Performance Studies On Stone Mastic Asphalt Mixes with Reclaimed Asphalt Pavement

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Abstract – Stone Mastic Asphalt (SMA) is a high-performance gap-graded bituminous mix widely recognized for its superior rutting resistance, durability, and long-term serviceability. However, its higher binder content and the need for stabilizing fibers make it costlier than conventional mixes, prompting the exploration of sustainable and economical alternatives. Reclaimed Asphalt Pavement (RAP), generated through pavement milling operations, offers an effective substitute for virgin aggregates and binder, reducing construction costs, conserving natural resources, and minimizing environmental burdens associated with waste disposal. This study evaluates the performance of SMA mixes incorporating RAP at varying replacement levels using two binder types—VG 30 and CRMB 55—along with 0.3% cellulose fiber as a stabilizing additive. The research program includes material characterization, Marshall mix design, drain-down assessment, Cantabro abrasion, moisture susceptibility analysis through Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR), permanent deformation (rutting), fatigue performance, resilient modulus testing, and rheological evaluation of binders using Dynamic Shear Rheometer (DSR). RAP-modified SMA mixes were prepared with RAP contents ranging from 10% to 60%. Results indicate that all materials, including RAP-derived binder, satisfy MoRTH specifications. SMA mixes with CRMB 55 exhibited higher stability, durability, and moisture resistance compared to those with VG 30. RAP incorporation increased mix stiffness and stability, with optimum performance achieved at 40% RAP for VG 30 and 50% RAP for CRMB 55. TSR values for these optimum RAP levels met the IRC: SP:079 requirement of >85%. Although durability decreased slightly with increasing RAP due to the aged nature of the material, all optimum mixes remained within permissible limits. Rheological studies confirmed improved high-temperature performance with modified binders. Overall, the study demonstrates that RAP-modified SMA mixes can effectively replace conventional mixes for heavy-traffic pavements while offering economic and environmental advantages without compromising performance.

***Key Words*: Stone Mastic Asphalt, Rut, Mix design, Marshall stability, Reclaimed Asphalt Pavement**

1.INTRODUCTION

The road network plays an essential role in the country's development as it provides better access to services, ease of transportation and movement of people. Since India is a developing country, there is a need for good infrastructure, transportation, and services. Most of the Indian roads are bituminous surfaced. The increased traffic intensity, overloading of vehicles and variation in temperature develops distress on the flexible pavements. The Indian Road network evolved tremendously in the past five decades and became the primary mode of transportation in the country. India has the second largest road network of over 6,371,847 km (2021) which includes 140,995 km of national highways and expressways, 171,039 km of state highways, and 6,059,813 km of other roads includes 96,214 km of national highways and expressways, 147,800 km of state highways, and 4,455,010 km of other roads as per MoRTH, but it has very small, paved roads considering overall area, which in turn leads to increase in transportation cost in the world market. Due to increase in the traffic volume and vehicle load on the pavement, it is essential to provide a pavement that meets the required standards.

To ensure durability of pavement with good riding quality, using high-durable asphalt mixes, will help to reduce the vehicle operating cost and maintenance cost of a flexible pavement. Bituminous concrete mix is a combination of aggregates and binder. The aggregates act as the pavement's structural skeleton and bitumen acts as the glue of the mix". The properties of the aggregates have a direct and significant effect on flexible pavement performance. utilizing industrial by-products and recycled materials (recycled aggregates) in construction as secondary and alternative materials has become recent development in flexible pavement construction and is also being widely accepted. Due to this recent development, the demand for recycled materials and industrial by-products increases per annum. Using industrial by-products in road construction leads possible savings over usage of new materials and reduces demands on conventional/natural available resources. 1 It also protects the environment from waste disposal of recycled materials. It makes cost of pavement construction more economical. A flexible pavement, which is designed and constructed properly, will eventually undergo various types of pavement distresses due to various reasons such as the type of paving materials used, number of years pavement served and environmental factors, etc. Among various types of pavement distresses rutting or grooving on the top layer, is the significant type of distress which reduces the life of the flexible pavements. This may be due to the improper compaction of base or sub-base layer or bituminous layers during construction. Therefore, the type of mix used in flexible pavement construction is essential for minimizing the rut depth. "Stone Mastic Asphalt or Stone Matrix Asphalt (SMA) is one such mix that provides tough and a durable asphalt mix. It is highly used as a rut-resistant mix for wearing and intermediate courses.

SMA is a gap graded asphalt mix that has a stone-on-stone contact to provide strength and has a rich mortar binder to provide durability. Generally, SMA is more expensive than conventional bituminous mixes because SMA requires high asphalt content, more durable aggregates, and fibers as a stabilizer". The cost of stone matrix asphalt is found to be 20 to 25 % more than the dense graded mixes. Hence, there is a need in laboratory studies of alternate/recycled materials that can decrease the cost of SMA mix. RAP is the scarified pavement material that contains aggregates and asphalt. Large quantities of RAP materials are generated during the construction and maintenance of the highway. The use of RAP materials can substitute the high consumption of coarse aggregates and binder in SMA mix. On the other hand, recycling of RAP also reduces depleting of natural aggregates and reduces the disposal issues of RAP materials generated from pavement rehabilitation.

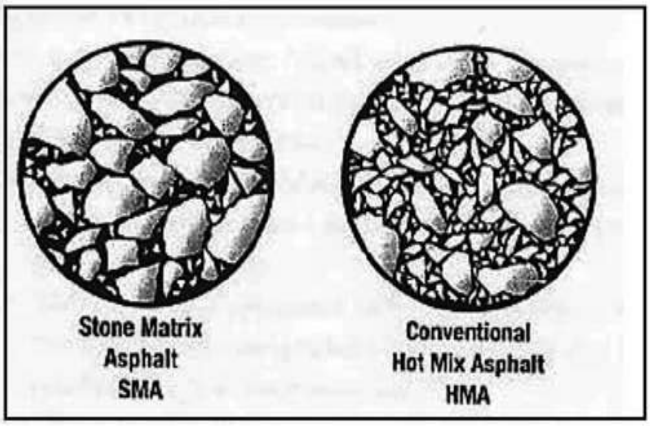

Fig. 1. Structure of SMA and Conventional HMA (Sandra et al., 2012)

OBJECTIVES

The main objective of this research work is to develop RAP Modified SMA mixes with unmodified and modified binders, which have to be compatible with dense and conventional gap-graded mixtures. It should also be globally accepted to accomplish the above goal and the following objectives.

To assess the suitability of using RAP in SMA Mix.

To study the effect of rutting at different temperatures and air voids using plain and modified binder for conventional and RAP replaced SMA mixes.

To study the fatigue characteristics at different temperatures and maximum stress level using plain and modified binder for conventional and RAP replaced SMA mixes.

To determine the optimum RAP content for SMA mix for heavy traffic conditions through a comprehensive evaluation of their performance characteristics.

2. LITERATUREREVIEW

Stone Matrix Asphalt (SMA) is a stable, tough, low permeable, improved low-temperature performance, durable, reduction of tire noise and rut resistant mix (Cooley and Hurley 2004). SMA was developed in Germany in 1960s after that it has been successfully used by many countries like Australia, Europe, and US, etc. U.S. designed SMA mix by following the "recipe" developed by German Specification (Bukowski 1991). In 1991, the Federal Highway Administration (FHWA) established technical group to develop guidelines for materials and construction of SMA mix which is entitled as "Guidelines for materials, Production, Placement of SMA" (NAPA). It is a gap graded mix consisting of 70-80% coarse aggregate, 8-12% filler, 6-7% binder, and 0.3% fiber. SMA consists of a higher percentage of coarse aggregates to form a stone skeleton-like structure, resulting in better rutting characteristics. An ideal SMA mix retains around 70% of coarse aggregates on or above 2.36mm sieve and 10% filler passing 0.075mm sieve (Brown 1993; Dong and Tan 2011).

SMA mix reduces maintenance and operation during pavement service life (Vale et al., 2006). As the binder content is high in this mix and due to its discontinuous gradation, mix requires the addition of fibers to prevent the drain down of the binder through the voids in the mix during storage and transportation. After the successful utilization of SMA mix in Europe, mix has been used in other countries like Germany, Spain, North America, and Belgium. Due to the performance of SMA mix in highly maintained traffic roads and in the airport as the layer is highly resistant and durable to assist the reduction of noise, a reflection of light during rainy nights, and reduction of water sprays from vehicle tires (Xue et al., 2009 and Dong and Tan 2011). SMA mix has rich binder content of about 6-7% due to the interlocking skeleton structure of mastic. After the compaction, SMA mix is impermeable with air voids less than 4% depending on the aggregates gradation system. Due to its gradation and high percentage of coarse aggregates, it has a rough macro texture, forming small channels between the aggregates accounting for an efficient drainage system (Motta et al. 2004)

NAPA (National Academy of Public Administration) has stated that the main advantage of SMA mix compared to conventional/dense graded HMA mix is extended life of pavement with improved performance throughout the pavement's service life. Other advantages are improved pavement performance i.e., out of 85 SMA projects (U.S.) (Brown et.al. 1999) evaluated by NCAT (National Centre for Asphalt Technology) it is observed 90% of SMA mix used in the projects has shown rut depth less than 4mm and it appeared to more rut resistant mix compared to dense graded HMA mix. 9 10 Meanwhile out of 85 projects there was no evidence of the raveling. (Watson and Jared 1996) concluded that SMA has 30 to 40% less rutting and 3 to 5% greater resistance to fatigue than conventional HMA mix.

Whereas EAPA (European Asphalt Pavement Association) has stated that failure mechanism such as stripping, raveling and surface cracking is not observed for SMA mix and provides 20 to 30 years of exceptional service life. As discussed above, noise reduction is a prime advantage in SMA mix i.e., one of the studies carried by Germany indicated that noise reduction is around 2.5 decibel (db) when dense graded mix is replaced with SMA mix (Hoppe 1991). 7.0 db noise reduction has been reported in Italy when SMA mix is compared with dense graded mix with 15mm nominal size aggregates were used (EAPA) and up to 5.2db noise level reduction has been reported in UK with 6mm nominal size SMA compared to hot rolled asphalt (EAPA). "Sousa et al. (2006) summarized all of the AR-Gap mixture design concepts and evolution of those principles, which reported the connection between mix design and pavement performance of these mixes". Serfass and Samanos (1992) studied the improved frictional resistance in SMA mix, even though water drain down is not the same as open graded frictional course (OGFC) but the surface texture of SMA mix is same as OGFC mix. Hence, they have concluded that SMA mix possesses a high frictional resistance, which provides safety for public when traveling on wet pavements and reduced the glare at rainy nights which is caused due to reflection of light from other vehicles. However, similar characteristics has been observed in OGFC mix.

Moisture susceptibility is a key cause of stripping failure in flexible pavements. Presence of water (moisture) weakens the asphalt aggregates bond which reduces the strength of the mix. In this direction, many research studies have been carried out to evaluate moisture susceptibility of SMA mixes and compared with dense graded mixes and mixes containing RAP materials are as discussed below. 22 Palit et al. 2004 studied the effect of adding CRMB in SMA mixes and evaluated the stripping properties of mixes through the Marshall method of mix design. By adding CRMB to SMA (modified mixes) stripping values are reduced 30 to 50% compared to dense graded mixes. Tensile strength ratio results indicated that crumb rubber modified asphalt mixes are less susceptible to stripping failure. Putman and Amirkhaian (2004) reported that adding crumb rubber to SMA mix helps reduce the moisture content in the mix and increases the tensile strength ratio of the mix by 90%. Chiu and Lu (2007) concluded that with the use of 20% fine ground tire rubber (GTR) with the maximum size of number 30 (0.6 00mm) sieve in SME mix will results in improving the tensile strength values compare to conventional mixes. Generally, RAP material is less prone to stripping compared to conventional mixes since, RAP is aged and stiffened material which will not allow water to enter the particles of the mix Karlsson and Isacsson (2006); Al Rousan et al. (2008) reported that with higher RAP percentage higher the moisture resistance of asphalt mixes. But if the blending of RAP binder and virgin binder is not carried out precisely and if there is variation in discharge temperature of mix it will result in reduction of moisture resistance of asphalt mix containing RAP.

Mogawer et al. (2012); Sondag et al. (2002) carried out tensile strength test on eighteen different mixes prepared with three different binders for various percentage of RAP (collected from two different sources) to evaluate moisture resistance. From the result they have reported that addition of RAP to conventional asphalt mixes has no effect on intensity of moisture damage. When the RAP is incorporated with different aggregates and binder types, it was observed that higher the RAP, tensile strength ratio of the mix is reduced. West et al. (2013) reported that the addition of RAP up to 40% has improved the TSR values and stated that absorption of binder into aggregates (RAP) would have formed a bond that will resist the stripping and incomplete blending would have resulted in double coaching of RAP.

Previous literature extensively discusses the use of RAP, concluding that there is little disparity in Marshall Properties and indirect tensile strength when employing either RAP or milled RAP. Additionally, numerous studies have conducted various tests on SMA mixes, including Marshall stability, fatigue, indirect tensile, and rutting tests, using different RAP percentages ranging from 0 to 40%. These tests reveal an increase in fatigue life with RAP content up to 30 to 40% in SMA mixes. Moreover, it's noted that a 30% RAP content offers superior rut resistance compared to conventional SMA mixes, with an observed increase in engineering properties as RAP percentage rises. Regarding binder types, researchers have investigated virgin bitumen and various modified binders such as SBS, polymer modified bitumen, crumb rubber modified bitumen, and penetration grade bitumen. Tests including indirect tensile, rutting, and fatigue tests were conducted, showing that polymer modified bitumen, crumb rubber modified bitumen, and PG bitumen (20-30) enhance fatigue life, rut resistance, and tensile strength of SMA mixes compared to virgin grade bitumen.

Additionally, studies indicate that the incorporation of waste tire and rubber into neat bitumen improves rheological properties. Combining RAP binder with virgin bitumen in SMA mix also demonstrates superior rutting and fatigue properties compared to SMA mix with virgin bitumen alone. Various types of fibers, such as cellulose fibers, natural fibers, polyester fiber, coconut coir, and asbestos, were introduced into SMA mixtures, with their effects on Marshall, fatigue, rutting, and drain down properties compared to SMA mixtures without fibers. It was observed that SMA mixtures containing 0.3 to 0.4% fiber exhibit reduced drain down, increased resistance to permanent deformation, and enhanced fatigue life compared to non-fiber SMA mixtures. Overall, from the literature review, it is evident that incorporating 30 to 40% RAP and using fibers at 0.3 to 0.4% and modified binders improve fatigue life, rut resistance, tensile strength ratio, and rheological properties in SMA mixes.

3. MATERILS AND ETHODS

The primary aim of this study is to integrate the maximum percentage of Reclaimed Asphalt Pavement (RAP) in Stone Matrix Asphalt (SMA) mixes. The experimental program primarily consisted of two significant tasks: conducting performance and characterization tests on conventional SMA mixes employing VG30 and CRMB 55 binders, and assessing RAP substituted SMA mixes also using VG30 and CRMB 55 binders. The experimental program details encompass material properties, the determination of binder rheological properties, stability assessments, durability tests, tensile strength analysis, moisture susceptibility evaluations, as well as performance studies such as permanent deformation analysis, fatigue cracking assessment, and resilient modulus examination.

Materials

The following materials were used for the present investigation.

a) Natural aggregates: Natural aggregates required for the present studies are procured from KMS crushers, Bagalur, Tamil Nadu.

b) Bitumen: Crumb Rubber Modified Bitumen CRMB-55 and VG 30 is procured from Mangalore refinery and petrochemicals limited (MD constructions, Bengaluru).

c) Filler: Baghouse dust is procured from Sri Venkateshwara crushers, Periyapatna.

d) Stabilizing additive: Cellulose fiber used as a stabilizing additive is procured from the Strategic Marketing and Research team (SMART), Peenya, Bengaluru.

e) RAP materials: For the present studies, RAP materials are scarified from wearing course of NH 206, Gangavaram, Andhra Pradesh.

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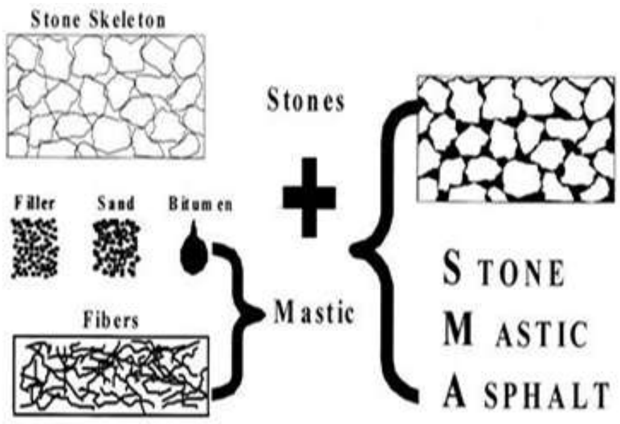


Fig. 2. Composition of Stone Mastic Asphalt (Vale et al., 2006)

MARSHALL MIX DESIGN

The bituminous mix is defined as a mix of two essential materials: aggregates and binder at a specified temperature in hot mix plant. This hot bituminous mix can be classified into Dense graded, Open-graded and Gap graded. These mixes are dividing based on their gradations. The dense-graded mixtures are most widely adopted for top layers, surface layers, or wearing courses. Each mix design has its own characteristics and should meet specific requirements. The design involves aggregate selection and its proportioning and selection of binder type and finally achieving the performance goal of the pavement structure. The main aim of mix design is to ensure economy, proper blending by gradation of aggregates and long-lasting binder properties. The mix design finalized should fulfil the following consideration.

Selection of suitable shape of aggregates to resist degradation either due to impact or abrasion and ensure better performance of the pavement.

Optimum binder content should be able to coat thoroughly coarse aggregates and fine aggregates.

It should be workable such that mix can be placed compacted with lower segregation.

Providing stable mix to sustain wheel loads. The stable mix can be obtained by proper selection of aggregates that can resist dislodging under the wheel loads and should be able to provide high internal friction. This is influenced by aggregates shape, gradation, surface texture, and binder content in the mix.

Selection of Mix

The mix selection was based on its wide application in road construction. Generally, not many National and State highways in India adopt gap graded mix at top layers as wearing course. The reason could be that this gap graded mix usually contains higher binder content, which enables to coat and hold the aggregate particles together. Therefore, considering its broad application in flexible pavement construction and its uniqueness in aggregate gradation distribution in all the sieves, the Gap Graded Mix (Stone Mastic Asphalt Mix) was selected in this research work. The detailed mix reference was taken from Table 500-18, Grading, MoRTH (4th revision).

Preparation of Test Specimen

For Conventional Marshall Stability Test, Indirect Tensile Strength

Test and Repeated Load Test as per MoRTH Specifications

Approximately 1200gm of aggregates are weighed and heated to a temperature of 175°C to 190°C. Compaction mould assembly and rammer were cleaned and kept pre-heated to a temperature of 100°C to 145°C.

Required quantity of Bitumen is heated to a temperature of 120°C to 165°C.

Filter paper was placed at the bottom of the Marshall mould and the entire batch of heated material is added to the mould in one lift.

Heated Bitumen is added to the heated aggregates and mixed thoroughly at the specified mixing temperature by hand mixing or using a mechanical mixer. The prepared mix is placed in a pre-heated and levelled and compacted by applying 50 blows on each side using a rammer of 4.54 kg weight with 45.7 cm height of fall.

The compacted specimens were removed after 24 hours using specimen extractor.

Further, diameters, mean height, weight in air, weight in water of the specimens were noted. Then specimens were kept in a thermostatically controlled water bath maintained at 60°C for 30 to 40 mins.

Marshall Stability value, which is the maximum in load in kg before failure is noted. The flow value, which is the deformation of the specimen in mm, was taken up to the maximum load. The equipment was strain controlled with strain rate of 5 cm per min.

The corrected Marshall value of each specimen as per ASTM D 1559-65, if the average height of the specimen is calculated.

Three specimens were prepared at different binder content which was varied at 0.5% increments from 5.5 to 7%. The stability test results were reported as the average of 3 specimens. The flow was recorded as the average of the three specimens in mm. obtained results after conducting test is as per MoRTH specifications.

The Optimum Bitumen Content (OBC) was calculated by taking the average of bitumen contents corresponding to max stability, specified voids content of 4% and max density.

INDIRECT TENSILE STRENGTH TEST

The bituminous mixes are tested for long-term stripping susceptibility through the indirect tensile strength test. The specimens are tested for the change in diametrical tensile strength due to the effects of water saturation and the accelerated stripping phenomenon observed due to freezing and thawing. The test is carried out for six sets of compacted asphalt mix. Three mixes are tested for ITS in a dry condition and the other three are tested after subjecting to a freeze-thaw cycle. As per ASTM D 6931 (2012), the test is carried out and Fig. 3.5 indicates indirect tensile strength testing assembly.

Fig. 3. Indirect Tensile Strength Test

Testing Procedure

ITS test is conducted for the Marshall specimens with 7+/-0.5% air voids. The required Percentage of air voids can be obtained by adjusting the number of blows for the Marshall specimens. Six specimens having air void content of 7% are casted. Three of them are tested for dry. The other three are subjected to vacuum pressure of 13-67 kPa then wrapped through plastic film and placed in a freezer for 16 hrs at 18+/-3°C. After freezing of the specimens, they are subjected to thawing by keeping them in a water bath maintained at 60+/-1°C for 24 hours. Both dry and wet specimens are placed in a water bath at 25+/-0.5°C for 2 hours then tested for indirect tensile strength. The equation 3.9 and 3.10 shows the calculation for indirect tensile strength for conditioned and unconditioned samples and to identify tensile strength ratio respectively.

4. RESULTS AND DISCUSSION

In the current work, investigations have been conducted on conventional SMA mixes utilizing VG 30 and CRMB 55 as binders. Additionally, RAP-modified SMA mixes with RAP percentages ranging from 10% to 60% have been examined, utilizing VG 30 and CRMB 55 as binders respectively. In the initial stage of the research, Marshall stability tests were conducted on both conventional SMA mixes and RAP-modified SMA mixes to determine the Optimum Binder Content (OBC), as presented in tables 4.1 to 4.4. Subsequently, in the second stage, Drain Down, Cantabro Abrasion, and Indirect Tensile Strength (ITS) tests were performed on conventional SMA mixes and RAP-modified SMA mixes using VG 30 and CRMB 55, respectively. By comparing the results of RAP-modified SMA mixes with conventional SMA mixes, the optimum RAP content was determined, as shown in tables 4.5 to 4.10. In the third stage of the research, rutting tests were conducted at different temperature levels and air voids, along with fatigue tests and resilient modulus values determined at varying stress and temperature levels for conventional SMA mixes and Optimum RAP-modified SMA mixes utilizing VG 30 and CRMB 55 as binders, as depicted in tables 4.11 to 4.3. Lastly, in the fourth stage, Dynamic Shear Rheometer tests were conducted to assess the rheological properties of VG 30, CRMB 55, RAP binder, and modified binders, as discussed in Chapter 5. Chapter 5 also includes a discussion on the statistical analysis performed on the results obtained for conventional and RAP-modified SMA mixes.

MARSHALL STABILITY TEST RESULTS

As per ASTM D6927–06, the Marshall Stability tests have been performed on conventional SMA mix using VG-30, SMA mix using CRMB-55. SMA mix using VG-30 with RAP and SMA mix using CRMB-55 with RAP is carried out for different binder contents. Tables below shows the Marshall properties for SMA mixes. In addition, Figures below shows a graphical representation of Marshall properties for SMA mixes.

Table .1. Marshall Properties of Conventional SMA Mix using VG 30 as a Binder

Property Tested	Bitumen content by weight of mix in %				
	5.75%	6%	6.25%	6.5%	6.75%
Marshall Stability(kN)	7.24	8.40	7.53	6.93	6.67
Flow value (mm)	2.26	3.08	3.71	4.23	4.86
Bulk density (g/cc)	2.35	2.35	2.35	2.34	2.33
Air voids (V_V) (%)	4.43	4.03	3.95	3.94	3.88
Volume of Bitumen (%)	12.56	13.08	13.56	14.03	14.50
Voids in mineral aggregates, VMA, (%)	16.99	17.12	17.52	17.98	18.38
Voids filled with Bitumen, VFB (%)	73.93	76.48	77.43	78.07	78.88

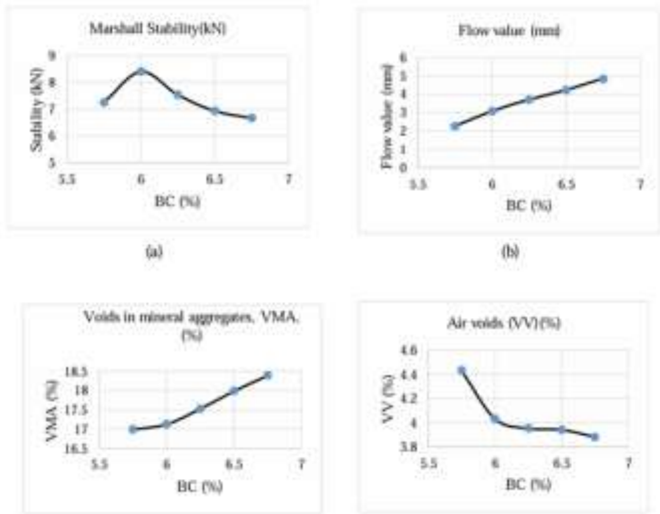


Fig. 4. (a) (b) (c) (d): Variation of Marshall properties with binder contents for conventional SMA mixes using VG 30

Table .2. Marshall Properties of Conventional SMA Mix using CRMB 55 as a Binder

Property Tested	Bitumen Content by weight of mix				
	5.6%	5.8%	6.%	6.2%	6.4%
Marshall Stability (kN)	7.79	8.23	8.61	8.35	7.55
Flow Value (mm)	2.51	3.12	3.56	4.07	4.21
Bulk Density(g/cc)	2.33	2.33	2.35	2.37	2.36
Air voids (V_V)(%)	6.03	5.50	4.51	3.66	3.78
Volume of Bitumen (%)	12.64	13.13	13.69	14.24	14.24
Voids in Mineral Aggregate VMA (%)	18.67	18.64	18.20	17.89	18.42
Voids Filled with Bitumen VFB (%)	67.72	70.46	75.23	79.56	79.45

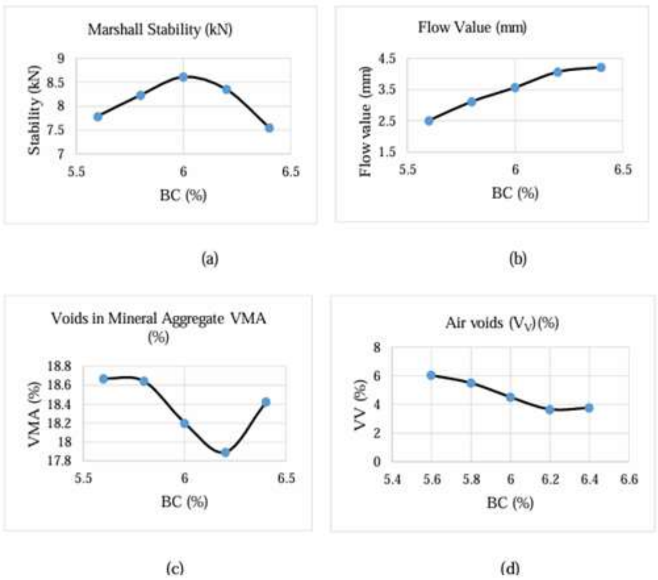


Fig. 5. (a) (b) (c) (d): Variation of Marshall properties with binder contents for conventional SMA mixes using CRMB 55

Table .3. Optimum Binder Content for RAP modified SMA mix using VG 30 as Binder

Property Tested	RAP content by weight of mix (%)				
	10%	20%	30%	40%	50%
Marshall Stability(kN)	7.86	8.24	8.53	9.03	8.87
Flow value (mm)	2.29	3.18	3.12	4.11	4.89
Bulk density (g/cc)	2.35	2.33	2.35	2.32	2.33
Air voids (V_V)(%)	4.43	4.03	4.00	3.99	4.14
Volume of Bitumen (%)	13.00	13.08	13.89	14.34	14.76
Voids in mineral aggregates, VMA, (%)	16.99	17.11	17.34	17.91	17.12
OBC (Optimum Binder Content)	6.1	6.2	6.25	6.40	6.50
Voids filled with Bitumen, VFB (%)	74.93	78.40	77.23	78.05	78.96

*Note – Optimum Binder Content (OBC) includes the binder present in the scarified RAP materials.

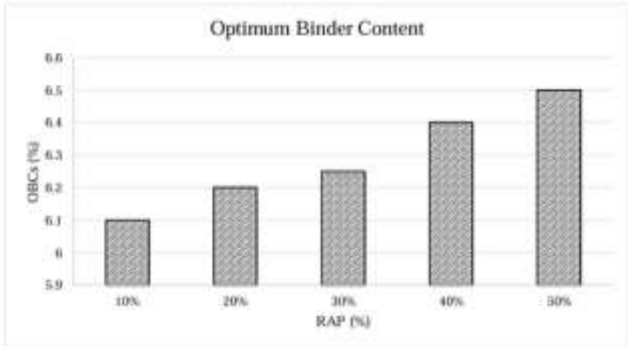


Fig. 6. Variation of binder contents with RAP content for SMA mix using VG30

Table .4. Optimum Binder Content for RAP modified SMA mix using CRMB 55 as Binder

Property Tested	RAP content by weight of mix (%)					
	10%	20%	30%	40%	50%	60%
Marshall Stability(kN)	8.84	8.97	9.20	9.31	9.40	9.03
Flow value (mm)	2.30	3.14	3.11	4.18	4.07	4.69
Bulk density (g/cc)	2.35	2.35	2.35	2.32	2.33	2.32
Air voids (V_V)(%)	4.31	4.01	3.98	4.12	4.07	4.12
Volume of Bitumen (%)	13.60	13.02	13.36	14.33	14.46	14.66
Voids in mineral aggregates, VMA, (%)	16.93	17.51	17.04	17.11	17.15	17.22
OBC (Optimum Binder Content)	6	6.15	6.25	6.30	6.40	6.55
Voids filled with Bitumen, VFB (%)	74.43	78.80	77.43	77.09	78.88	78.66

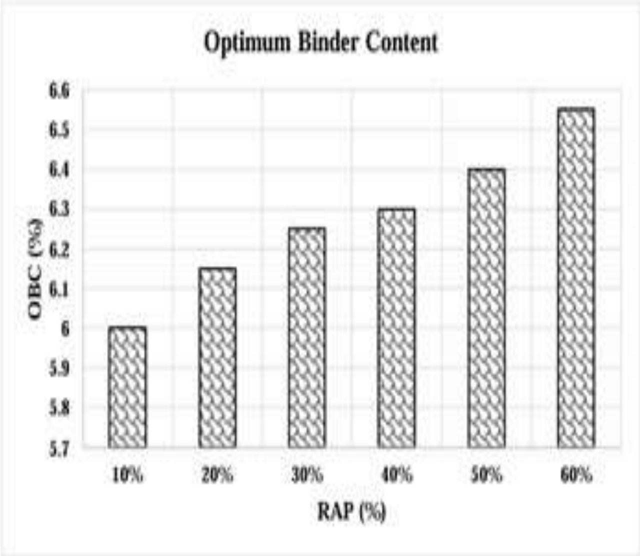


Fig. 7.: Variation of binder contents with RAP content for SMA mix using CRMB 55

INDIRECT TENSILE STRENGTH (ITS) TEST RESULTS

The Indirect Tensile Strength tests were performed as per ASTM D6931-17 on Conventional and RAP modified SMA mixes with VG30 and, Conventional and RAP modified SMA mixes with CRMB 55. The Tables below shows the ITS and TSR values for Conventional and RAP modified SMA mixes with VG30 and CRMB 55 respectively. Figs below shows the graphical representation of ITS value and TSR values for Conventional and RAP modified SMA mixes with VG30 and CRMB 55 respectively.

Table .5. ITS test results for Conventional and RAP modified SMA mixes with VG 30

Type of SMA mix	Samples	Maximum load (N)	Tensile strength (kPa)	Tensile Strength Ratio (TSR)
Conventional SMA Mix (VG 30)	Unconditioned	6186	357.19	92.25%
	Conditioned	5921	311.55	
10% RAP modified SMA with VG 30	Unconditioned	5986	349.87	90.21%
	Conditioned	5321	315.64	
20% RAP modified SMA with VG 30	Unconditioned	5554	675.68	88.88%
	Conditioned	4986	600.34	
30% RAP modified SMA with VG 30	Unconditioned	5686	505.61	89.10%
	Conditioned	5321	450.54	
40% RAP modified SMA with VG 30	Unconditioned	4400	505.61	87.48%
	Conditioned	3400	442.35	
50% RAP modified SMA with VG 30	Unconditioned	4250	465.01	83.75%
	Conditioned	3650	389.45	

Table .6. ITS test results for Conventional and RAP modified SMA mixes with CRMB 55

Type of SMA mix	Samples	Maximum load (N)	Tensile strength (kPa)	Tensile Strength Ratio (TSR)
Conventional SMA Mix (CRMB 55)	Unconditioned	7750	360.00	94.44%
	Conditioned	6850	340.01	
10% RAP modified SMA with CRMB 55	Unconditioned	6400	369.87	93.54%
	Conditioned	5800	345.98	
20% RAP modified SMA with CRMB 55	Unconditioned	6231	699.87	92.23%
	Conditioned	5556	645.51	
30% RAP modified SMA with CRMB 55	Unconditioned	5986	730.67	91.83%
	Conditioned	6113	671.01	
40% RAP modified SMA with CRMB 55	Unconditioned	5761	735.76	90.34%
	Conditioned	5321	664.04	
50% RAP modified SMA with CRMB 55	Unconditioned	4986	750.98	89.91%
	Conditioned	4176	675.25	
60% RAP modified SMA with CRMB 55	Unconditioned	3986	687.76	83.60%
	Conditioned	3452	574.97	

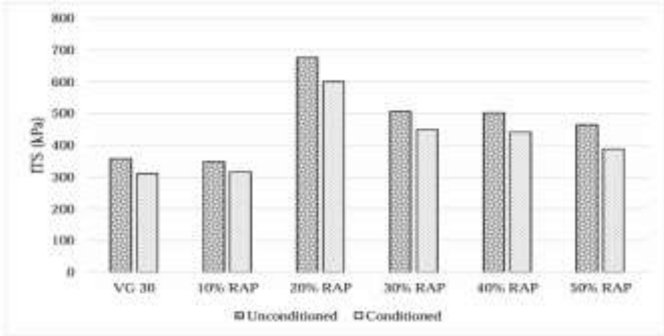
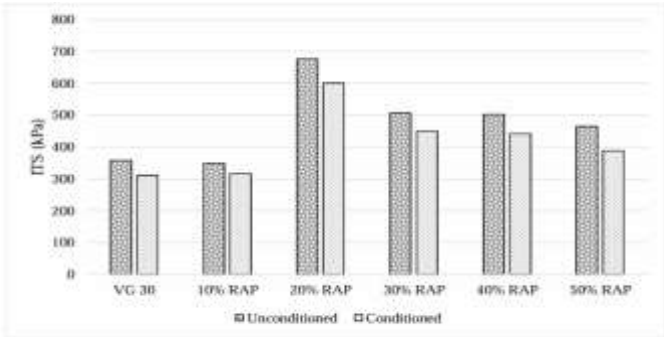


Fig.8.: Variation of ITS value with RAP contents for conventional and RAP modified SMA mixes with VG 30



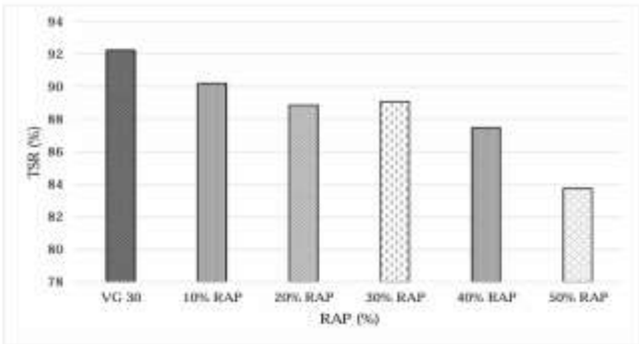


Fig. 9. Variation of TSR value with RAP contents for conventional and RAP modified SMA mixes with VG 30

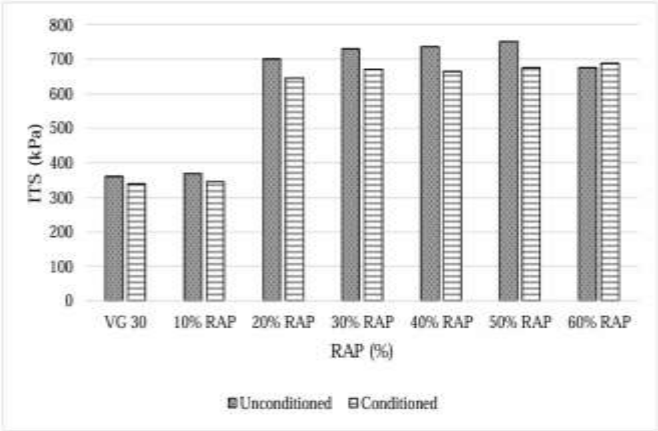


Fig. 10. Variation of ITS value with RAP contents for conventional and RAP-modified SMA mixes with CRMB-55

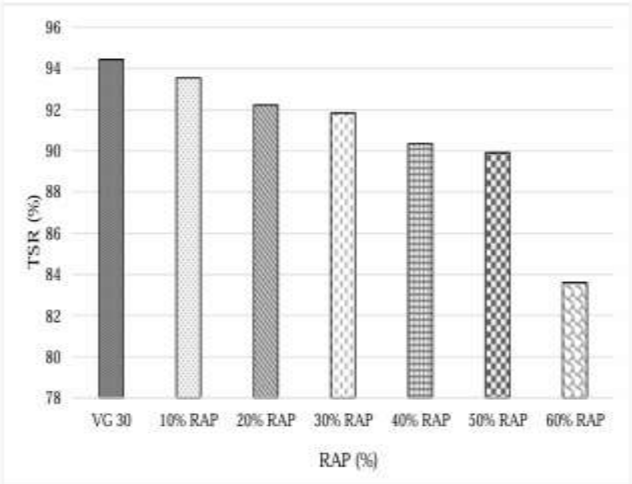


Fig. 11. Variation of TSR value with RAP contents for conventional and RAP-modified SMA mixes with CRMB-55

As per IRC: SP: 079: 2008 Tensile Strength Ratio value should be min 85% in order to satisfy the requirements as per norms. Table 4.7 shows tensile strength values obtained for conventional SMA mix prepared using VG 30 as binder and 10%, 20%, 30%, 40% and 50% RAP modified SMA mixes with VG 30 are tabulated i.e., 92.25%, 90.21%, 88.88%, 89.10%, 87.48% and 83.75% respectively. Table 4.8 explains TSR values for conventional SMA mix prepared using CRMB 55 as binder and 10%, 20%, 30%, 40%, 50% and 60% RAP modified SMA mixes with CRMB 55 are tabulated i.e., 94.44%, 93.54%, 92.23%, 91.83%, 90.34%, 89.91% and 83.60% respectively. The tensile strength value obtained for conventional SMA mix with CRMB is found to be higher than conventional SMA mix with VG 30 as a binder. Concerning to RAP modified SMA mixes using VG 30 as a binder, up to 40% RAP modified SMA mixes, TSR values were found to be more than 85% but further increase in RAP percentage Tensile strength of the RAP modified reduced, i.e., 83.75%, which does not the satisfy the requirement (IRC: SP: 079) of Ideal SMA mixes. Whereas for RAP modified SMA mix using CRMB 55 as a binder, up to 50% RAP modified TSR values were found to be more than 85%, but further increase in RAP percentage Tensile strength of the RAP modified reduced, i.e., 83.60%, which does not the satisfy the requirement (IRC: SP: 079: 2008) i.e., min TSR value 85%.

Summary

This section undertakes a comprehensive laboratory performance evaluation of various SMA mixes, encompassing both conventional and RAP-modified formulations with VG 30 and CRMB 55 binders, supplemented with 0.3% cellulose fiber by weight of the mix. The evaluation entails examining Marshall properties indirect tensile strength, tensile strength ratio, abrasion loss, permanent deformation, and fatigue cracking. These assessments are conducted while considering the variations in different parameters, as illustrated in the tables provided above. Further, this chapter delves into detailed discussions on the aforementioned tests, aiming to elucidate the implications of the observed results and their significance in understanding the performance characteristics of the SMA mixes under consideration. Through critical analysis and interpretation, the discussions offer insights into the effects of varying parameters on the mechanical and functional properties of the SMA mixes.

5. CONCLUSIONS

The present study aims to investigate Stone Mastic Asphalt (SMA) mixes that incorporate Reclaimed Asphalt Pavement (RAP) with different binders, specifically VG 30 and CRMB 55. In these SMA mixes, 40% optimal RAP content is utilized for the mix with VG 30, while 50% optimal RAP content is employed for the mix with CRMB 55. Various tests as per specifications were conducted, encompassing characteristics such as voids in coarse aggregate under dry-rodded conditions, Marshall Stability, flow value, density of the mix, voids within the bituminous mix, voids within the mineral aggregate, voids filled with bitumen, drain down, abrasion loss, and indirect tensile strength. Drawing from the observations and results obtained, conclusions regarding the research findings are provided across various categories.

1. In the present studies, all binders, including both VG 30 and CRMB 55, whether virgin or derived from Reclaimed Asphalt Pavement (RAP) aggregates, complied with the specifications set forth by the Ministry of Road Transport and Highways (MoRTH).

2. The optimal binder content for conventional and RAP modified SMA mixes using VG 30 was found to be lower than those utilizing CRMB 55.

3. Stability values were greater in conventional SMA mixes containing CRMB 55 compared to those with VG 30 binders. Moreover, the introduction of RAP into SMA mixes led to increased stability, especially when 50% RAP was used to replace the mix with CRMB 55 and 40% RAP replaced the mix with VG 30.

4. The results of the drain test showed that both conventional SMA mixes with VG 30 and CRMB 55, and mixes incorporating 40% RAP with VG 30 and 50% RAP with CRMB 55, satisfied the specifications set by the Ministry of Road Transport and Highways.

5. The results of aged abrasion loss tests demonstrated that conventional SMA mixes containing CRMB 55 displayed greater durability compared to those with VG 30. However, the durability declined with an increase in the percentage of RAP, as anticipated due to the aged condition of the material.

Nonetheless, mixes incorporating 40% RAP with VG 30 and 50% RAP with CRMB 55 still adhered to the specifications outlined by Ministry of Road Transport and Highways.

6. Based on the results of the indirect tensile strength tests conducted on SMA mixes in this study, it can be inferred that the tensile strength attained for the conventional SMA mix with CRMB 55 binder was greater than that of the conventional SMA mix with VG 30 binder. Furthermore, the incorporation of RAP to SMA mix resulted in a higher tensile strength ratio when 50% RAP replaced SMA mix compared to 40% RAP replaced SMA mix using VG 30 as a binder.

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