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Low cost water resistive bituminous pavement mixes prepared by modified binder

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Abstract

Nation-wide connectivity, efficient, durable and heavy-duty road network is essential for socio-economic development, industrial development as well as for national integration. In Bangladesh, almost 90% roads are made with flexible pavement whose construction cost are too high. Whereas these are greatly damaged due to heavy traffic loads, long time presence of water on the road surface, inconsistency of the weather conditions, poor maintenance etc. So, an attempt has been tried to have a long lasting as well as low-cost and water resistive flexible pavement compare to conventional pavement. The investigation includes; (a) Modification of conventional binder by waste tire crumb rubber for enhancing binder properties, (b) An open graded aggregate gradation has been taken for the preparation of bituminous mixes for lowering the construction cost & (c) A cement mortar with high water cement ratio has been applied in the void of open graded modified flexible pavement mixes for avoiding seal coat of conventional pavement so that huge amount of cost can be reduced. After evaluating the properties of conventional and modified bituminous binder, Marshall mix design method has been used to find out the optimum binder content. Using the optimum binder content, normal stability, retained stability and indirect tensile strength tests are conducted for crumb rubber modified bitumen with and without cement mortar. In this study, cement mortar has been intruded in one face of Marshall sample and the samples have been cured for 14 days under water. Finally, a cost comparison has been made between conventional bituminous road and crumb rubber modified bituminous road using cement mortar on the basis of per square meter. It has been found that bituminous mixes which is filled by cement mortar have higher stability than bituminous mixes. And the mixes intruded by cement mortar has shown much more cost effective and water resistive than conventional mixes. Moreover, modified binder reduces the environmental hazard as waste tire creates comfortable breeding places of harmful insects.

Keywords: Modified binder, moisture sensitivity, cement mortar, seal coat, low cost.

1. Introduction

Now-a-days, most of the cities in the world is facing water logging problem on pavement during the rainy season. Sometimes most of the roads are submerged under water for a long

duration. As a result, roads are greatly damaged and their life span is reduced. The problem of conventional flexible pavement associated with water logging is shown in Figure 1. It may cause a great loss of any country's economy because the construction cost of these conventional flexible pavement with bituminous seal coat roads are too high. So, an attempt has been tried by the authors to develop a low-cost as well as water resistive flexible pavement road which is modified by waste crumb rubber.

Fig. 1. Problem of flexible pavement for water logging

A pavement designer wishes to design a pavement structure which is reliable and cost effective. Various materials have been used for pavement construction so as to economize the design. Depleting natural resources of construction materials and disposal problem of industrial waste products further necessitate use of alternative materials in pavement construction.

Table 1
Properties of collected materials

Aggregate		Binder			Cement	
Properties	Results	Properties	Normal Bitumen	Modified Bitumen	Properties	Results
Specific Gravity	2.65	Penetration value (mm)	68	41	Compressive Strength (MPa)	19.1 (3 Days)
Aggregate Impact Value	5.97%	Ductility (cm)	100^{+}	46		28.7 (7 Days)
Flakiness Index	24.32%	Softening point (℃)	52	61		39.8 (28Days)
Elongation Index	14.35%	Flash Point (℃)	262	228	Soundness	Sound
Abrasion loss	11.84%	Fire Point (℃)	280	239	Fineness (cm^2/gm)	4000
Water Absorption	0.90%	Loss on Heating	0.10%	0.30%	Initial Setting Time	1.60 hrs
		Specific Gravity	1.037	1.045	Final Setting Time	2.80 hrs
		Stripping Value %	4.0	0.0		
		Solubility	95.3%	-		

Crumb rubber is a one kind of waste material which is produced from tires. Approximately 1.5 billion tires are produced each year which will eventually enter the waste stream representing a major potential waste and environmental problem (Williams, 2013). In Bangladesh waste tire generation of each year is about 90,000 tons (BBS, 2008). Vehicle tires contain long chain polymer which cross-linked with sulfur thus having excessive resistance to degradation. One common way for disposal of these waste tires is land filling. Almost 75% of the tire portion is void, so the land filling tires have several difficulties. Tires tend to float or

rise in landfill and come to the surface. Under the ground, the void space of waste tires captures various gases such as methane which has tendency to burn suddenly with a vast explosion. If the waste tire is scattered on land, it comes with rain water and may be a good place for breeding mosquitoes or other harmful organisms. This causes harmful diseases to human beings.

Table 2
Results for retained Marshall stability test

Sample Types	Marshall Stability of Unconditioned Sample (KN)	Marshall Stability of Conditioned Sample (KN)	Retained Stability, %
CRMB sample without cement mortar	8.0	6.26	78.25
CRMB sample with cement mortar	11.42	10.81	94.66

In recent years, the major problems of road maintenance and condition have been related to an increase in a number of transportations by heavy vehicles and insufficient financing allocated for the road sector and the required road maintenance and repair programs (Ziliute *at el*, 2010). The most often and negative type of pavement distress is rutting. It significantly depends on type of pavement structure, kind and quality of materials used for different types of structure layers, also pavement construction techniques and quality (Vaitkus & Paliukaite, 2013). Moreover, environmental conditions are very important for asphalt pavement behavior–bitumen is known as brittle in cold environments and soft in hot environments. As a pavement material, it is characterized with a number of failures represented by the low temperature cracking, fatigue cracking, and the permanent deformations at high temperature (Cong *at el*, 2013).

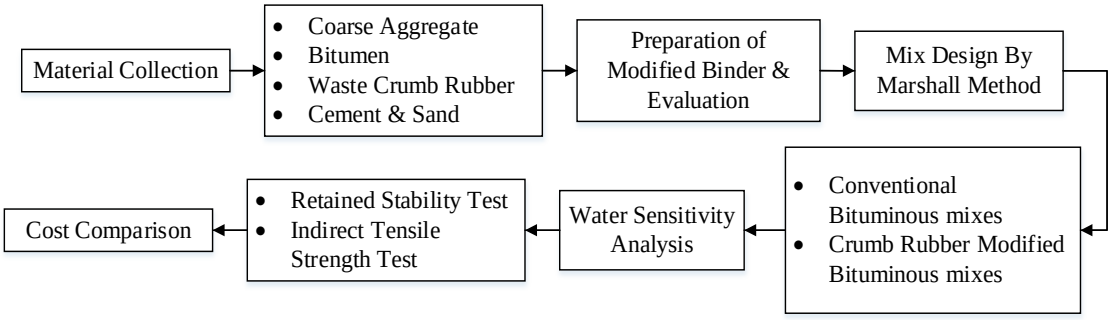

Fig. 2. Work flow diagram

In order to prevent asphalt pavement from failures, scientists suggest estimate pavements' loading conditions, environmental/climate conditions, design materials at the designing stage. Designing materials as high modulus asphalt mixes with polymer modified bitumen could be a proper example of failures preventive solution. Additionally, there is suggested to apply continuously monitoring of different pavement structures performance and to elaborate on the most suitable and economically effective pavement structures (Vaitkus*at el*,2014). Modification of bitumen is a very common these days practice in order to improve its physical properties and performance. Modification of bitumen decreases its temperature susceptibility and this enables asphalt to withstand more load and more severe environments (Ghavibazoo*at el*, 2013). However, modification of bitumen is relatively expensive procedure. Considering these facts, less expensive modification technologies or modificators should be used. Bangladesh is a country with vast variation in temperature and the amount of rain is not uniform over the year. Most of the roads in Bangladesh are bituminous road & the roads get easily deteriorated due to high temperature susceptibility of the conventional

bitumen used in Bangladesh. Water logging is an increasing problem & during water logging the road get deteriorated due to lower resistance to moisture induced damage of conventional bitumen in Bangladesh.

Table 3
Results for indirect tensile strength (ITS)

Sample Types	Indirect Tensile Strength of Unconditioned Sample (KPa)	Indirect Tensile Strength of Conditioned Sample (KPa)	Tensile Strength Ratio (TSR)
CRMB sample without cement mortar	492.96	469.78	0.953
CRMB sample with cement mortar	678.60	636.62	0.938

The maintenance cost of roads in Bangladesh is high. With economic development at the rate of 6.5% Gross Domestic Product on average the heavy traffic intensity is even increasing which require heavy duty road but cannot be achieved with conventional bitumen. But government initiative to face that problem is very poor. This problem can easily be solved by incorporating waste tire powder with bitumen to have the desired properties for roads in Bangladesh. Hence, it has been tried to overcome the moisture induced failure of flexible pavement using modified binder with low cost in comparison with conventional bituminous pavement. So the following specific objectives are selected for the present investigation.

- To evaluate the properties of conventional and modified binders.
- To compare the properties of conventional bituminous mixes and modified bituminous mixes in terms of Marshall properties & water sensitivity tests.
- To compare the cost of bituminous construction prepared with cement mortar and conventional practices.

Table 4
Comparison between the prices of different seal coat

Item	Unit	Price in BDT
Mortar with cement sand ratio of 1:4 (According to local market basis)	1 sq m	75
Bituminous Seal Coat (According to PWD item no.24.17 + 24.19 + 24.20)	1 sq m	426

2. Materials and methods

2.1 Methodology

The present investigation has been conducted by the following ways given in Figure 2.

2.2 Materials

2.2.1 Collection of coarse aggregate

Crushed coarse aggregates collected from Sylhet were used in this investigation. The properties of the collected aggregate are shown in Table 1.The aggregate gradation used in this investigation as per AASHTO 2350, consists of crushed angular stone with maximum size not exceeding 19 mm which is shown in Figure 3.

2.2.2 Collection of waste crumb rubber

Waste Crumb rubbers passing through #30 sieve were collected from local volcanizing shop in Chittagong to modify the bitumen.

2.2.3 Collection of cement

Confidence cement was collected for this investigation. The properties of the cement are shown in Table 1.

Table 5
Cost comparison of different types of pavement

Types of Pavement	Cement mortar with modified binder	Bituminous seal coat with modified binder	Bituminous seal coat with conventional binder
TK.	(900+105) = 1005	900+(436+30) = 1356	(900+426) = 1326
% of Cost Higher	---	34.93% ≅ 35%	31.94% ≅ 32%

2.2.4 Collection of Sand

Sylhet sand was collected. Sand passing through #16 sieve was used for cement mortar in this research.

2.2.5 Collection of bitumen

60/70 graded bitumen was collected from Eastern Refinery in Chittagong for this investigation and its properties are shown in Table 1.

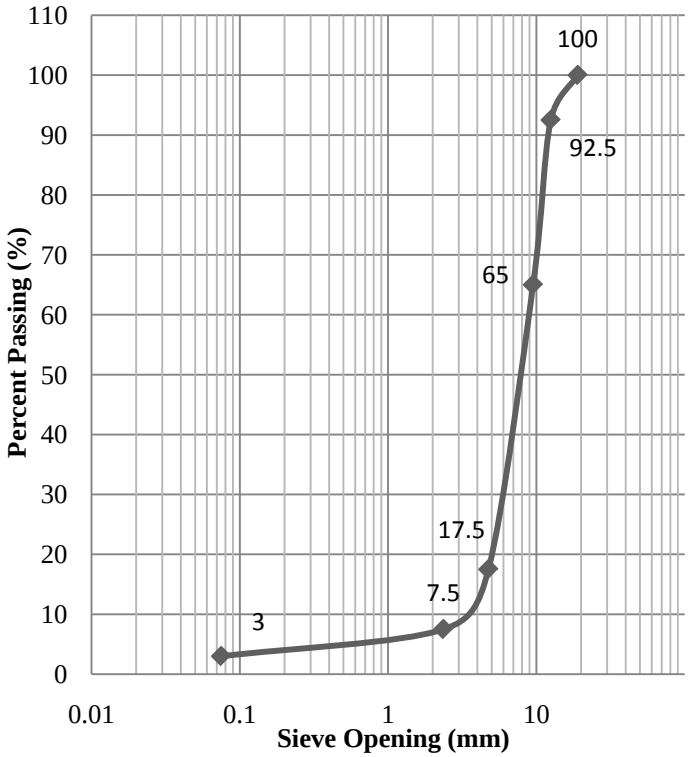

Fig. 3. Particle size distribution curve of coarse aggregate (AASHTO 2350)

2.3 Methods

2.3.1 Preparation of modified bitumen (Palit 2001)

2850 grams of bitumen was taken in a steel container having a lid. The container was placed over an electric hot plate. When the temperature of bitumen reached 160°C, required quantity of the CR (7.5% CR by weight of bitumen) was added to it gradually while stirring the contents manually. The mixing was heated while manual stirring was continued. The

container was then shifted to a preheated sand bath for maintaining the temperature of the mix at 170°C. The mixture was vigorously agitated by a mechanical stirrer operating at 1350 rpm for 45 minutes. The arrangement of locally made 1/8-hp mechanical stirrer rotating machine is shown in Figure 4. The properties of modified bitumen have been presented in Table 1.

2.3.2 Mix design by Marshall method

Marshall Mix design is still widely used by most of the countries in the world. The Marshall method criteria allows the engineer to choose an optimum asphalt content to be added to specific aggregate blend to a mix where the desired properties of density, stability and flow are met. The procedure adopted was similar to that specified in ASTM D1559. The mineral aggregate and binder were heated separately. For normal mixes, Aggregate and normal bitumen were heated to 150-160°C & mixed at 150-160°C and compaction temperature was120-130°C. For modified mixes, aggregate and normal bitumen were heated to 160-170°C and compaction temperature were 130-140°C. 4.5%, 5%, 5.5%, 6%, and 6.5% bitumen and modified bitumen by weight of the total mix were used in the mix design.

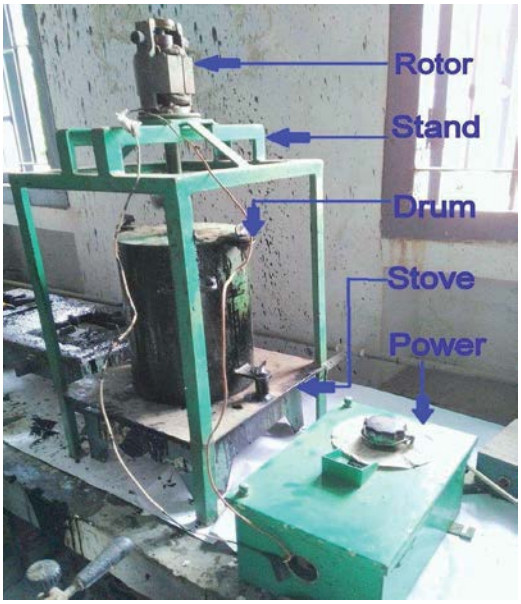

Fig. 4. Arrangement for preparation of modified binder.

2.3.2.1 Optimum binder content (OBC)

The following equation is used to determine the optimum binder content (OBC)

OBC = Binder content at (max. stability + max. density + avg. air void + 80% VFA)/4 (1)

2.3.3 Preparation of cement mortar

In the preparation of cement mortar, the ratio of cement to sand is 1:4 and the ratio of water/cement was high so that it becomes fluid.

2.3.4 Water sensitivity test

Following water sensitivity tests for bituminous mixes are normally used. They are-

- Retained Marshall Stability Test (ASTM D 1075)
- Indirect Tensile Strength Test (ASTM D 6931)
- Moisture Induced Damage Test (AASHTO T-283)

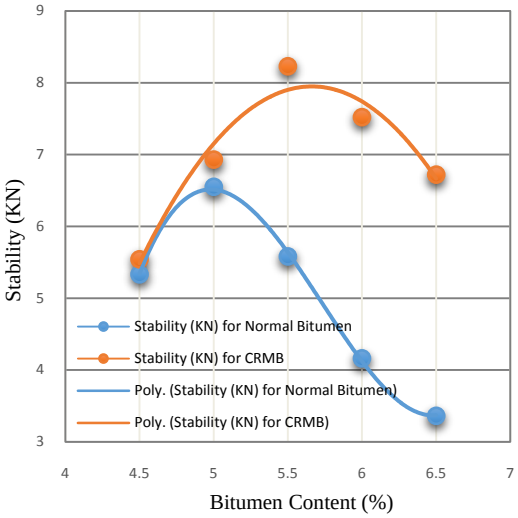

Fig. 5. Flow value (mm) of normal bitumen & CRMB

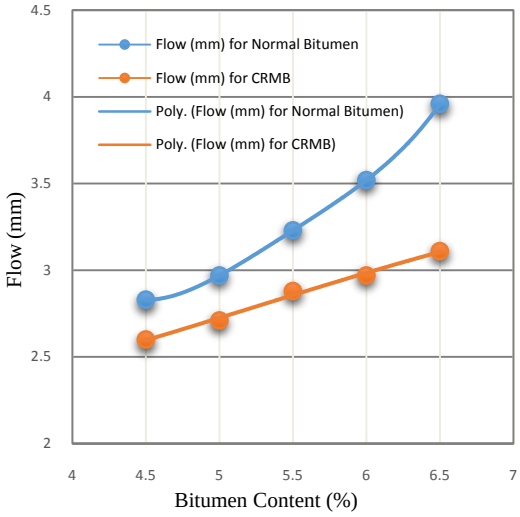

Fig. 6. Stability (kN) of normal bitumen & CRMB

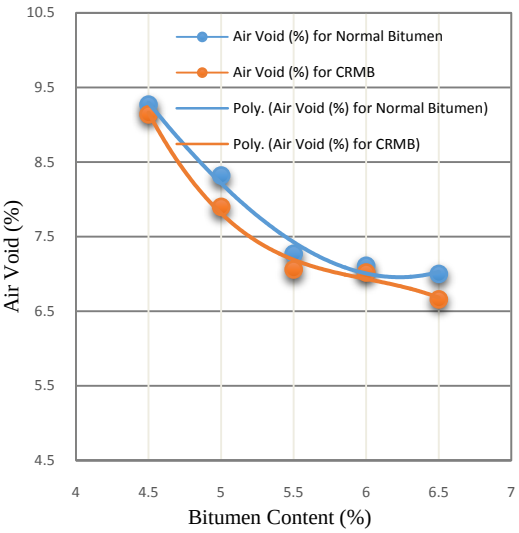

Fig. 7. Air void (%) of normal bitumen & CRMB

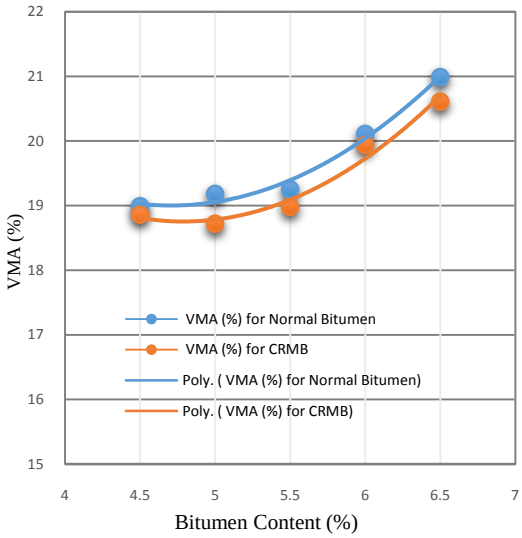

Fig. 8. VMA (%) of normal & CRMB

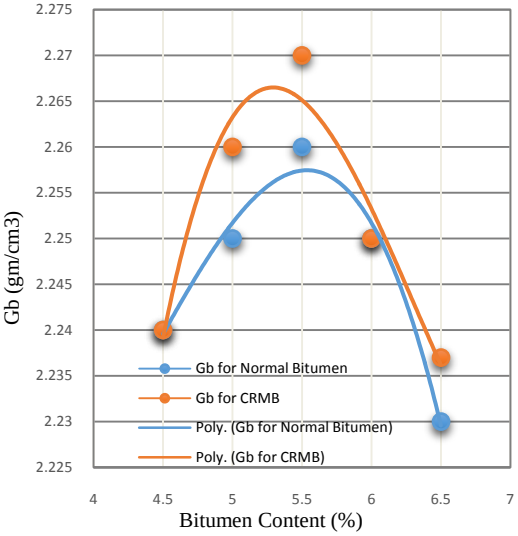

Fig. 9. VFB (%) of normal bitumen & CRMB

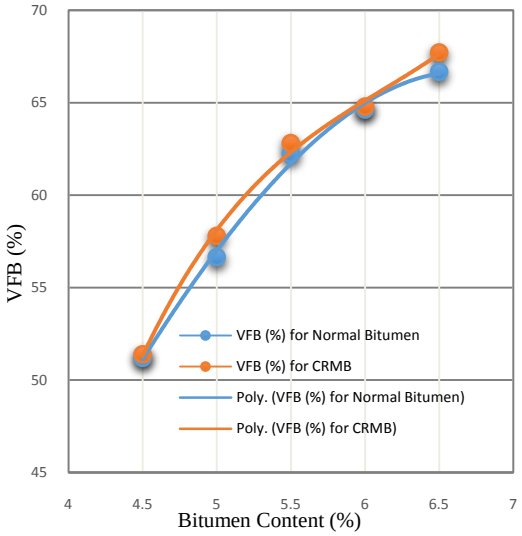

Fig. 10. Bulk density of normal bitumen & CRMB

Retained Marshall Stability & Indirect Tensile Strength test are conducted for performance evaluation of CRMB with and without cement mortar using OBC of CRMB. It is not necessary to do the moisture induced damage test on open graded pavement. Because moisture has no harmful damage for passing water through flexible pavement with open graded aggregate according to Wisconsin Asphalt Pavement Association (WAPA).

2.3.4.1 Retained Marshall stability test

The method ASTM D 1075 determines the retained Marshall stability on Marshall compacted specimens after curing for 24 hours in a water bath at 60°C. Retained stability can be found at using equation (2).

Retained stability (%) = [(Soaked Stability/Standard Stability) x 100] % (2)

2.3.4.2 Indirect tensile strength test

This test is done according to ASTM D 6931 specification. The ITS for each specimen has been calculated using equation (3).

S_t= [(2000*P)/(π*h*d)] (3)

Where,
S_t= Indirect Tensile Strength in kPa
h= average height of specimen before test in mm
P= maximum applied load in N
d= diameter of specimen in mm

Tensile strength ratio (TSR) is calculated using equation (4).

$$TSR = \frac{ITS\ at\ 60°C\ for\ 24\ hours\ at\ water\ \ (conditioned\ \ )}{ITS\ at\ 25°C\ for\ 2\ hours\ at\ air\ (unconditioned\ \ )} \quad (4)$$

3 Experimental investigation

3.1 Marshall mix properties

To determine stability, flow & OBC of the bituminous mixes, Marshall Method has been used. The Marshall Parameters are represented in Figure 5 to Figure 10.

3.1.1 Determination of OBC

To determine OBC for conventional and modified binders, equation (1) has been used. According to WAPA for open graded aggregate, the standard range of air void is 16-22%.From Figure 5 to Figure 10, average air void is not found & the value is less than the standard value. 80% VFA value is also not available. So the optimum binder content is calculated as average of binder corresponding to maximum stability & maximum bulk density. Hence, 5.22% & 5.45% are the OBC of conventional bituminous mix and modified bituminous mix respectively. According to WAPA for open graded aggregate, the range of optimum binder content (OBC) for both normal and CRMB is within the range of 5.2% to 6.0%. As modified bituminous mix shows better binder property than normal bitumen, that's why OBC of CRMB is used for further performance test. At OBC of modified bituminous mix, Flow value, stability, air void, VMA, VFB & bulk density are 2.875mm, 7.85kN, 7.25%, 19.1%, 62.7% &2.266 gm/cm^3 respectively which are almost within the specification limit.

3.2 Water sensitivity test results

Water sensitivity test has been conducted in terms of retained stability & indirect tensile strength in order to find out the mix performance against the water & temperature.

3.2.1 Retained Marshall stability test result

Retained stability has been calculated using equation 2. The values obtained are shown in Table 2. So, retained stability of CRM bituminous sample with cement mortar=94.6% > 75%. From Table 2, it is seen that retained stability of CRM bituminous sample with cement mortar gives better result as compare to CRM bituminous sample.

3.2.2 Indirect tensile strength test result

Indirect tensile strength has been calculated using equation (3). The values obtained are shown in Table 3. From Table 3, it has been seen that CRMB sample with cement mortar shows higher performance in terms of indirect tensile strength than CRMB sample without cement mortar.

4. Cost analysis

4.1 Pavement comparison

The Figure 11 describe the comparison between conventional bituminous pavement having bituminous seal coat and the proposed pavement where the cement mortar penetrated through the voids also acted as an additional binding material to serve the facility like seal coat.

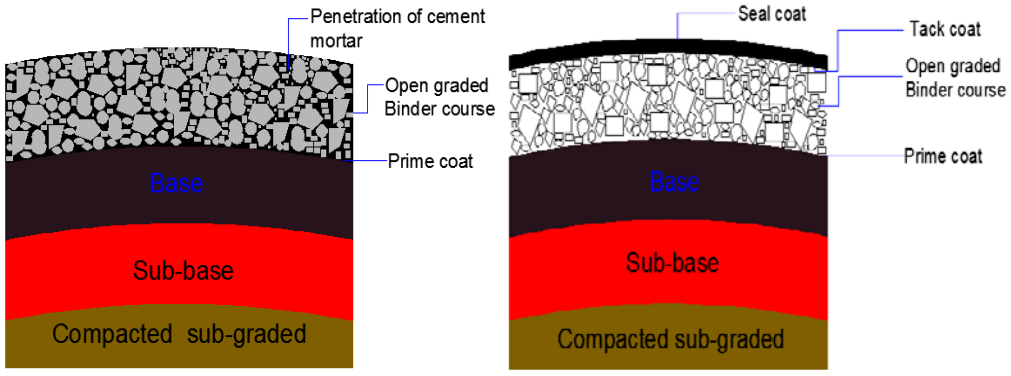

Fig. 11. Comparison of conventional flexible pavement and modified flexible pavement with cement mortar.

4.2 Cost comparison

According to the schedule proposed on 2014 by Public Works Department (PWD) and Department of Roads and Highway of Bangladesh (RHD), the cost comparison of seal coat with conventional binder has been shown in Table 4. The cost is considered above the prime coat for both conventional bituminous pavement and pavement with cement mortar. For modified pavement with cement mortar, high water cement ratio is used & the cost has been assumed as per as follows.

Cost of crumb rubber = TK. 25 for 1 sq m pavement
Cost of CRMB preparation = TK. 5 for 1 sq m pavement
So, cost of modified pavement with cement mortar =TK. (75 + 25 + 5) = TK. 105
The cost of binder course is assumed to be TK 900. The cost comparison of three types of pavement is shown in Table 5. They are:

– Cement mortar with modified binder
– Bituminous seal coat with modified binder
– Bituminous seal coat with conventional binder

5. Conclusion

From the above investigation, the following salient features can be noted that using crumb rubber in modifying bitumen may be an effective environmental solution for waste tire management problem. CRMB shows better properties than conventional bitumen. Crumb rubber modified bituminous mixes shows higher stability than conventional bituminous mixes. Retained stability is increased 20.97% for using cement mortar on CRMB sample than normal CRMB sample. Cement mortar used as penetration type construction which reduces greatly construction cost and is more effective in resisting water as compare to conventional bituminous mixes with seal coat.

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