International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 12, December-2021

Studies on Performance Characteristics of Warm Recycled Asphalt Mixes

Varuna M[1*], Bhavani Prasad G[2], Anjaneyappa Venkateshappa[3], Amarnath Macheri Srinivasarao [4]
[1,2,3]Department of Civil Engineering, RV College of Engineering,
Visvesvaraya Technological University, Bengaluru-560059, India
[4]Department of Civil Engineering, University
Visvesvaraya College of Engineering, Bangalore University Bengaluru-560056, India

***Abstract*: Recycling of asphalt pavement materials and incorporation of warm mix asphalt (WMA) technology are the two methods adopted for recycling existing pavements and also to reduce carbon emission. The quality of reclaimed asphalt pavement (RAP) materials depends on its age, as the material rheology plays the prominent role. Studies were carried out on two different aged RAP materials viz, 8 years and 12 years using VG30 binder. The RAP materials were blended at varying proportions of 10, 20 and 30% for SMA mixes. Zycotherm is used as warm mix additive. Recovered binder and VG 30 with warm mix additive were characterized by complex modulus test. Mix design was carried out by Marshall method to determine stability and optimum binder content (OBC). The RAP Warm SMA mixes were tested for its indirect tensile strength (ITS) and rutting resistance. The binder rutting properties G*/Sin improved with increase in RAP content and fatigue parameter G*Sin decreased with increase in RAP age and its percentage. Based on performance tests conducted, it is observed that 12 years aged RAP indicated better resistance to rutting when compared to 8 years RAP binder. Similarly mixes prepared using WMA additives indicated better resistance to moisture for both 8 and 12 years aged RAP mix.**

Keywords: Warm mix asphalt, Stone matrix asphalt, Reclaimed asphalt pavement, Rutting, ITS

I. INTRODUCTION

Aggregates account to about 97% volume of bituminous mixes. Continuous dependency on new and freshly available materials leads to depletion of natural resources. Thus this can be reduced by adopting recycling techniques (Ferreira et al.2021). Recycling is a technique of replacing and rehabilitating the pavement structure influenced by the adverse effect of distresses. Using more quantity of RAP in asphalt mix increases stiffness and causes failure of pavements due to fatigue damage (McDaniel and Anderson.2001;Huang et al.2004;Daniel et al.2010 and Martin et al.2014).However, the studies conducted by (Widyatmoko et al.(2008); Al-Qadi et al. 2012 McDaniel et al.2012) showed that the dynamic modulus of the mix as compared to virgin mixes. The utilization of higher percentage of old RAP materials in bituminous mixes could be achieved by adding a softer grade of bitumen, use of gap graded mixes, or using warm mix additive (Elkashef et al.2018).The addition of warm mix asphalt in Stone matrix asphalt mix may be a one of the option to incorporate higher amount of RAP content as it contains rich binder with less ageing properties to improve durability. The addition of RAP improved fracture resistance of asphalt mixtures at intermediate temperatures and decreased with addition of warm mix asphalt (Singh et al. 2018). Beh et al (2017) carried out to investigation on the aging properties of low carbon emission mixes. (Xu et al.2021; Li et al.2021 and Behl et al. 2013) and proposed that WMA technology can be utilized at 20 to 30 degree Celsius lower than current HMA technology. Use of RAP in the conventional mix reduces the construction cost by 20-25%. Use of SMA has reduced rutting by 30-40% and increased moisture susceptibility with WMA additive. Guidelines are developed for using maximum RAP content. However, RAP gradation and RAP binder quality are the major concern in adopting appropriate quantity of RAP in construction. Hence in this study, an attempt is made to determine amount of RAP that can be utilized for SMA mixes with focus on mix performance using WMA technology.

II. SCOPE AND IBJECTIVES OF THE PRESENT STUDY

The scope of the study is to assess the effect of RAP material in SMA mix using warm mix asphalt as an additive. An attempt is made to find the influence of WMA on RAP materials with varied age of 8 and 12 years.

III. EXPERIMENTAL WORK

A. Materials and Mix

The conventional crushed aggregates used for preparation of specimen were collected from the nearby crushing plant. The RAP materials of having the age of 8 and 12 years were collected from various locations across the state of Karnataka; India.VG30 is used as binder and 0.2% Zycotherm is used as warm mix additive.

The representative sample of conventional and recovered binder was extracted by centrifuge method and later tested for basic properties. Complex modulus of binder i.e rutting and fatigue cracking parameters were determined and results are presented in Table I.

The gradation adopted for SMA binder layer is as per IRC SP 79-2008 and is shown in figure1. Marshall mix design was carried out as per Asphalt Institute-Sixth edition (MS 2). The SMA mix was prepared using 10, 20 and 30% percentage of RAP materials. Performance studies on the above mixes were carried out by conducting indirect tensile strength and rutting studies.

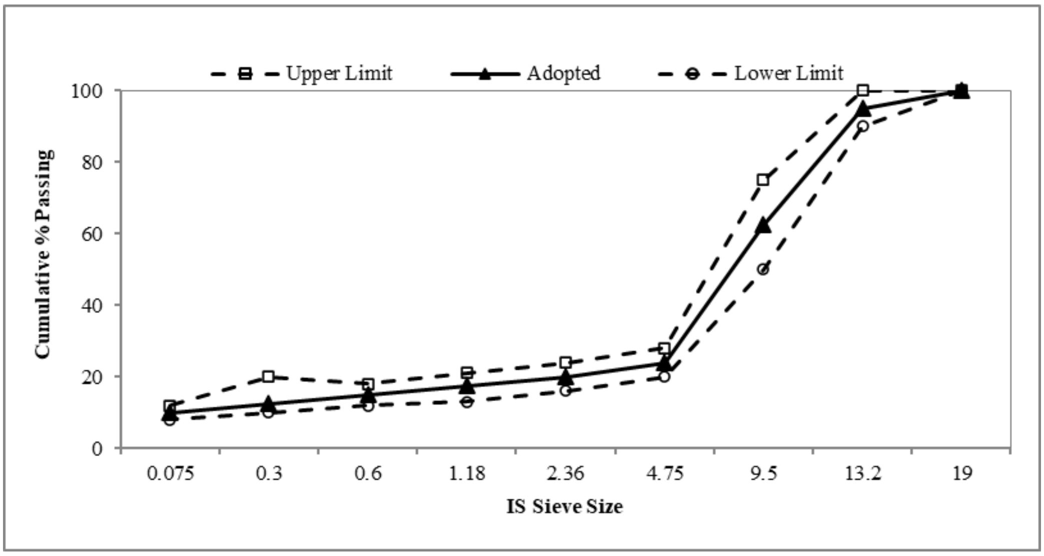

Fig.1: SMA binder course gradation as per MoRTH V revision

B. Marshall mix design

Marshall mix design was carried out on conventional and RAP mixes as per ASTM D 6927. Marshall Specimens were prepared for SMA mixes by incorporating RAP at proportions of 10%, 20% and 30% using VG30 with bitumen contents of 5%, 5.5%, 6% and 6.5%. The mixing and compaction temperature adopted for Warm SMA specimens for Marshall tests is 130 and 110 degree Celsius. IRC SP 79:2008 suggests minimum optimum binder content for SMA mixes to be 5.8%. Marshall properties at different binder contents and at Optimum binder content for different SMA mixes are presented in Table II.

C. Indirect Tensile Strength Tests

Moisture resistance of SMA mixes was evaluated by performing indirect tensile strength test as per AASHTO T283 at 7% air voids content. A compressive load was applied on cylindrical specimens at a rate of 5cm/min and the failure load for the specimen was noted.

Moisture sensitivity was determined by determining tensile strength ratio as per IRC SP 79:2008 on Marshall specimens The conditioned and unconditioned specimens were tested for ITS and TSR is calculated using equation

$$TSR = \frac{S_2}{S_1} x\ 10 \qquad (1)$$

where,

S1 = Unconditioned samples tensile strength, kPa

S2 = Conditioned samples tensile strength, kPa

As per IRC SP:79-2008, the minimum TSR percentage for SMA mixes should be 85 and the results of ITS test are shown in Fig 2.

D. Rutting studies

The behaviour of SMA mixes to permanent deformation was assessed by conducting rutting test at 60 degree Celsius. Slab specimen of dimensions 600mm × 200mm × 50mm is conducted at 60 degree using immersion wheel tracking machine. The deformation was recorded for 10,000 cycles for tyre pressure of 7kg/cm^2.

A. Rheological Properties

The binder rheological properties were evaluated by conducting rutting and fatigue parameter at 25 and 60 degree respectively. The binder rutting parameter (G*/Sin(δ)) should be more than 1.0 kpa and 2.2kpa for unaged and aged binder samples, likewise fatigue parameter (G*.Sin(δ)) should be less than 5000kpa for aged binder . From table I, it is observed that the binder rutting parameter improved with increase in RAP age and percentage due to increase in stiffness of binder. The decrease in rutting by addition of warm mix additive is due to increase in viscosity of binder. However, G*/Sinδ values are within the permissible limit (2.2 Kpa).

Similarly, from Table I, the fatigue parameter G*Sinδ increased with in RAP age and percentage indicating possibility of fatigue cracking due to stiffening of binder. All the mixes except 12 years aged mix with 30% RAP failed to meet criteria. However, 5 years aged RAP of all combinations exhibited better resistance to fatigue cracking. Similar trend was observed in published literature where fatigue cracking of mixes was decreased with the addition of WMA additive to hot asphalt mixtures containing different RAP percentages (Singh et al.2018 and Liu et al .2009).

B. Marshall Properties

The OBC and stability was determined for varied age and percentages of RAP. From Table II, the following observations were made. Optimum binder content increases with increase in age of RAP from 5 to 12 years, indicating more amount of bitumen is required to prepare SMA mix, however the stability of the mix increased with increase in age of the RAP indicating better strength of the mix.

C. Indirect tensile strength ratio

IRC SP 79:2008 recommends that TSR percentage should be more than 85% for SMA mixes. From Fig 2, it is observed that all the mixes satisfy the requirements of Indian roads congress. However, the mixes prepared using WMA additive indicated better resistance to moisture compared to mixes

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 12, December-2021

prepared without WMA. This may be due to the coating of WMA additive around the aggregates and acts as anti-stripping agent.

D. Rutting test

The test was conducted for 10,000-wheel passes, and the final deformation is presented in Table III.

TABLE I. RHEOLOGICAL PROPERTIES OF VG 30 AND RAP BINDER

Age of RAP, years	**Combinations**	**Rutting Parameter, kpa at 60°C**		**Fatigue cracking, kpa at 25°C**	
		Without WMA	***With WMA***	***Without WMA***	***With WMA***
Virgin 0 years	VG 30 binder	8.78	5.56	2987	1670
8	10% RAP binder + 90% VG30	14.2	8.56	3243	2830
	20% RAP binder+ 80% VG30	17.2	10.2	3860	2890
	30% RAP binder+ 70% VG30	26.7	19.3	4875	4678
12	10% RAP binder + 90% VG30	22.4	20.6	3768	3680
	20% RAP binder+ 80% VG30	36.4	30.4	4767	4789
	30% RAP binder+ 70% VG30	62.5	56.8	5002	4897

TABLE II. MARSHALL PROPERTIES OF SMA MIX

Particulars	**Type of mix**	**Conventional SMA**	**8 years aged RAP**			**12 years aged RAP**		
			10%	***20%***	***20%***	***10%***	***20%***	***30%***
OBC, %	Without WMA	5.8	5.8	6.0	6.3	6.0	6.1	6.4
Stability, KN		8.8	8.9	10.2	11.4	9.3	15.3	15.9
OBC, %	With WMA	5.8	5.8	5.8	6.0	5.8	5.9	6.1
Stability, KN		8.6	8.6	8.9	11.0	9.0	16.2	14.2

Table III. Rutting resistance for SMA mix

Particulars	**Conventional SMA mix, No of cycles**	**8 years aged RAP, Deformation, mm**			**12 years aged RAP, Deformation, mm**		
		10%	***30%***	***50%***	***10%***	***30%***	***50%***
Without WMA	4.3	3.8	3.5	2.9	3.7	2.8	2.5
With WMA	4.5	4.1	3.9	3.4	4.0	3.1	2.8

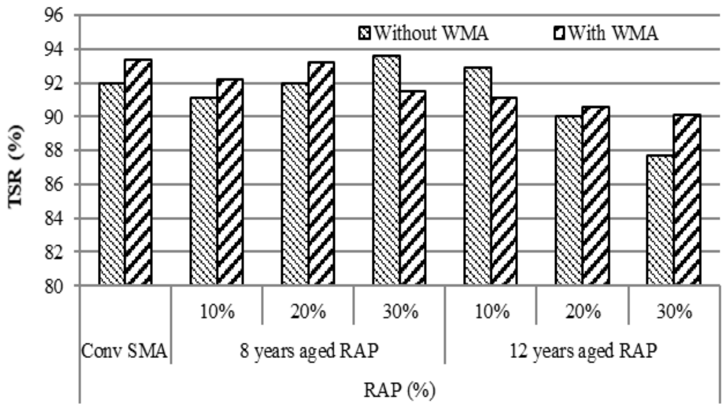

Fig.2: Tensile strength ratio values for SMA mixes

It is observed that SMA mixes prepared using WMA additive showed more deformation compared to mixes prepared without WMA. This may due to addition of WMA additive makes mix less ageing thereby less stiffness and more deformation. Likewise, it is also observed that, addition of RAP content increased rutting susceptibility of mix. RAP mix of 12 years aged showed better resistance to rutting when compared to conventional and 8 years aged RAP material.

V. CONCLUSIONS

The following conclusions were drawn from present study,

- Binder rutting property increased with RAP content and resistance to fatigue cracking decreased. However, 12 years aged mix having 30% RAP content will be prone to fatigue cracking as it fails to meet the requirements. Therefore, it may be necessary to rejuvenate the binder or use softer binder if the percentage or age exceeds the mentioned limits.
- Optimum binder content increased with increase in age and RAP percentage. For WMA mixes, the amount of binder required is less compared to mixes prepared without WMA additive.
- WMA mixes showed better resistance to moisture for all combinations of SMA mixes compared to mixes prepared without WMA additive.
- Addition of RAP in SMA mixes showed better resistance to Rutting due to increased stiffness of mix. SMA mix having 12 years aged with 30%RAP content showed better resistance to deformation compared to 8years aged RAP mix.

Thus, integrating Warm mix technology and RAP materials in gap graded asphalt mixes may be a step towards durable and sustainable pavements.

ACKNOWLEDGMENT

The authors declare there is no financial assistance or personal relationship that appeared to influence the work reported in this research article.

REFERENCES

[1] Al-Qadi, I. L., Aurangzeb, Q., Carpenter, S. H., Pine, W. J., &Trepanier, J. (2012). *Impact of high RAP contents on structural and performance properties of asphalt mixtures*.

[2] ASTM, D. (2006). Standard test method for Marshall stability and flow of bituminous mixtures. *Annual Book of ASTM Standards*, *4*.

[3] Behl, A., & Chandra, S. (2017). Aging characteristics of warm-mix asphalt binders. *Journal of Materials in Civil Engineering*, *29*(10), 04017155.

[4] Congress, I. R. (2008). Tentative specifications for stone matrix asphalt. *IRC: SP*, 79-2008.

[5] Daniel, J. S., Pochily, J. L., &Boisvert, D. M. (2010). Can more reclaimed asphalt pavement be added? Study of extracted binder properties from plant-produced mixtures with up to 25% reclaimed asphalt pavement. *Transportation research record*, *2180*(1), 19-29.

[6] Elkashef, M., Williams, R. C., & Cochran, E. (2018). Investigation of fatigue and thermal cracking behavior of rejuvenated reclaimed asphalt pavement binders and mixtures. *International Journal of Fatigue*, *108*, 90-95.

[7] Ferreira, W. L., Branco, V. T. C., Vasconcelos, K., Bhasin, A., &Sreeram, A. (2021). The impact of aging heterogeneities within RAP binder on recycled asphalt mixture design. *Construction and Building Materials*, *300*, 124260.

[8] ForoutanMirhosseini, A., Tahami, A., Hoff, I., Dessouky, S., Kavussi, A., Fuentes, L., &Walubita, L. F. (2020). Performance Characterization of Warm-Mix Asphalt Containing High Reclaimed-Asphalt Pavement with Bio-Oil Rejuvenator. *Journal of Materials in Civil Engineering*, *32*(12), 04020382.

[9] Huang, B., Zhang, Z., Kingery, W., &Zuo, G. (2004, May). Fatigue crack characteristics of HMA mixtures containing RAP. In *Fifth Int RILEM Conf Reflective Crack Pavements* (pp. 631-638).

[10] McDaniel, R. S., Shah, A., & Huber, G. (2012). *Investigation of low-and high-temperature properties of plant-produced RAP mixtures* (No. FHWA-HRT-11-058). United States. Federal Highway Administration. Office of Pavement Technology.

[11] Jattak, Z. A., Hassan, N. A., &Satar, M. K. I. M. (2021). Moisture susceptibility and environmental impact of warm mix asphalt containing bottom ash. *Case Studies in Construction Materials*, *15*, e00636.

[12] Li, Q., Sun, G., Lu, Y., Meng, Y., Luo, S., &Gao, L. (2021). Effects of warm-mix asphalt technologies and modifiers on pavement performance of recycled asphalt binders. *Journal of Cleaner Production*, *282*, 125435.

[13] Liu, S., Cao, W., Fang, J., & Shang, S. (2009). Variance analysis and performance evaluation of different crumb rubber modified (CRM) asphalt. *Construction and Building Materials*, *23*(7), 2701-2708.

[14] MoRT&H "Specifications for Road and Bridge Works"- 2013, Fifth Revision, Indian Roads Congress, New Delhi

[15] McDaniel, R. S., & Anderson, R. M. (2001). *Recommended use of reclaimed asphalt pavement in the Superpave mix design method: technician's manual* (No. Project D9-12 FY'97). National Research Council (US). Transportation Research Board.

[16] Singh, D., Ashish, P. K., &Chitragar, S. F. (2018). Laboratory performance of recycled asphalt mixes containing wax and chemical based warm mix additives using semi circular bending and tensile strength ratio tests. *Construction and Building Materials*, *158*, 1003-1014.

[17] Widyatmoko, I. (2008). Mechanistic-empirical mixture design for hot mix asphalt pavement recycling. *Construction and Building materials*, *22*(2), 77-87.

[18] Xu, W., Li, W., &Ji, Y. (2021). Mechanical Behavior Investigation of Reclaimed Asphalt Aggregate Concrete in a Cold Region. *Materials*, *14*(15), 4101.

[19] Zaumanis, M., Mallick, R. B., & Frank, R. (2014). 100% recycled hot mix asphalt: A review and analysis. *Resources, Conservation and Recycling*, *92*, 230-245.