Evaluation Of Warm Mix Asphalt Containing Reclaimed Asphaltic Pavement And Coir Powder

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***Abstract*—The prevalence of potholes has become a significant concern in Kerala, particularly in recent times, with the infiltration of water during the rainy season and drastic increase in the vehicle count being the major causes of pavement distresses. To address this problem, a novel asphalt mix has been proposed that incorporates Recycled Asphalt Pavement (RAP) and coir powder, using warm mix technology to prevent the formation of cracks in the pavement. In this study, coir powder and Sasobit were used to modify the bitumen, and various percentages of coir powder were mixed with VG30 bitumen. Aggregates were replaced by RAP in various proportion which is then combined with coir powder-modified bitumen. 54 blocks of modified bitumen mix were investigated by using the Marshall stability test, Indirect tensile strength test, and Scanning Electron Microscopy (SEM) analysis. The results of the Marshall stability test and indirect tensile strength test demonstrate that a 40% Recycled Asphalt Pavement modified bituminous mix shows remarkable improvement in durability and strength. It is anticipated that incorporating Recycled Asphalt Pavement and coir powder into bituminous pavements will provide several benefits, including cost reduction, improved sustainability, enhanced pavement durability and strength, nonetheless it also contributes to circular economy concept.**

***Index Terms*—Reclaimed asphaltic pavement, Warm mix technique, Obtimum bituminous content Scanning electron microscopy, Marshall stability test**

I. INTRODUCTION

The pavement industry is a vital sector that has actively availed the Indian economy by contributing more than 5% to the country's GDP. Due to rampant construction activity in the pavement sector, tons of wastes are produced every year. The last stage for such waste is either dumping or stockpiling and improper disposal which has imbalanced the terrestrial and aquatic ecosystems. To utilize such wastes, pavement researchers, and engineers have strived to develop novel ideas to apply and recycle the industrial-pavement wastes in construction. Therefore, a need was felt to conduct a review regarding prospective ways in which the waste can be productively utilized.

The conventional method of providing bituminous surfacing on flexible pavements require significant amount of energy for production of bituminous binder, drying aggregates and subsequently production of bituminous mix at Hot Mix Plant (HMP). The heating of bituminous binder, aggregates and production of huge quantities of hot mix asphalt(HMA) releases a significant amount of greenhouse gases and harmful pollutants. The amount of emissions becomes twofold for every 10°C increase in mix production temperature, and increasingly, higher temperature is actually being used for the production of HMA with modified binders. Also, there is a problem of the scarcity of aggregates, which forces transportation of materials from long distance. The use of diesel for running trucks leads to emission of pollutants. Therefore, an attempt has to be made to develop and adopt alternative technologies for road construction and maintenance to reduce consumption of fuel and aggregates.

Recycling of RAP material is found efficient and enhance the durability and strength of pavements (Sukanta Karati et al.,2021). But bituminous pavement recycling techniques in India are still prevalent that way. Although, India is the second-largest road network in the world after the United States (about 4.2 million kilometers) [1]. However, developed countries use higher amounts of RAP material in the pavement industry. It has been found that 33 million tons of RAP material are used for recycling purposes each year in the USA, which is about 80% of the total RAP material collected from the old asphalt pavement [2]. And Sweden, about 0.84 million tons, Germany 7.3 million tons, Denmark 0.53 million tons, and the Netherlands about 0.12 million tons of RAP are used each year [3]. Because the utilization of RAP material has multiple advantages such as economic, environmental, technical, conservation of energy, it can also used as asphalt concrete aggregate and asphalt cement supplement in hot mix asphalt and cold mix asphalt. Furthermore, the investigation is needed to use a higher proportion of RAP material to construct the surface course of flexible pavement.

Even the pervious paver blocks (PPB) using reclaimed asphalt pavement (RAP) aggregates mixed in various proportions indicate that up to 50% RAP can be used in pervious concrete paver block with G1-coarser gradation, which will increase the sustainability aspect of pervious concrete , while it doesnot affect the strength of pavement (Nikhil Saboo et al. 2021). Several studies had undergone assessing the use of fine reclaimed asphaltic pavement to substitute natural aggregates in the production of alkali-activated slag mortars (AAM) (Juliana O. Costa et al., 2021). A study conducted by ZS Hussain et al., 2020 shows that the type and dosage of a rejuvenating agent should be chosen according to the extent to which they can enhance asphalt binder properties. While 100% of RAP can be utilized, a range of considerations should be taken into account. An asphalt binder's viscoelasticity depends on the ratio of asphaltenes to other components. The laboratory results indicate that the bituminous mixes with RAP and recycling agent provide better performance compared to virgin mixes (T.Anil Pradymn et al., 2019). Long-term performance of RAP inclusive dense bituminous macadam (DBM) mixes, in post ageing condition, via inclusions of a Warm Mix Additive. The effect of inclusions of both the technologies (RAP & WMA) on various properties of DBM mixes found to significantly improve the aforementioned properties of the DBM mixes regardless of the type of aggregate used (GD Kumari Monu et al., 2019). In India variety of Reclaimed Asphalt Pavement (RAP) Materials are available. Depending on Sources of RAP i.e. deteriorated asphalt pavement and type of bituminous mixes used in these pavements during construction and cyclic renewal or resurfacing of road. Indian RAP can be categorized in different categories or groups (Anil Kumar Yadava et al., 2019). Coir powder act as a fibre and studies shows that adding coir powder along with sasobit act as a better binder (Shriram P Marathe et a., 2019). Adding coconut fibre in asphaltic mix has been studied and it is observed that the stability value increases with increase in fiber content upto certain level then reduces (Vivek B. R et al., 2016).

In this study, a modified bituminous mix was designed by incorporing both RAP and coir powder along with sasobit. Modified bituminous mix was experimentally evaluated and compared with the virgin bituminous mix..

II. MATERIALS & METHODOLOGY

A. Materials

RAP material was collected from the construction site of Kuttipuram bridge (NH 66), Malappuram, Kerala, India as shown in Figure 1. And the virgin basalt aggregate was utilized as base aggregate and it was collected from the local PWD work at ponnani, Kerala, India. Conventional 60/70 penetration grade bitumen (VG-30) was selected as the binder material of the bituminous concrete mix.

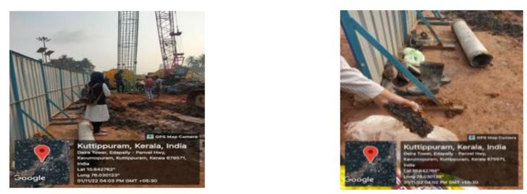

Fig. 1. RAP collected from NH 66

Sasobit, which is a fine crystalline long chain aliphatic hydrocarbon. It is manufactured from natural gas using Fisher process of polymerization. For this study Sasobit provided by KPL chemical industry, Delhi was used as shown in Figure 3. It has a melting point range of between 185-239 ^{o} F and is completely soluble in asphalt at temperature above 239^{o} F. Below the melting point, it form crystallin network with binder. Homogenous solution cause a noticeable reduction in bitumen's viscosity. Lowering of viscosity of bitumen leads to low mixing temperature.

Fig. 2. Warm mix additive sasobit collected from KPL Chemical Industry, Delhi, India.

Third material coconut fibre , generally called as coir powder was collected from Neptune coir industry, Melmuri, Kerala as shown in figure 3. There are two type of coconut fiber, brown fiber extracted from mature coconut and white fiber extracted from immature coconut. Brown fibers are thick, strong and have high abrasion resistance. Due to the dominance of Engineering property shown by the brown coir fibre, it was used in this study.

Fig. 3. Coir powder collected

B. Methodology

Bitumen was modified with various proportion s of Coir powder and warm mix addictive Sasobit as given in Table I.

TABLE I PROPORTION OF COIR POWDER AND SASOBIT ADDED TO WMA

		Percentage of sasobit			
		0%	1%	2%	3%
Percentage of coir powder	0%	B0C0S	B0C1S	B0C2S	B0C3S
	0.2%	B0.2C0S	B0.2C01S	B0.2C2S	B0.2C3S
	0.4%	B0.40S	B0.4C1S	B0.4C2S	B0.4C3S
	0.6%	B0.60S	B0.61S	B0.62S	B0.63S
	0.8%	B0.8C0S	B0.8C1S	B0.8C2S	B0.8C3S
	1%	B1C0S	B1C1S	B1C2S	B1C3S

In order to analyse various property of modified bitumen with coir powder and sasobit several tests like, softening point, ductility, flash and fire point tests were conducted. The results of laboratory experiments are summarized in Table II.

TABLE II PROPERTIES OF DIFFERENT PROPORTIONS OF COIR POWDER AND SASOBIT

Mix proportions	Softening point(°c)	Ductility(cm)	Flash point(°c)
B0C0S	46	86.5	86.5
B0C1S	50	106	143
B0C2S	53	102	139
B0C3S	54	78	133
B0.2C1S	43	46	210
B0.2C2S	49	42	215
B0.2C3S	49	41	220
B0.4C1S	45	55	240
B0.4C2S	47	49	243
B0.4C3S	49	49	245
B0.6C1S	46	108	240
B0.6C2S	48	105	263
B0.6C3S	51	101	267
B0.8C1S	59	117	180
B0.8C2S	62	114	179
B0.8C3S	63	100	190

B0.2C0S in the table indicates bitumen contains 0.2% Coir powder and 0% Sasobit. Marshall mix design on nominal mix was conducted to calculate optimum binder content. Using the obtained optimum binder content, further stability test and indirect tensile test were conducted on various proportion of RAP. Gradation of Reclaimed Asphalt Pavement (RAP) and virgin aggregates, were identified in accordance with ASTM by using sieve analysis. The result of the sieve analysis is embedded in Table III.

TABLE III SIEVE ANALYSIS OF VIRGIN AGGREGATERS

Sieve (mm)	19	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.75
Upper limit	100	100	88	71	58	48	38	28	10
Lower limit	100	79	70	53	42	34	26	18	4
Obtained value	100	99.73	80.43	59.07	44.86	36.18	27.70	20.28	8.42

The results of sieve analysis is represented graphically as shown in Figure 4. To prepare modified bituminous mix, virgin aggregate is heated separately at 170°C to 180°C, respectively. Modified bitumen (0.6% COIR POWDER + 2% SASOBIT) is Preheated (135°C) and added with virgin aggregate and mix it properly. They are maintaining the temperature of the mix at 150°C-

160°C and compacted in a preheated mold with a Marshall hammer by applying specific force as per the standards guideline. Bituminous mixes are usually prepared in the field at a mixing temperature not exceeding 160°C. The bitumen content is selected as 5.1% ,5.4%,5.7%, 6% in 0.30% increment. A total of 12 samples (i.e., 3 replicates × 4 binder content) are prepared to find Marshall properties and optimum bitumen contents (OBC). Figure 5 shows the preparation and Marshall stability testing of samples .

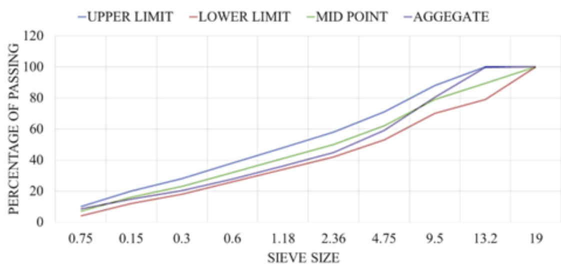

Fig. 4. Gradation of aggregate

Fig. 5. preparation and testing of samples

Graphical representation of Marshall test results are shown in Figure 6,7,8 & 9. Limiting value of air voids in mix was in between 3 to 5%. From the plotted graphs it was found that the optimum bitumen content (OBC) is 5.4%. 500 g of RAP was extracted by using centrifugal machine. The optimum content of bitumen in RAP was found to be 5.7%.

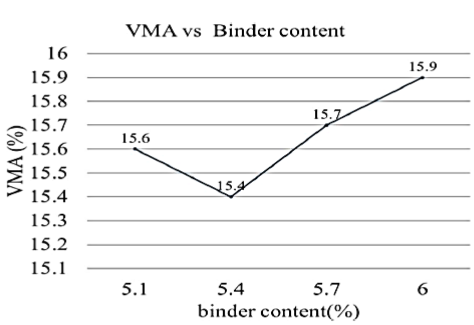

Fig. 6. Air voids in mix corresponding to binder content

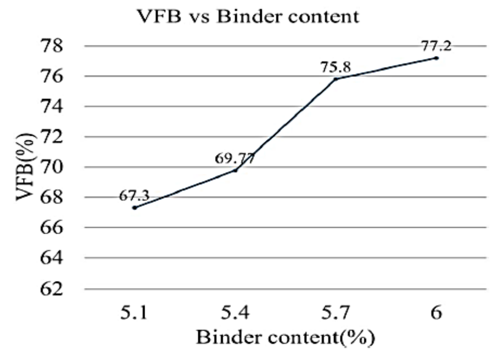

Fig. 7. Voids filled with mineral aggregate

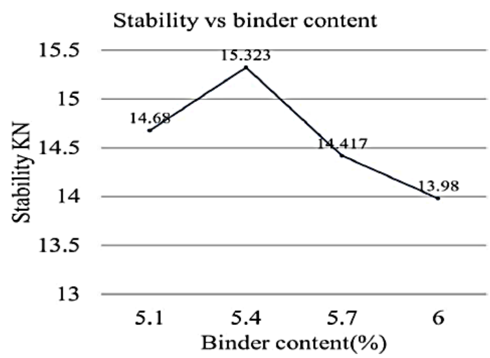

Fig. 8. Stability of specimen

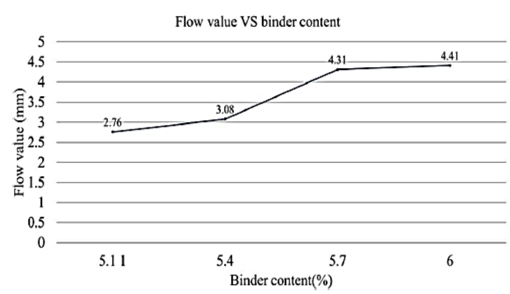

Fig. 9. Flow value corresponding to binder content

In order to find optimum RAP percentage that have capability to best perform than the other studied mix in terms of durability and strength. For that RAP is mixed in asphalt as 30%, 40%, 50% and 60%. Bitumen content is taken same as the content obtained from nominal mix design. To prepare RAP enriched bituminous mix, RAP aggregate and virgin aggregate was heated separately at 154°C-160°C and 170°C to 180°C, respectively. Preheated virgin bitumen at135°C was added with virgin aggregate and it was mixed thoroughly. Aged bitumen [2] was stirred manually for about 5 minutes, the temperature was maintained at 150°C-160°C. The RAP aggregate and aged binder were then mixed with this mixture, and a homogeneous mixture was prepared and compacted in a preheated mould with a Marshall hammer by applying specific force as per the standards guideline. A total of 15 samples were prepared.

The indirect tensile strength test was conducted to determine the tensile properties of cylindrical concrete and asphalt concrete specimen through the application of a compression load along a diametrical plane through two opposite loading heads. This type of loading produces a relatively uniform stress acting perpendicularly to the applied load plane, causing the specimen to fail by splitting along the loaded plane. The indirect tensile strength has been used in this study to evaluate the maximum resistance of pavement to cracking. After conducting the ITS tests, the ITS values of the specimens in kPa were calculated using equation (1) as:

$$ITS = \frac{2000P}{Dt} \quad (1)$$

where P is the maximum load applied to the specimen in N, t and D are the thickness and diameter of the specimen in mm, respectively.

For sample characterization Scanning Electron Microscopy (SEM) analysis was done. A rotary and a diffusion pump were used to vacuum-seal the samples at a maximum vacuum level of 1 × 10−4 torr. The metallization process was performed using the aluminium coating. Coating of samples is required to make the samples conductive to avoid charging of electrons as well as to reduce thermal damage and improve the secondary electron signal required for topographic examination in the SEM. Therefore, a thin layer of aluminum (with a thickness of about 8 ± 3 Å) was coated on all samples.

III. RESULT AND DISCUSSION

A. Evaluation of new asphalt mix by Marshall stability and flow value test

Marshall stability test was conducted to address the design parameters and optimum bitumen content (OBC) of bituminous concrete (BC) mix. Marshall properties obtained from the tests are given in Table IV. And the results of Marshall stability tests are provided in Table V. The optimum bitumen content was obtained as 5.4%.

TABLE IV. MARSHALL PROPERTIES FOR VARIOUS BITUMEN CONTENT

Properties	Bitumen content in percentage			
	5.1	5.4	5.7	6
Stability value	14.68	15.323	14.417	13.98
Flow value	2.76	3.08	4.31	4.41
Bulk density	2.47	2.49	2.48	2.49
VIM	5.1	4.7	3.8	3.4
VMA	15.6	15.4	15.7	15.9
VFB	67.3	69.77	75.8	77.2

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VFB	67.3	69.77	75.8	77.2

Flow is another important parameter of the Marshall stability test. It is defined as the vertical deformation when the maximum load has been applied to the sample at a time of the Marshall stability test. In this study, as per Table V, the flow value is consistently increasing from 3.08 to 4.15 mm for RAP modified bituminous mix. From the table It can be summarised that 40% RAP enriched bituminous mix leads to better service life for flexible pavement because molecular bonding of carbonyl compound between aged and virgin bitumen is suspected in the mix improvement factor after that physical aging is prominently activated on the other studied mixes

TABLE V. RESULTS OF STABILITY AND FLOW VALUES

Properties	RAP (%)				
	0%	30%	40%	50%	60%
Stability value(KN/ mm)	15.32	21.36	24	21.11	20.05
Flow value (mm)	3.08	3.55	3.8	4.1	4.15

B. Marshall Mix Design of Modified Asphalt Mix

The bitumen content is selected between 5.1% to 6% in 0.20% increment. A total of 12 samples were prepared to find optimum bitumen content (OBC). Marshall properties for modified asphalt mix is shown in Table VI.

TABLE VI. MARSHALL PROPERTIES OF MODIFIED ASPHALT MIX

Properties	Bitumen content (%)			
	4.9	5.4	5.9	6.4
Stability value (N/mm)	21.183	22.093	20.88	20.78
Flow value(mm)	3.63	4.12	4.23	4.26
Bulk density g/cc	2.449	2.49	2.478	2.45
VIM(%)	5.0	4.7	4.4	4.3
VIA(%)	15.7	15.4	15.8	15.9
VFB(%)	67.1	69.77	76.9	77.9

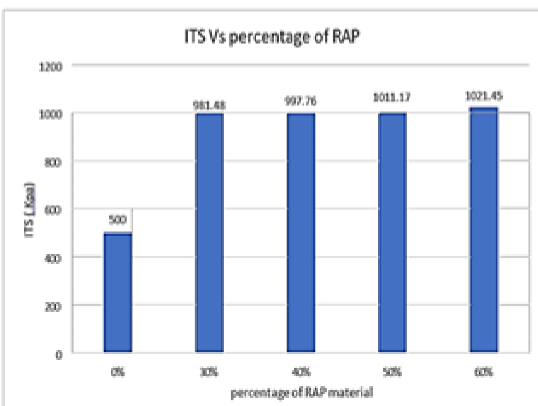

Fig. 10. Indirect tensile strength for various percentage of RAP material

C. Evaluation of indirect tensile strength test

For conducting indirect tensile test, the temperature was 300 °C. Figure 10. shows the influence of RAP on indirect tensile strength. The adopted design mix with 60% RAP has the highest tensile strength of 1021.45 Kpa., while the mix with OBC has the lower tensile strength of 500 Kpa . This implied that the RAP mix has the highest resistance to cracking.

D. SEM analysis result

SEM has been used to investigated the micromorphology of asphalt binders and mixtures. Figure 11 represents microstructural features of nominal and modified asphalt mix. From the figure it is concluded that the modified asphaltic mix is distributes and interconnects well, which indicates the probability of crack formation is less in modified mix than in normal mix

IV. CONCLUSION

In this present work, the effect of usage of Reclaimed asphaltic pavement (RAP) along with coir powder and sasobit in bituminous concrete were investigated. Marshall stability, indirect tensile strength and SEM analysis was conducted for the evaluation of the modified bituminous mix. Marshall stability test OBC as 5.4%, and percentage of RAP was found to be 40% fo higher stability value and lower flow value, while the indirect tensile strength provided a better tensile strength

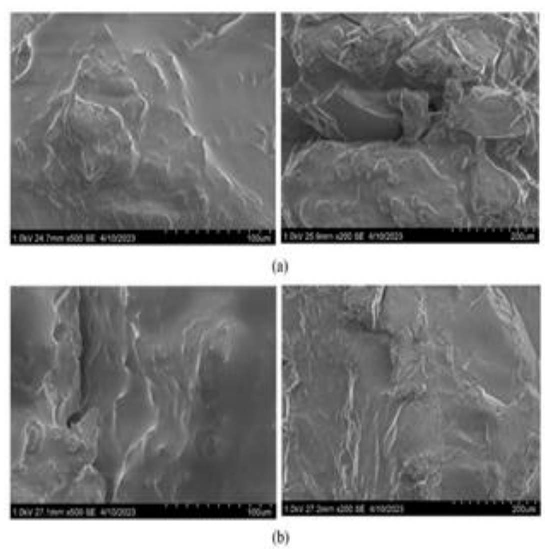

Fig. 11. SEM image of unmodified asphalt (a) and modified asphalt (b)

with increase in RAP content. SEM analysis provided the micromorphology of the modified aswell as ordinary bituminous mixes, and provided a uniform dispersion of binders were found in modified bituminous mixure, which ensure the crack resistance of the pavement layers.

In short this study found that RAP material along with coir powder have the ability to enhance the strength and life span of the warm mix asphalt pavement, which in turn contribute to the circular economic principles. Hence reusing the Asphaltic pavement and coir powder helps us to reduce the resource consumption and provides a sustainable pavement construction techniques.

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