*B*	*C*	
OMC	0.008	0.011	7.063	0.99	0.010	0.012	7.444	0.99	0.003	0.078	7.601	0.98	0.012	0.079	7.163	0.99
MDD	0.003	0.062	1.939	0.95	0.002	0.028	2.031	0.99	0	0.005	2.130	0.99	0	0.008	2.201	0.91

Where the coefficient A in all the combinations is close to zero and can be neglected, and the coefficients B and C has a more significant effect. In all the cases the R^2 value is more than 0.9 which has a close relationship between the dependent and independent variables.

8.2. Unconfined Compressive Strength(UCS)

UCS test is performed on the specimens of dimensions 100 mm diameter and 200 mm height. The results of UCS for 7 days of curing period are shown in Figure 2. From Figure 2 (a) the strength increases with the increase in the VA and cement content and getting reduced as RAP content increases because an increase in RAP content increases the surface area coated with asphalt in a specimen which forms the weaker bond with the other aggregates which requires the higher quantity of stabilizing agent. On the other hand from Figure 2(b), 50% RCA shows higher strength irrespective of the cement content; this is due to the better interlocking of RCA with the VA which increases the strength. At 6% cement content, all the mixes exhibit higher strengths. 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 value, i.e., 2.67MPa and didn't satisfy MoRTH specifications, i.e., 5 MPa. So, 25% RAP/RCA-75%VA and 50% RCA and 50%VA with 6% cement content can be used in low volume roads as they acquired the required strength properties. Equations were developed for UCS variation with cement content for different blends as shown in the Figure 2.

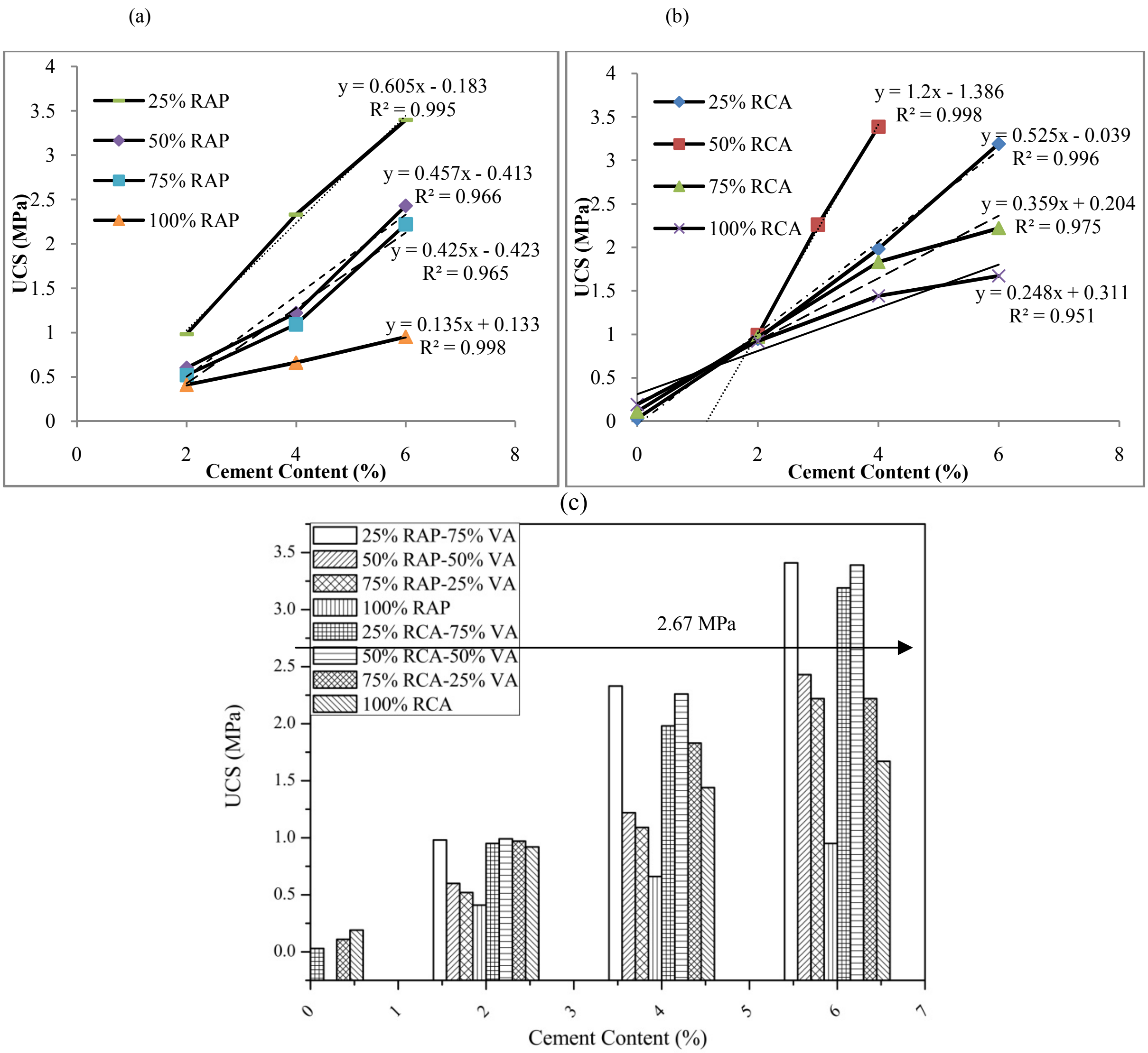

Fig. 2. (a) Unconfined Compressive strength of RAP - VA blends at 7 days of curing period, (b) Unconfined Compressive Strength of RCA-VA blends at 7 days of curing period, (c), Unconfined Compressive Strengths of RAP - VA and RCA - VA blends of varying cement percentages

From Figure 2c, compared with RAP blends, RCA blends show more strength. 100% RCA blends show almost double strength compared with 100% RAP blends. This is due to the existence of a strong bond between RCA, VA and cement. Mortar which is coated with the RCA aggregates contributes to the development of strength. RAP blended mixes have a weak bond compared with RCA due to existing bitumen coating. Attempts were made to perform the UCS for the RAP blended mixes without stabilization, but they are fragile and collapsed while removing from the split mould. This represents the weak bonding between the untreated RAP and RAP and VA blends. On the other hand, all the untreated RCA blends withstand after the removal of the split mould. This represents the mortar present in the RCA helps in bonding in the RCA blends which is also represents the self-cementing property of the RCA in agreement with the studies carried by Poon et al. (2006). The strength development in the blends depends on the mix proportion, cement content and the residual cement present in the existing RCA whereas bitumen coating of RAP did not have a contribution towards the strength development Yuan et al. (2011). A relationship between the UCS and cement content of different blends are established which is almost linear. The higher presence of RAP slows down the rate of strength gain which is represented by using the slopes of lines. Out of which 25% RAP-75% VA blends show a rapid gain in strength rate. In case of RCA blends a similar trend is observed in all cases except 50% RCA - 50% VA blend which has a higher rate of strength gain.

8.3. Stress-Strain curve:

A stress-strain curve is drawn to understand the behaviour of the different specimens of RAP and RCA blends. The larger the area under the curve represents the more energy stored in the specimen. The stress-strain curves are plotted in Fig. 3.

(a) (b)

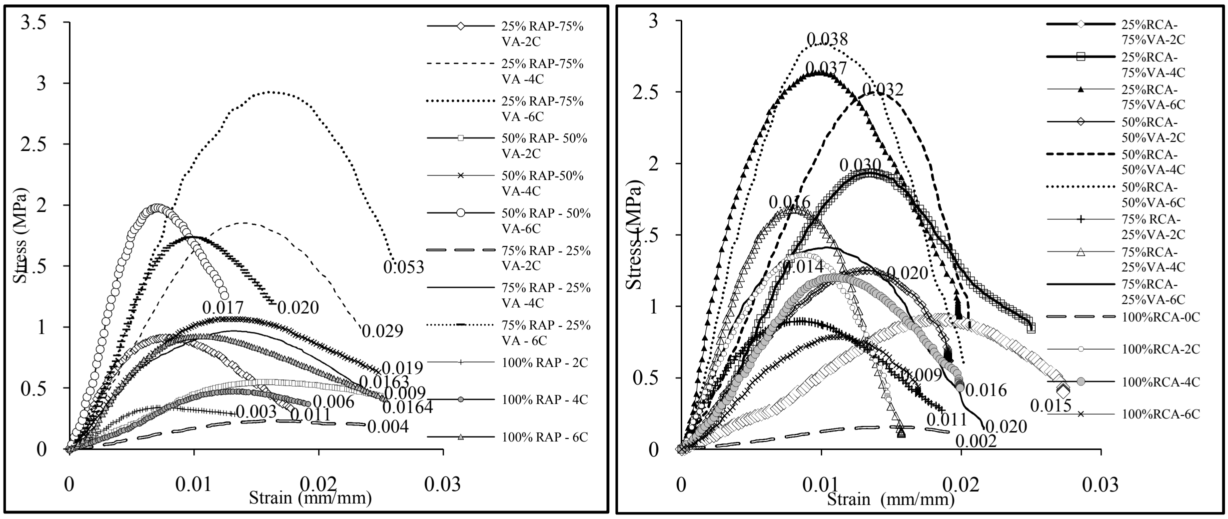

Fig.3. (a) Stress-Strain curve for RAP blended mixes; (b) Stress-Strain curve for RCA blended mixes

From the Stress-strain curves of RAP blends at different cement contents; it is observed that 25% RAP blended aggregate with 6% Cement content exhibits higher strength covering the larger area under the curve which represents more energy stored in it and in case of RCA blends, 50% RCA- 50% VA at 6% cement content exhibits peak represents high strength. The area under the curve is calculated by using Microsoft Excel by adding individual trapezoidal areas.

8.4. Elastic Modulus (E):

Elastic modulus is the term used to characterize the materials which are defined as the ratio of stress to strain within the elastic limit. The more the elastic modulus represents that the material can regain its original position under maximum loads. In the case of pavements, this property is essential as the vehicle passes over a certain point, it should be able to regain its original position under that load without causing permanent deformation. With the continuous application of this load, the recoverable character of these materials will be declined, and finally, permanent deformation occurs, this repeated application of load property is measured by using Resilient Modulus (MR) which is the ratio of the deviator stress to the recoverable strain.

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 whereas 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.

From Fig. 4, it is observed the modulus of elasticity of cement treated RAP and RCA blended mixes increases with the cement content. For 75% RCA and 100% RCA blends further increase in the cement content beyond 4%, shows brittle nature and decline in the elastic modulus whereas RAP blends show an increased trend in the elastic modulus.

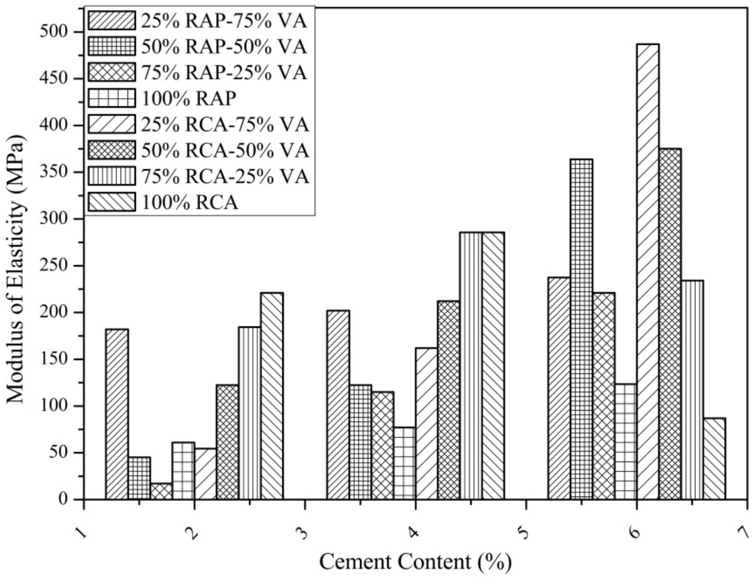

Fig.4. Modulus of Elasticity of RAP VA and RCAVA mixes

8.5. Indirect Tensile Test

ITS is indirect tensile strength which is an essential property in the pavement analysis. 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. Higher the ITS value represents that the base is more resistance to the tensile stresses. ITS test is carried out on RAP, and RCA blends at different cement contents of dimensions 100 mm diameter and 63 ± 2mm. The results of the ITS test are shown in Figure 5.

From Figure 5, it is observed that an increase in RAP content led to lower ITS values, whereas an increase in cement content led to higher ITS values. ITS value decreases as the RAP content increases with constant cement; this is due to weak bonding between the RAP and virgin 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. From Figure 5c, RCA blends show more strength compared with RAP blends. 50% RCA blends followed by 25% of RCA blends shows higher strength compared with remaining blends. This is due to the existence of proper interlocking between RCA and VA and self-cementing behaviour of RCA whereas the RAP blended mixes have a weak bond compared with RCA due to the existing bitumen coating. A similar trend as UCS is observed in the case of ITS in which the rate of gain in strength depends on the material proportions.

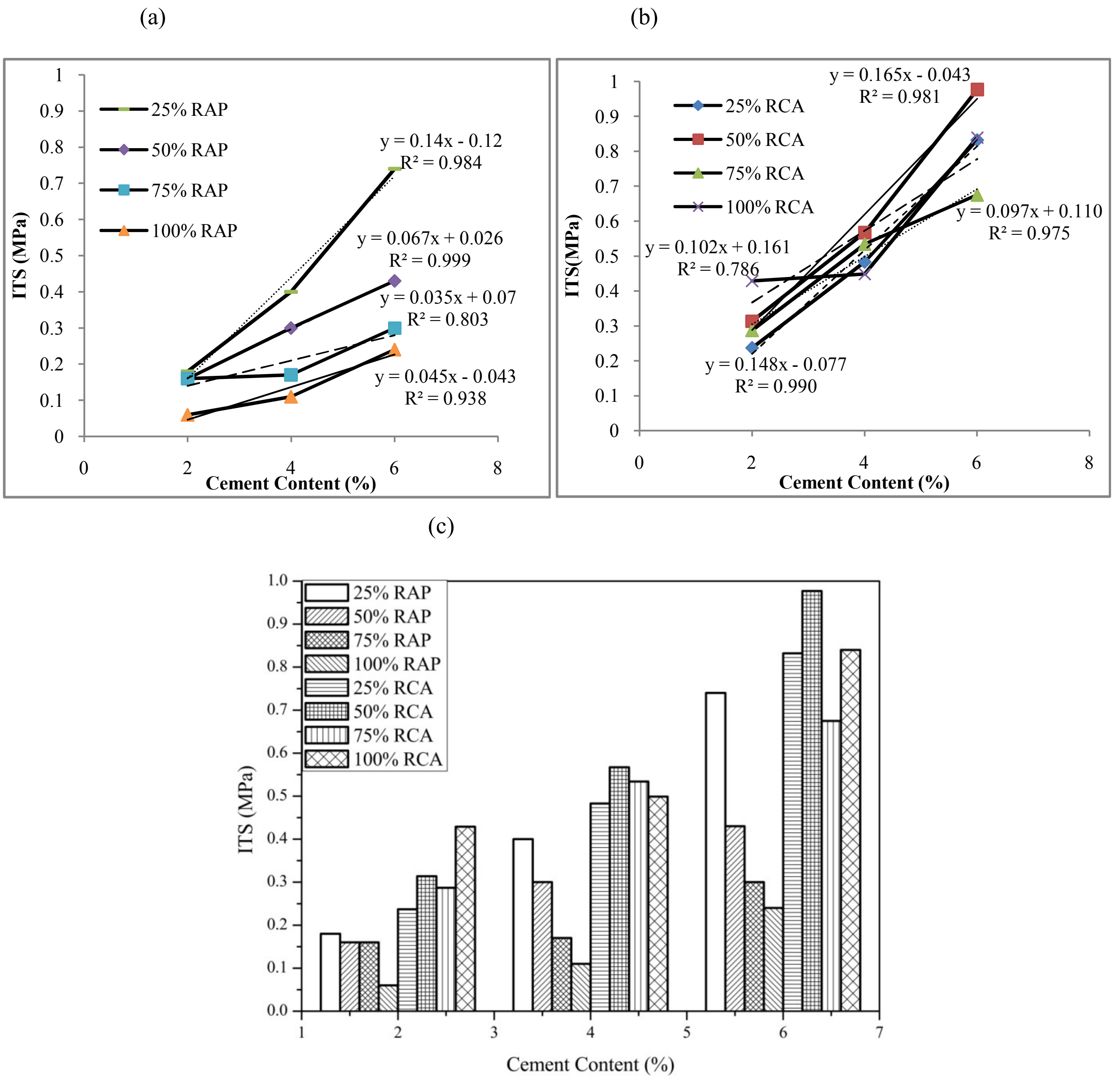

Fig.5. (a) Indirect Tensile strength of RAP VA blends at 7 days of curing period, (b) Indirect Tensile strength of RCA VA blends at 7 days of curing period, (c) Indirect Tensile strength of RAP VA and RCA VA blends of varying cement percentages

9. Conclusions

The following are the specific conclusions drawn from the study as presented below.

- It is concluded that the recycled concrete aggregate and reclaimed asphalt pavement bases requires more than 6% of cement contents to satisfy the Indian specifications for constructions of roads. Further, it is observed that as cement content in the mix increases, the values of maximum dry density increasing and when the percentage of RAP increases, the values of maximum dry density is decreasing due to low specific gravity of the RAP. It is further observed that there is a significant less change in OMC with the

RAP and cement content. A linear relationship was observed between cement content and OMC/ MDD for RAP blends. Fluctuations in OMC of RCA blends are observed due to the difference in the mortar presence in the RCA mixes.

- The unconfined compressive strength values increase with the cement content and decrease with the RAP content. The increase in strength is due to the formation of a strong bond with more cement content. The decrease in strength with RAP is due to the increase in creep surface area. The same phenomenon is observed in case of Indirect Tensile Strength (ITS). Also, the ITS and UCS of the RCA mixes are higher compared with the RAP blended mixes due to their self cementing properties.

- The RAP blends show an increased trend in the elastic modulus with cement content and decrease with the increase in the RAP content. For 75% RCA and 100% RCA blends further increase in the cement content beyond 4% shows brittle nature and decline in the elastic modulus. Summarily, 25% RAP and 75% VA with 6% cement content and 50% of RCA and 50% VA at 6% of cement exhibited significantly good strength.

10. Acknowledgements

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