Crumb Rubber Modified Binder may More Sustainable than Other Binders for Pavement Construction in Rain Prone Area.

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Abstract- Flexible pavement gets less durable using conventional binders, whereas modified binders may provide higher performance, specially using waste crumb rubber modified binder (CRMB) in pavement construction. The CRMB was produced by incorporation of crumb rubber which was collected from discarded tires. This waste tires are increasing significantly with the increasing of vehicles day by day. With this era of strategy, an attempt has been tried to compare various binders like neat 60/70 bitumen, polymer modified bitumen (PMB) and CRMB in terms of their mechanical properties, Marshall properties and water sensitiveness. Mechanical property tests indicated that modified bitumen exhibit higher softening point, higher elastic recovery, lower temperature susceptibility and better resistance to stripping compared to neat bitumen. The performance of asphalt mixes at OBC prepared by neat 60/70 bitumen, PMB and CRMB were met the mix design criteria specified in the Marshall mix design approach. Both neat and modified bituminous samples undergone water sensitivity analysis. The retained stability of various bituminous mixes was found to be 79.0%, 92.6%, and 95.0% for the respective mixtures. The tensile properties of asphalt mixtures and their resistance to cracking, stripping due to frost and thawing action were also investigated by TSR based on moisture induced damage test and were found to be 83.1%, 90.1% and 92.7% for the bituminous mixes prepared by 60/70 bitumen, PMB, and CRMB respectively. Overall, the modified bitumen, especially CRMB, performed better than neat 60/70 bitumen as they are less susceptible to temperature variations and moisture, leading to reduced maintenance and hence the lifespan of pavement may increase. Therefore, taking into account both the performance and the environment, CRMB can be considered as sustainable alternative for durable and effective pavement construction in rain prone country like Bangladesh. Moreover, using CRMB in pavement construction, environmental hazard will be reduced to some extent.

Keywords – Flexible Pavement, Crumb Rubber, Water Sensitivity, Sustainable Development

I. INTRODUCTION

Nationwide connectivity is becoming a prerequisite for developing social, economic, industrial & cultural aspects of a country. So, a sufficient, sustainable, safe & efficient road network is very essential for rapid development of the same as it significantly reduces maintenance cost, vehicle operating cost, travel time cost etc. Approximately 90% of paved roads in Bangladesh are flexible pavements where bitumen is the main binding material on which pavement life is mainly dependent. However, conventional bituminous pavements in Bangladesh experience numerous types of defects which require frequent maintenance and are extremely vulnerable to traffic loading, moisture damage and temperature fluctuations. Thus, bitumen quality must be enhanced in order to minimize the imperfections in the roadways. Hence, an effort has been made to enhance the bitumen quality by adding modifiers with the neat bitumen.

In Bangladesh, vehicles are increasing approximately 0.5 million [1] per year with the increase of life standard, country development, economic zones, population and road network. Hence, every year, a significant amount (90,000 tons) [2] of non-biodegradable waste tires is produced in Bangladesh, out of which as major consumptions, 50,400 tons [3] are used in pyrolysis process to produce liquid fuel (Furnace Oil & Diesel). Remaining discarded tires, one of the main sources of municipal solid waste, may take up large space in the landfill, produce harmful gases, contaminates the soil, groundwater, and farmland, trap the rain water helps to propagate pests, specially mosquitoes, and many other environmental hazards if not properly recycled. Whereas it may be advantageous for the environment and the economy by using this waste material as a bitumen modifier, producing CRMB. CRMB plays a significant role in sustainable infrastructure development by enhancing the performance, durability of flexible pavements with reducing the environmental hazards by using waste tires. In addition to the CRMB, since PMB is used in many countries over the world due to its enhanced properties such as good performance, durability and longevity of flexible pavement, it has also been considered to verify the suitability of the binder, with the view of durability of the roads, vulnerable to temperature changes, and resistant to moisture damage.

According to Al-Azawee & Qasim (2018), The utilization of 10% crumb rubber [4] demonstrates the most significant impact on the Marshall stability of the mixture. The use 8% of 30 µm crumb rubber content for 80/100 grade bitumen modification to obtain best results of the penetration, softening, and ductility tests [5]. The Xu et al. (2021), observes that the CR modifier enhanced the resistance of the neat binder against rutting [6]. Ge et al. (2016), conducted an experiment on bitumen mixed with 5% and 10% of CR, which indicates an enhancement in the softening temperature of asphalt binder, leading to an improvement in high temperature stability [7]. Carlos et al. (2021), characterize and compare different fundamental material properties and the expected mechanical performance of a regular polymer modified (range between 2.5 and 3.5% by weight of asphalt binder) and a HiMA / HP (range between 7 and 8% by weight of asphalt) modified binder, under different ageing conditions. The results confirm an enhanced expected long-term mechanical performance of the HiMA asphalt in road projects as compared to conventional polymer modified binders [8]. According to Behnood & Modiri (2018), once the polymer is properly mixed with the asphalt binder, a swallowed polymer network is formed, which contributes to the changes in visco-elastic behavior [9].

Thus, conventional 60/70 penetration grade bitumen is required to be replaced by modified binders like polymer modified bitumen (PMB) or crumb rubber modified bitumen (CRMB) to withstand against the adverse action of pavement deformation, fatigue and thermal cracking, moisture induced damage. The use of waste crumb rubber to produce CRMB is needed for optimization reduction of environmental hazards as well. Hence an attempt has been made to identify the suitable binder from neat conventional bitumen, PMB & CRMB in pavement construction.

The rest of the paper is organized as follows. The research objectives are outlined in section II. Materials used in investigation and methodology are explained in section III. Experimental results are presented in section IV. Concluding remarks are given in section V.

II. Objectives

The aim of this investigation is to find a suitable modified binder used in flexible pavement construction in terms of performance, durability and sustainability. Based on the discussion above, the following objectives have been selected for the present investigation.

- To evaluate the properties of neat & modified binders (by SBS polymer and waste crumb rubber).
- To determine the optimum binder content based on Marshall properties.
- To identify the best suitable binder on the basis of water sensitivity analysis of neat and modified bituminous mixes.

III. Materials & Methods

3.1 Materials –

The materials used to prepare bituminous mixes for the laboratory experiment are natural aggregates (coarse and fine aggregate), stone dust as mineral filler, neat 60/70 bitumen, PMB and waste crumb rubber (CR). Table 1 shows the details of materials are used in this investigation.

Table -1 Source and Specification of Materials

Items	**Source / Origin**	**Place of Collection**	**Specification**
Coarse Aggregate	**Dubai, U.A.E.**	**Materials Lab., CUET**	**25 ~ 4.75mm**
Fine Aggregate	**Sylhet, Bangladesh**	**Materials Lab., CUET**	**4.75 ~ 0.075mm**
Stone Dust (Filler)	**Meghalaya, India**	**Stone Crusher, Project**	**Passing #200 Sieve**
Neat 60/70 Bitumen	**Eastern Refinery, Bangladesh**	**Transportation Lab., CUET**	**60/70 Penetration Grade**
PMB	**Dubai, U.A.E.**	**Materials Lab., Project**	**5% SBS with 60/70 Bitumen**
Waste CR	**Discarded Waste Tires**	**Chittagong, Bangladesh**	**7%, No. Sieve 50 Passing**

3.2 Work Flow Diagram –

The investigation has to be completed through comprehensive laboratory evaluation. The complete investigation has been presented in Figure 1 as work flow diagram.

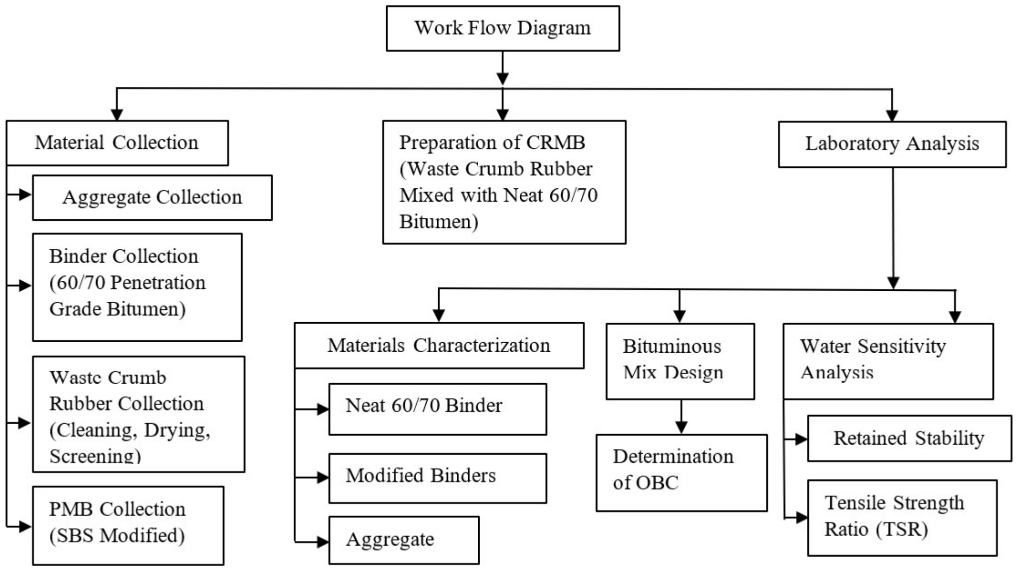

Figure 1. Work Flow Diagram of the Present Investigation

3.3 Preparation of Crumb Rubber –

60/70 penetration grade bitumen is heated to 160°C in the mixing machine before crumb rubber is added. 7.0% (by weight) of No. Sieve 50 passing (0.3mm) CR is mixed at low speed for about 5 min [5]. Then, the mixture is heated to 170°C to 180°C and agitated vigorously for about 60 minutes [10] using a mechanical stirrer operated at 1400 rpm. After 60 minutes, the developed modified bitumen is removed from the mixing machine and after cooling to room temperature kept it in a sealed container.

3.4 Determination of Optimum Binder Content (OBC) –

Marshall mix design method is used for the bituminous mixes using both neat 60/70 bitumen, PMB and CRMB to determine optimum binder content (OBC) and to check whether bituminous mixtures meet Marshall mix design requirements at OBC or not.

3.5 Retained Marshall Stability –

Loss of stability due to immersion of flexible pavement under water is determined by ASTM D 1075. At least six Marshall compacted specimens, three for conditioned and three for unconditioned sample of both neat and modified bitumen are required. Three samples are set at room temperature and three samples in a water bath at 60°C for 24 hours. The three standard specimens are conditioned at the end of a 24hour waiting period. Normal stability tests are run on each sample and the average results for each set is taken. Retained stability was calculated by the following equation 1. Bitumen having higher retained stability value is more resistant to damage of road stability due to immersion under water.

$$\text{Retained Stability (\%)} = (\text{Conditioned Stability} \div \text{Unconditioned Stability}) \times 100 \quad (1)$$

3.6 Tensile Strength Ratio –

Tensile strength ratio (TSR) is calculated for both neat and modified bitumen by following equation 2 (ASTM D 4867). TSR is the ratio of the tensile strength of the conditioned subset to that of the unconditioned subset. Bitumen having higher TSR value is more resistant to damage due to moisture. The higher the tensile strength of a bitumen, the more it is resistant to rutting and lower temperature cracking.

$$\text{Tensile Strength Ratio, TSR (\%)} = S_{t\,(Conditioned)} \div S_{t\,(Unconditioned)} \times 100 \quad (2)$$

Where, TSR = Tensile strength ratio, %

$S_{t\,(Conditioned)}$ = Average tensile strength of the moisture conditioned subset, kPa (psi)

$S_{t\,(Unconditioned)}$ = Average tensile strength of the dry subset, kPa (psi)

According to AASHTO T 283 specification the moisture induced damage of flexible pavement is determined by conducting of freezing-thawing action on the test samples which is the measure of long-term stripping susceptibility of asphalt mix. The test is carried on two sets of Marshall samples having air void 7 ± 0.5%. The set of samples are divided into two subsets. The first set includes 3 samples are kept at a temperature of 25˚C for a period of 2 hours without soaking i.e., unconditioned subset. The second subset are conditioned by vacuum saturation by 70-80 percent with water and then placed in a freezer at 0ºF (-18ºC) for 24 hours. The conditioned specimens are then placed in a water bath at 25ºC for 24 hours. After the freeze-thaw conditioning is done, the indirect tensile strength (IDT) is measured by using equation 3 or 4. The tensile strength of conditioned sample $S_{t\,(Conditioned)}$ is compared to the tensile strength of unconditioned sample $S_{t\,(unconditioned)}$ to determine TSR. Bitumen having more TSR value is more resistant to moisture induced damage including freezing thawing condition.

$$\text{Indirect Tensile Strength, } S_t = \frac{2000P}{\Pi Dt} \text{ in kPa or} \quad (3)$$

$$S_t = \frac{2P}{\Pi Dt} \text{ in psi} \quad (4)$$

Where, S_t = Split tensile strength, kPa (psi)

P = Maximum load, N (lbf)

t = Specimen height immediately before tensile test, mm (in)

D = Specimen diameter, mm (in)

IV. Experimental Investigation and Result

4.1 Gradation of Aggregate –

The surface course gradation is selected according to the specification of ASTM D 3515. The gradation of aggregate is shown in the Table 2.

Table -2 Gradation of Aggregate (ASTM D 3515)

Sieve Size (mm)	Percent (%) Passing (19mm Nominal Max. Aggregate Size, NMAS)	Mid Value	Weight in 100% (1100 gm) Mix (gm)
25	100	100	0
19	90-100	95	55
12.5	67-88	77.5	192.5
9.5	56-80	68	104.5
4.75	35-65	50	198
2.36	23-49	36	154
1.18	14-34	24	132
0.6	9-24	16.5	82.5
0.3	5-19	12	49.5
0.15	3-13	8	44
0.075	2-8	5	33
<0.075	-	-	55

4.2 Mechanical Properties of Binder –

The conventional 60/70 Penetration Grade Bitumen, Polymer Modified Bitumen (PMB) and Crumb Rubber Modified Bitumen (CRMB) are three binders which have been used in bituminous mix design to assess the efficacy of binders. The mechanical properties of both neat and modified bitumen have been determined by laboratory analysis and presented in the Table 3.

Table -3 Mechanical Properties of Various Binders

Name of The Test	Unit	Neat 60/70	PMB	CRMB	Reference	ASTM / AASHTO Specifications
Specific Gravity @ 25˚C	-	1.024	1.015	1.037	AASHTO T228 / ASTM D70	ASTM: Min. 1.0 ~ 1.2 AASHTO: 1.0 ~ 1.1
Penetration @ 25˚C & 100gm loading, 5 Sec	0.1 mm	68.5	42.5	32.5	AASHTO T49 / ASTM D5	60/70 Bitumen = 60 ~ 70
Softening Point (R&B)	˚C	48.5	67.5	68.5	AASHTO T53 / ASTM D36	Lower Grade Bit. = 40 ~ 60 Higher Grade Bit. = 60 ~ 70
Ductility	cm	100+	100+	32.8	AASHTO T51 / ASTM D113	Min. 100
Loss on Heating for 5 hrs. at 163˚C	% Loss	0.91	0.0	0.0	AASHTO T179 / ASTM D6	Max. 1%
Flash Point	˚C	305	340	330	AASHTO T48 / ASTM D92	Min. 230
Fire Point	˚C	320	357	350	AASHTO T48 / ASTM D92	Min. 300
Elastic Recovery at 25˚C, 10 cm elongation	%	17	61	70	AASHTO T301 / ASTM D6084	ASTM: Min. 60% AASHTO: 40 ~ 85%
Striping of Bitumen-Aggregate Mix	%	0.7	0.0	0.0	AASHTO T182 / ASTM D1664	Max. 5%

4.3 Marshall Properties of Bituminous Mixes –

Marshall mix design test results ensure that both neat 60/70 bitumen, PMB and CRMB met Marshall mix design requirements. Optimum binder content (OBC) of neat 60/70 bitumen, PMB and CRMB are found to be 5.05%, 5.10% and 5.30% respectively. The Marshall mix design test results at OBC for both neat and modified bitumen are shown below by Table 4.

Table -4 Comparison of Marshall Test Results at OBC for Various Binders

Marshall Properties	Neat 60/70 @ 5.05% OBC		PMB @ 5.10% OBC		CRMB @ 5.30% OBC		Marshall Criteria As per MS-2, 2014 [11]
	From Trial	From Verification	From Trial	From Verification	From Trial	From Verification	
Stability, kN	19.20	17.80	15.50	15.37	17.40	17.11	Min. 8
Flow, 0.25mm	3.00	3.80	3.90	3.98	3.70	3.96	2 ~ 4
Air Voids (%)	4.00	3.80	4.00	3.93	4.00	3.96	3 ~ 5
VMA (%)	13.80	13.36	13.60	13.34	13.85	13.62	Min. 13
VFA (%)	70.50	71.55	72.00	70.52	73.00	70.91	65 ~ 75

4.4 Water Sensitivity Analysis of Bituminous Mixes –

The retained stability test results for both neat and modified bitumen are shown in Table 5.

Table -5 Retained Stability of Various Bituminous Mixes

Type of Bitumen	Retained Stability of Unconditioned Sample (kN)	Retained Stability of Conditioned Sample (kN)	Retained Stability (%)	Standard Value (%) AASHTO T 165
Neat 60/70	**17.80**	**14.07**	**79.05**	**≥75**
PMB	**15.37**	**14.23**	**92.58**	
CRMB	**17.11**	**16.25**	**94.97**	

The moisture induced damage test results for both neat and modified bitumen are shown in Table 6.

Table -6 Moisture Induced Damage Test of Various Bituminous Mixes

Type of Bitumen	Unconditioned Sample (kpa)	Conditioned Sample (kpa)	TSR (%)	Standard Value (%) ASTM D 6931 & AASHTO T 283
Neat 60/70	**1040**	**864**	**83.08**	**≥80**
PMB	**1127**	**1015**	**90.06**	
CRMB	**986**	**914**	**92.70**	

V.CONCLUSION

Based on the mechanical properties of various binders, the modified binders are less susceptible to temperature variation and moisture compared to neat 60/70 bitumen. These provide improved rutting resistance to resist permanent deformation under heavy traffic loads, enhanced crack resistance to withstand stress and strain caused by temperature fluctuations or repeated loading, fatigue resistance to prevent fatigue damage over time under repeated traffic loads. In addition, it assures that modified bitumen will adhere firmly to the aggregates and withstand water penetration, lowering the possibility of water-related damage like raveling or potholes. The Marshall parameters at OBC for modified and unmodified bitumen are within the limit specified in MS-2, 2014. The variation in the results of Marshall stability of bituminous mixes made at OBC does not exceed ±10%.

In water sensitivity analyses, the results of retained Marshall stability and tensile strength ration (TSR) of various bituminous mixes has been satisfied the criteria specified in AASHTO T 165, AASHTO T 283, ASTM D 6931 and ASTM D 4867. When compared to neat 60/70 bitumen, the modified bitumen, specially CRMB, performs best in water-sensitive conditions.

Finally, it can be concluded that CRMB may be a suitable binder for sustainable flexible pavement construction in Bangladesh.

REFERENCES

[1] BRTA Annual Report 2022-2023, Page-7 https://brta.gov.bd/sites/default/files/files/brta.portal.gov.bd/annual_reports/9c5532fd_05da_4e14_9feb_d606ce97bbbf/2023-11-01-08-44-d71a318c9e1f579dbb115d83edbeb110.pdf

[2] Adnan Abedeen, Md Shameem Hossain, Uday Som and MD Moniruzzaman (2021). "Catalytic cracking of scrap tire-generated fuel oil from pyrolysis of waste tires with zeolite ZSM-5", *INTERNATIONAL JOURNAL OF SUSTAINABLE ENGINEERING 2021*, VOL. 14, NO. 6, 2025–2040, https://doi.org/10.1080/19397038.2021.1951883

[3] Turning waste tires into energy, The Financial Express, Oct 19, 2017. https://thefinancialexpress.com.bd/views/opinions/turning-waste-tires-into-energy.

[4] Al-Azawee, E. T., & Qasim, Z. I. (2018). "The influence of crumb rubber modifier (CRM) on the properties of asphalt concrete mixtures." *International Journal of Civil Engineering and Technology*, 9(10), 201–212. https://www.researchgate.net/publication/328643477_The_influence_of_crumb_rubber_modifier_CRM_on_the_properties_of_asphalt_concrete_mixtures

[5] Humagain, P., Homagai, P. L., & Tamrakar, G. B. singh. (2017). "Properties Study of Crumb Rubber Modified Bitumen". *Journal of Nepal Chemical Society*, 37(November 2017), 69–76. https://doi.org/10.3126/jncs.v37i0.32151

[6] Xu, X., Leng, Z., Lan, J., Wang, W., Yu, J., Bai, Y., Sreeram, A., & Hu, J. (2021). "Sustainable Practice in Pavement Engineering through Value-Added Collective Recycling of Waste Plastic and Waste Tyre Rubber". Engineering, 7(6), 857–867.

[7] Ge, D., Yan, K., You, Z., & Xu, H. (2016). "Modification mechanism of asphalt binder with waste tire rubber and recycled polyethylene". *Construction and Building Materials*, 126, 66–76.

[8] Carlos Rivera, Silvia Caro, Edith Arambula-Mercado, Diana B. Sanchez, Pravat Karki, 2021. "Comparative evaluation of ageing effects on the properties of regular and highly polymer". https://doi.org/10.1016/j.conbuildmat.2021.124163

[9] Behnood, A., Modiri Gharehveran, M., "Morphology, Rheology and Physical Properties of Polymer-Modified Asphalt Binders", *European Polymer Journal (2018)*, https://doi.org/10.1016/j.eurpolymj. 2018.10.049

[10] Palit, S.K., (2001). "An Investigation on Bituminous Mixtures Modified with Reclaimed Crumb Rubber", http://www.idr.iitkgp.ac.in/xmlui/handle/123456789/8102

[11] MS-2, 7th Edition, Asphalt Mix Design Method, 2014. https://www.scribd.com/document/517224295/MS-2-7th-Edition