USE OF CRUMB RUBBER IN FLEXIBLE PAVEMENTS

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ABSTRACT

In the modern era, nationwide connectivity is a precondition for the economic and social development. In Bangladesh, flexible pavements count about 98% of paved roads. But these conventional bituminous pavements are highly susceptible to moisture damage, temperature variation and need routine maintenance. So, conventional bitumen modification is a crying need. Bangladesh generates about 90000 tons of non-biodegradable waste tires annually which creates a huge environmental problem. But this waste tires can effectively be incorporated with neat bitumen to make bituminous roads durable, less susceptible to temperature variation and highly resistant to moisture induced damage. Marshall mix design method was used to evaluate the performance of neat bitumen and crumb rubber modified bitumen (CRMB) mixtures whether they meet mix design requirements or not. Water sensitivity analysis was done for both bituminous sample. Loss of stability due to waterlogging was investigated by retained stability test. Resistance to lower temperature cracking and rutting was investigated by indirect tensile strength test. Stripping due to frost and thawing action was investigated by moisture induced damage test. After conducting all tests, it can be concluded that CRMB showed higher softening point and lower stripping value. Water sensitivity tests indicate modified bituminous mixes showed higher resistance to moisture induced damage, lower temperature cracking and rutting which in turn alludes less maintenance work is needed for CRMB road. So, it can be said that CRMB is a sustainable solution for durable and efficient road construction in Bangladesh considering economically and environmentally.

Keywords:*Flexible pavement, Water sensitivity, Temperature variation, Waste tire, Sustainable Development*

1. INTRODUCTION

Approximately 1.5 billion tires are produced globally in each year which will normally enter the stream of waste representing a major potential waste and environmental problem (Williams, 2013). In Bangladesh waste tire generation of each year is about 90000 tons (BBS, 28 edition, 2008).One common way for disposal of these waste tires is land filling or dumping it in the waterbody. Tires are bulky and more than 75% of the space a tire occupies is void, so the land filling by waste tires has several major problems. Tires tend to rise in landfill and come to the surface of ground. Under the ground waste tires capture various types of gases such as methane which has natural tendency to burn suddenly with a vast explosion. If the waste tire is scattered on land in vain then it comes with rain water and may be a good place for breeding mosquitos or otherpathogenic bacteria. This causes harmful diseases to human beings and animals. Bangladesh is a country with vast variation in temperature and the amount of rain is not uniform over the year. About 98% paved roads in Bangladesh are bituminous flexible pavementand these roads get easily deteriorated due to high temperature susceptibility of the conventional bitumen used in Bangladesh. Water logging is an ever-increasing problem for Chittagong city and during waterlogging the roads get deteriorated due to lower resistance to moisture induced damage of the conventional bitumen used. Although road maintenance cost in Bangladesh is high but sufficient fund is not allotted for maintenance in the national budget. With an economic development rate of 6.5 % or more of GDP on average the number and capacity of vehicle is increasing very rapidly for increased import export activity within the country. Vehicles with ever increasing carrying capacity require improvedheavy-duty roadsbut cannot be achieved with conventional bitumen. So, modification of conventional bitumen in a cost-effective manner is a crying need for Bangladesh. This problem can easily be solved by incorporating crumb rubber with bitumen to have the desired properties for flexible pavements of Bangladesh.

1.1 History of Using Crumb Rubber as a Modifier in Bituminous Pavement

Incorporation of crumb rubber with conventional bitumen has been practiced for more than a century. The first attempt was taken in early 1840s, which involved mixing of natural rubber with bitumen to improve the desired engineering properties. Modification process of bitumen by natural and synthetic rubber was introduced at early 1843 (Thompson, 1979). The modification process both by natural and synthetic got further improvement in 1923 (Isacsson and Lu 1999; Yildrim, 2007). Yildrim stated that the development of rubber-bitumenmaterials being used as joint sealers and patches began in the late 1930s. According to the study of Hanson, in 1950 the use of scrap tire in asphalt pavement was reported (Hanson,Foo, Brown& Denson 1994).

In 1960, Charlie Mac Donald reported successfull use of scrap tyre rubber asan additive in bitumen binder modification. He concluded that after mixing of crumb rubber with the neat bitumen and allowing it to blend for mixduration of 45 to 60 min, there were new materialproperties produced, which resulted in swelling in the sizeof the rubber particles at higher temperatures allowing forhigher concentrations of liquid bitumen contents in pavement mixes (Huffman,1980). In the mid-1980s, theEuropeans began the development of different polymers and additives for application in bitumen binder modification (Brule, 1996). In recent years, the use of crumb rubberhas gained interest in pavement modification and hasshown that crumb tyre rubber can improve the bitumenperformance properties (Brown,Jared, Jones& Watson 1997).It is reported that during thebitumen-rubber thermal blending, due to higher stiffness andtensile strength at elevated temperatures, the modified bitumen had decreased rutting capability (Palit,Sudhakar&Pandey, 2004).

2. MATERIALS USED IN INVESTIGATION

Crumb rubber collected from a local tire retreading shop near New market,Chittagong was used to modify 80/100 penetration graded asphalt obtained from Eastern refinery located also in Chittagong. The crumb rubber was generated byscraping old tires of automobiles. Crumb rubber passing ASTM 30 sieve andretained on ASTM 50 sievewas used for bitumen modification. Stone chips collected from local quarry in Chittagong were used as aggregates.Due to local practiceIRC, 81 specifications for aggregate gradation for 50-65 mm thick bituminous surface course was used in this investigation. Stone dust passing 0.075 mm sieve was taken as filler material. Apparent specific gravity of different types of aggregates were determined to use them in Marshall mix design.Physical properties of different types of aggregate are given in Table 1. The aggregate gradation chart is given below by Table 2 and gradation curve is shown in Figure 1.

Table 1: Physical Properties of Aggregates Used

Properties	Coarse aggregate	Fine aggregate	Filler material
Apparent Specific Gravity	2.71	2.64	2.86
Los Angles Abrasion %	21.4	_	_
Aggregate Impact value %	7.16	_	_
Water Absorption %	2	_	_
Combined Elongation and Flakiness index%	24.3	_	_

Table 2: Gradation of Aggregates Used

IS Sieve (mm)	% passing	Individual % retained by wt. of total agg. Passing	Individual retained (gm)
26.5	100	00	00
19.0	79-100	13.3	146
13.2	59-79	18	198
9.50	52-55	7.27	80
4.75	35-55	16.37	180
2.36	28-44	10	110
1.18	20-34	9	99
0.6	15-17	6	66
0.3	10-20	6	66
0.15	5-13	6	66
0.075	2-8	4	44

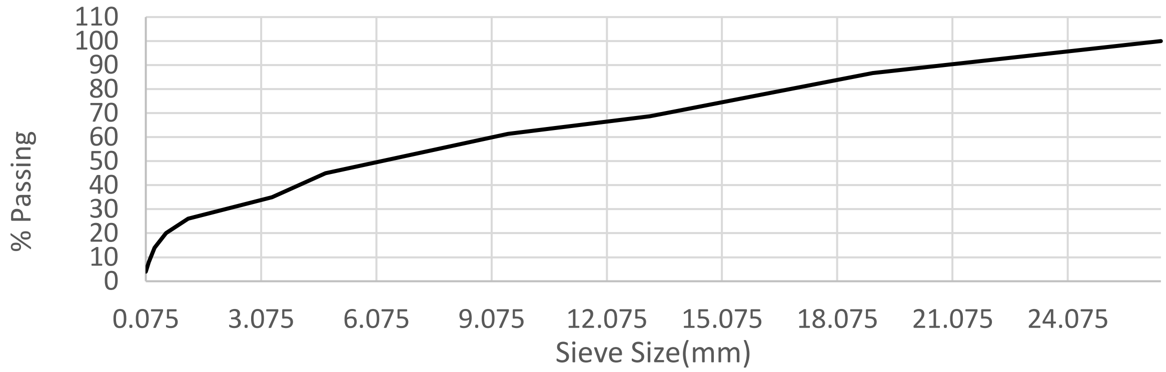

Figure 1: Aggregate Gradation Curve

2.1 Scrap Tire Grinding Process

Crumb rubber was produced by shredding waste tires, which is a material free of fibre and steel. Crumb rubber is normally designated by the mesh screen or sieve size through which it passes during the production process. To produce good quality crumb rubber, it is important to reduce the size of the tire powder to the required degree. There are generally two techniques to produce crumb rubber: ambient grinding and the cryogenic process (Becker, Mendez, Rodriguez,2001). The ambient grinding process can be divided into two methods: granulation and cracker mills. The ambient describes the temperature when the waste tyres rubber as its size is reduced. The scrap tire is loaded inside the crack mill or granulator at ambient temperature. Then the Crack mill reduces the scrap tire to powder. Cryogenic grinding is associated with application of liquid nitrogen to make the scrap tire solid to make it easy to turn it into powder.The cryogenic grinding is a cleaner, slightly faster operation resulting in production of fine mesh size, but the high cost of this process is a disadvantage due tothe added cost of liquid nitrogen. The process is also dangerous as it is related with the handling of liquid nitrogen. Ambient grinding is more popular in the crumb rubber production industry.

3. METHODOLGY

3.1 Preparation of Crumb Rubber Modified Bitumen

There are different methods for blending crumb rubber with bitumen. Among the different specification developed the specifications developed by Palit 2001 were used for blending crumb rubber with asphalt. In this process, 80/100 penetrationgrade asphalt was heated to 160°C in the mixing machine before crumb rubber was added andwas mixed at low speed for about 5 min. Then 0.5 kg crumb rubber was added with 5 kg neat bitumen to get the optimum result (Issa, 2016). The mixture was heated to 170°C to 175°C and agitated vigorously for about 40 to 45 minute using a mechanical stirrer operated at 2,000 rpm.After 40 to 45 minute the developed modified bitumen was removed from the mixing machine and kept in a sealed container after cooling to room temperature.

3.2 Determination of Optimum Binder Content

Marshall mix design method was used for both neat and modified bitumen to determine optimum binder content (OBC) and to check whether bituminous mixtures meet Marshall mix design requirements at OBC or not. Test results of Density-Void analysis and Stability-Flow analysis of Marshall mix design method are presented below by Figure 2and 3

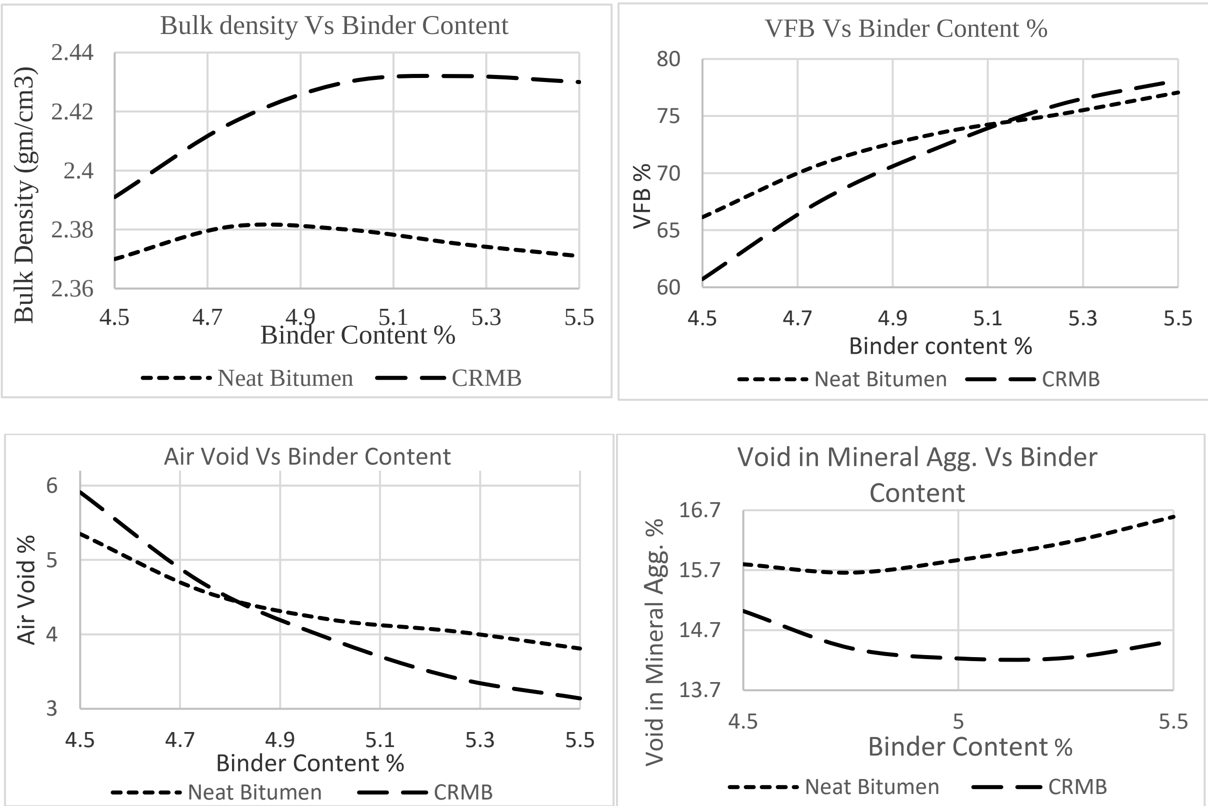

Figure 2: Density- Void Analysis

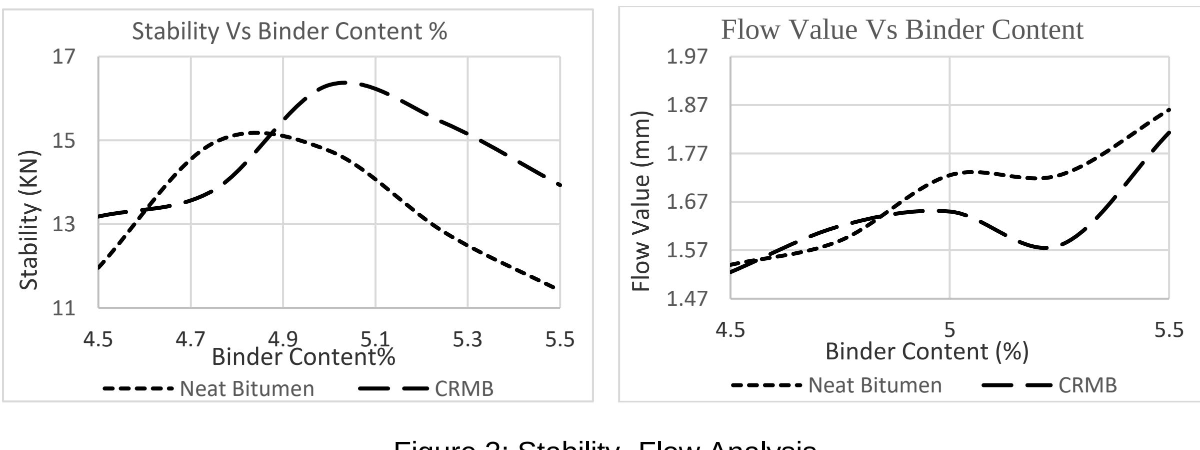

Figure 3: Stability- Flow Analysis

Marshall mix design test results ensured that both neat bitumen and CRMB met Marshall mix design requirements. Optimum binder content was determined 5% and 5.2% for neat bitumen and CRMB respectively. All other tests of sample were conducted at OBC for both types of bitumen.

Indirect Tensile Strength Test (IDT)

Tensile strength of flexible pavement is an indirect measure of resistance to rutting problem and lower temperature cracking. This test was done according to ASTM D 6931 specification. The tensile characteristics of bituminous mixtures were evaluated by loading the Marshall specimen along a diametric plane with a compressive load at a constant rate acting parallel to and along the vertical diametrical plane of the specimen through two opposite loading strips. The compressive load indirectly creates a tensile load in the horizontal direction of the sample. The peak load was recorded, and it was divided by appropriate geometrical factors to obtain the split tensile strength using the following equation(1)

$$S_t = [\frac{2000p}{\pi t D}]$$
(1)

Where,
S_t = IDT strength, kPa
p = maximum load, N
t = specimen height immediately before test, mm
D = specimen diameter, mm

The results can also be used to determine the resistance to field moisture of flexible pavement when results are obtained on both water conditioned and unconditioned specimens.A total of 06 specimenswere prepared. The first group (3 specimens) was immersed in a water bath at 60˚C, for a period of 24 hours (conditioned samples). The samples were then removed from the water bath and kept at a temperature of 25˚C for a period of 2 hours. Other set (3 specimens) of samples (unconditioned samples) were kept at a temperature of 25˚C for a period of 2 hours without soaking. These specimens were then mounted on the conventional Marshall testing apparatus and loaded at a deformation rate of 51mm/min and the load at failure was recorded at each case. The tensile strength(St) of water conditioned as well as unconditioned specimen was determined. Finally, tensile strength ratio(TSR)was calculated for both neat and modified bitumen by equation (2). 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.

$$TSR = [\frac{St(conditioned)}{St(unconditioned)}] \quad (2)$$

3.4 Retained Marshall Stability Test

Loss of stability due to immersion of flexible pavement under water was 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 were required. The specimens were at the optimum binder content and designed gradation.Density and air voids of each specimen was determined. Three samples were set at room temperature and three samples in a water bath at 60°C for 24 hours. Normal stability tests were run on each sample and the average results for each set was taken. The three standard specimens were conditioned at the end of a 24hour waiting period. Retained stability was calculated by the equation (3). Bitumen having higher retained stability value is more resistant to damage of road stability due to immersion under water.

$$Retained\ Stability\ \% = [\frac{Conditioned\ Stability}{Unconditioned\ Stability}]x100 \quad (3)$$

3.5 Moisture Induced Damage Test

Damage of flexible pavement due to freezing-thawing action was determined by moisture induced damage test according to AASHTO T 283 Specification. The test was carried on two sets of Marshall samples having air void between 6% and 8%. The samples were divided into two sets: the first setwas the control group, or “unconditioned”, while the second set, or “conditioned”, was vacuum saturated by 70-80 percent (AASHTO T283-03) with water and then placed in a freezer at 0º F for 16 to 18 hours. The conditioned specimens were then placed in a water bath at 140º F for 24 hours. After the freeze-thaw conditioning was done, the indirect tensile strength (S_t) was measured. The tensile strength of “conditioned” sample S_t(Conditioned) was compared to the tensile strength of “unconditioned” sample S_t(unconditioned) to determine tensile strength ratio (TSR) similar to equation (2). Bitumen having more TSR value is more resistant to moisture induced damage including freezing-thawing condition.

4. RESULTS

The different physical properties testsof both the neat and modified bitumen were conducted according to ASTM specifications. Theproperty testresults of both neat and modified bitumen are shown below by table 3

Table 3: Physical Properties of Bitumen Used

Name of Property Test	Neat Bitumen	Crumb Rubber Modified Bitumen
Specific Gravity	1.02	1.018
Penetration (1/10 th of mm)	91	73
Ductility(cm)	75	56
Softening point (°C)	43	46
Flash point and Fire point (°C)	321 and 342	320 and 340
Stripping Value (%)	01	00

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 Result at OBC

Bitumen type	Stability (KN)	Bulk Density (gm/cm^3)	% air void	Flow Value (mm)	Volume of Bitumen %	Void In mineral agg%	Void filled with asphalt %
Neat Bitumen	14.80	2.382	4.10	1.6	11.676	15.78	73.98
CRMB	16.60	2.43	3.67	1.5	12.293	15.97	76.97

The indirect tensile test results for both neat and modified bitumen are shown in table 5

Table 5: IDT Test Results of Neat and Modified Bitumen

Bitumen type	S_t Unconditioned (Mpa)	S_t Conditioned (Mpa)	TSR
Neat Bitumen	0.425	0.364	0.86
CRMB	0.45	0.414	0.92

The retained stability test results for both neat and modified bitumen are shown in table 6

Table 6: Retained Stability Test Results of Neat and Modified Bitumen

Bitumen type	**Marshall Stability Unconditioned (KN)**	**Marshall Stability conditioned (KN)**	**Retained Stability (%)**
Neat Bitumen	14.80	13.27	89.66
CRMB	16.60	15.24	91.80

The moisture Induced damage test results for both neat and modified bitumen are shown in table 7

Table 7: Moisture Induced Damage Test Results of Neat and Modified Bitumen

Bitumen type	**S_t Unconditioned (Mpa)**	**S_t Conditioned (Mpa)**	**TSR**
Neat Bitumen	0.425	0.346	0.813
CRMB	0.45	0.407	0.906

From property tests results it was observed that 80/100 penetration graded neat bitumen showed penetration value 91, while modified bitumem showed penetration value of 73 which is similar to 60/70 penetration graded bitumen. The softening point of neat bitumen was 43°C, while 46°C was for modified bitumen. So, modified bitumen is more suitable with respect to global warming. Flash and fire point for both neat and modified bitumen are similar. Neat bitumen showed 1% stripping value while it was 0% for modified bitumen. So,modified bitumen is more resistent to damage due to water contact of flexible pavement. From Marshall test result at optimum binder content it was observed that modified bitumen showed 10.84 % more stability value than neat bitumen. With higher stability value modified bituminous road cancarry heavier traffic than neat bitumen. Modified bituminous Marshall sample showed higher bulk density and less air void than neat bituminous sample. High density and less air void reduces the chance of oxidation and moisture absorption. So, pavement failure for oxidation and moisture absorption is less for modified bituminous road than neat bitumen. From indirect tensile strength test the unconditioned samples of neat and modified bituminous sample showed test value of 0.425 mpa and 0.45 mpa respectively. As indirect tensile strength test is an indirect measure of resistence to damage of flexible pavement due to rutting and lower temperature cracking. So, due to higher indirect tensile strength modified bituminous roadsare more resistent to rutting and lower temperature cracking damage. Tensile strength ratio (TSR) for modified bitumen was6.5% more than neat bituminous sample. Due to higher TSR value modified bituminous roads are more resistent to reduction of tensile strength due to water contact than neat bituminous roads. From retained stability test value is 2.33% more for modified bituminous sample than neat bitumen. So, higher retained stabilty value of modified btumen indicates more resistent to loss of stability of road due to waterlogging of flexible pavements than neat bitumen. Tensile strength ratio(TSR) of modified bituminous sample obtained by moisture induced damage test was 9.3% more than neat bituminous sample. Due to higher TSR value of moisture induced damage test modified bituminous sample is more resistent to damage due to moisture induced damage including freezing- thawing action.

5. CONCLUSIONS

The experimental resultsand related information presented in this research leads to the following conclusions:

Crumb rubber modified (CRM) asphaltic road can carry heavier traffic than the conventional bituminous road. The bleeding problem of bituminous road during summer can be solved to a limited degree by using crumb rubber modified bitumen(CRMB). CRMB has enhanced adhesive characteristics and bonding property which indicates enhanced strength and durability.Crumb rubber modified asphaltic road has less chance of moisture absorptionwhich may lead to stripping of aggregate and subsequent chance of pavement failure. The chance of oxidation of bitumen by entrapped air which makes the bitumen brittle is also less for CRMB. CRM asphaltic road can withstand waterlogging more successfully than the conventional asphaltic road for a certain period. CRM asphaltic road is more resistant to lower temperature cracking than the conventional bituminous road. This means that roads constructed with CRMB will show less crack during winter season. CRM asphaltic roads are less susceptible to damage due to freezing and thawing condition than conventional bituminous road. This suggests that CRM asphaltic road can withstand extreme temperature variation more successfully. We can use CRMB as a replacement of 60/70 penetration graded bitumen as 80/100 penetration graded bitumen modified by crumb rubber shows properties similar to conventional 60/70 penetration graded bitumen. At the end,it can be said that CRMB is a sustainable solution for durable and efficient road construction in Bangladesh considering economically and environmentally.

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