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Effect of Water Submergence on the Characteristics of Bituminous Mixes Using Reclaimed Asphalt Pavement

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Abstract: Now a-days, the cost of asphalt pavement materials have been increasing excessively, which led to find alternative materials which must be cheaper than that of asphalt pavement materials. In addition, more concerns are pointed to reserving natural resources and reducing environmental impacts of using virgin asphalt binders, thus more attention is focused on the use of recycled materials in pavement designs. The main purpose of this study is to investigate the effect of water on the use of reclaimed asphalt pavement materials in bituminous mix and to determine the optimum percentage of reclaimed asphalt pavement materials with virgin pavement materials and optimum days of water submergence according to the Marshall Mix design criteria based on medium traffic condition. To achieve the objectives of this study the basic properties tests were performed on the studied materials and then Marshall Test was conducted on asphalt mixtures with different percentages of reclaimed asphalt pavement materials with optimum bitumen content determined for 100% fresh aggregate. The different percentages of reclaimed asphalt pavement material in asphalt mixtures are 0%, 10%, 20%, 30% and 40%. Marshall Criteria was satisfied up to 20%. Then the specimen prepared with 20% reclaimed asphalt pavement material was submerged in water at 0, 5, 10, 15 and 20 days. Optimum days of water submergence was 15 days on the basis of Marshall mix design criteria.

Keywords: Reclaimed Asphalt Pavement, Gradation, Optimum Bitumen Content, Marshall Stability, Water Effect

1. Introduction

Reclaimed asphalt pavement (RAP) creates a mean for reusing materials that optimizes the use of natural resources. RAP is an economical alternative to virgin materials because it reduces the need to use virgin aggregate, which is a scare material many parts of Bangladesh. It also reduces the amount of binder required in the production of asphalt paving mixtures. Using RAP is environmentally friendly. It helps to conserve natural resources and reduce the amount of land for the disposal of these materials.

Hot mix recycling is the process in which reclaimed asphalt pavement materials are combined with new materials, sometimes along with a recycling agent, to produce hot mix asphalt (HMA) mixture The two steps in the mix design procedure are material evaluation and mix design.

The objective for the design of bituminous mix is to determine a logical and economical blend and gradation of aggregates with the corresponding bitumen content. The two fundamental properties of bituminous paving mixture which are held to be of utmost importance are stability and durability. In addition to stability and durability, a well-designed mixture must satisfy traffic safety requirement. Above all, the mix must also be economical as possible.

In recent years, a lot of research work has been done to make use of reclaimed asphalt pavement materials into the bituminous mix to make it cost effective.

Hussain et al. (2012) represented on “Laboratory evaluation of asphalt mixtures containing various percentages of reclaimed asphalt pavement” that mixtures containing RAP shows significant variability and the variability increases with the increase in RAP content. Four mixtures, which are the combination of two different virgin aggregates and two different RAP sources, are studied in this research.

Pradyumna et al. (2013) examined on “Characterization of Reclaimed Asphalt Pavement (RAP) for using in bituminous road construction” that the addition of RAP improves all the properties of the bituminous mixes. This indicates that mixes with 20% RAP would perform better than the virgin mixes under similar condition. The bituminous rejuvenating agent which was prepared in the laboratory was added to the recover binder obtained from the RAP material in various dosages of 10%, 15% and 20%.

Udayshankar et al. (2013) found that "Laboratory studies of dense bituminous mixes-II with reclaimed pavement materials" that the mixtures containing RAP showed significant variability and the variability increased with the increase in RAP content. The mixtures were designed by Marshall method as per Asphalt institute (MS-II) at 20% and 30% RAP. The total is reduced around 20%-30% comparing with the virgin mixes.

Srikant et al. (2014) determined that "Comparative evaluation of warm mix asphalt containing reclaimed asphalt pavement for DBM II mix" that the test results indicate improvement in laboratory performance, encouraging the use of reclaimed asphalt pavement materials in warm mix asphalt mixes. Warm mix prepared at 1200°C mixing with 30% RAP content shows higher stability when compared with warm mix prepared at 110°C.

Mohamady et al. (2014) examined on "Effect of using Reclaimed Asphalt Pavement on asphalt mix performance" that the percent of RAP maybe 30% to ensure superior field performance after construction. Asphalt concrete specimens are prepared at optimum asphalt content resulted in Marshall test to be investigated through indirect tensile strength test and loss of stability test. The six asphalt mixtures contain different percentages of RAP (i.e. 0%, 10%, 20%, 30%, 40% and 50%).

Sunil et al. (2014) represented on "Experimental investigations on the performance of bituminous mixes with reclaimed asphalt pavement (RAP) materials (case study Tumkur to Chitradurga-NH_4)" that RAP mixes shows good Marshall stability, indirect tensile strength and fatigue life similar to conventional asphalt mix. Bituminous mixes prepared with 10%, 20%, 30% and 40% RAP material obtained by scarifying distressed asphalt pavement, surface new aggregate and bitumen such as VG-30 without using any rejuvenator. The study shows that about 20% and 30% of the cost of the wearing courses or binder courses can be effectively reduced with all the other liabilities.

Elmohr et al. (2015) examined on "Characterization of reclaimed asphalt pavement (RAP) for using flexible pavement" that the bituminous mixes with RAP especially at 50% to 100% replacement ratio provide better performance compared to those of new conventional HMA mixtures where they minimize the environmental impacts through the reduction of energy consumption, improves the mechanical properties, durability performance and also stripping resistance. The addition of RAP has a great influence on improving the indirect tensile strength where the highest values are achieved at 50% RAP content.

2. Methodology

The study was based on materials collection, materials properties, experimental program and compare the values with Marshall Mix design criteria based on medium traffic condition.

2.1. Materials Collection

Black stone chips to the size of 25mm and less was used in this investigation as fresh coarse aggregate. The source of the black stone chips is Pakur, India. RAP material is collected from Natore. Combination of Domar sand and Padma river sand was the main source of fine aggregate and mineral filler. The bitumen was of 80-100 penetration grade bitumen collected from eastern refinery, Chittagong.

2.2. Material Properties

Material properties were determined according to the test procedures specified by AASHTO and BS standards.

Table 1. *Properties of Mineral Aggregates.*

Properties	Method (AASHTO)	Coarse Aggregate (Fresh)	Coarse Aggregate (RAP)	Fine Aggregate	Mineral Filler
Unit weight, kg/m^3	T19	1528	1524	1430	1150
Specific gravity	T85	2.76	2.72	2.46	2.63
Water absorption, (%)	T85	75	72		
L. A. A., (%)	T96	19	22		
AIV, (%)	BS812	7	9		
ACV, (%)	BS812	17	20		

Table 2. *Properties of Bitumen.*

Properties	Method (AASHTO)	Test Value
Specific gravity (at 25°C)	T229	1.01
Penetration (at 25°C, 100 gm and 5 seconds)	T49	83
Loss on heating (at 163°C, 5 hours), (%)	T47	0.42
Ductility (at 25°C), cm	T51	100$^+$
Solubility (by CCl_4), (%)	T44	99.6
Flash point, °C	T48	272
Fire point, °C	T48	280

2.3. Experimental Program

Experimental program is divided into three steps, such as determination of optimum bitumen content, determination of optimum percentage of RAP and optimum days of water submergence.

2.3.1. Determination of Optimum Bitumen Content

At first optimum bitumen content was determined for 100% fresh aggregate. The test procedure introduced by Bruce Marshall and developed by the U.S. corps of engineers has been followed in the laboratory investigations. It was observed from the trial mixes that about 1200 gms of aggregates were required to prepare one specimen of 101.6 mm (4 in.) diameter and 63.5 mm (2.5 in.) thick. Aggregate were selected according to the aggregate grading proposed by The Asphalt Institute giving in Table 3. Specific gravity of the specimen was determined according to AASHTO (1983) T 166. Then the specimen was subjected to Marshall stability and flow test.

Table 3. *Aggregate grading (The Asphalt Institute, 1974).*

Sieve mm	% passing by weight	Individual Retain (%)	% of CA, FA & MF	Individual weight, for 1200 gm
25	100	00		
19	90	10		120
9.5	70	20	CA= 58%	240
4.75	56	14		168
2.36	42	14		168
0.60	25	17		204
0.30	18	07	FA= 38%	84
0.15	11	07		84
0.075	4	07		84
			MF= 4%	48

2.3.2. Determination of Optimum Percentage of RAP

After determination of OBC, RAP materials mixes with fresh aggregates on 0%, 10%, 20%, 30%, 40% of total percentage of coarse aggregate. Bituminous mould was prepared of this percentage with OBC by Marshall mix design method. Specific gravity of the specimen was determined according to AASHTO (1983) T 166. Then the specimen was subjected to Marshall stability and flow test. Optimum percentage of RAP was determined according to the Marshall mix design criteria based on medium traffic condition.

Table 4. *Marshall Mix Design Criteria (The Asphalt Institute, 1997).*

Marshall Method Mix Criteria	Light Traffic Surface & Base		Medium Traffic Surface & Base		Heavy Traffic Surface & Base	
	Min.	Max.	Min.	Max.	Min.	Max.
Compaction No. of Blows each end of specimen	35		50		75	
Stability, kg (N)	340 (3336)		544 (5338)		816 (8006)	
Flow (0.25 mm)	8	18	8	16	8	14
% V_a	3	5	3	5	3	5
% VMA	See Table 4.10					
% VFB	70	80	65	78	65	75

Table 5. *Minimum % VMA for the Marshall Method.*

Nominal Particle Size (mm)	Minimum VMA (%)		
	Design Air Voids (%)		
	3.0	4.0	5.0
1.08	21.5	22.5	23.5
2.36	19	20	21
4.75	16	17	18
9.5	14	15	16
12.5	13	14	15
19.0	12	13	14
25.0	11	12	13
37.5	10	11	12
50.0	9.5	10.5	11.5

Traffic Classification:

Light: Traffic conditions resulting in a Design EAL < 10^4 or C. V < 150 / day

Medium: Traffic conditions resulting in a Design EAL = 10^4 - 10^6 or C. V = (150 – 300)/day. (Where C. V = Commercial Vehicle)

Heavy: Traffic conditions resulting in a Design EAL > 10^6

2.3.3. Determination of Optimum Days of Water Submergence

After that Marshall criteria satisfied economical RAP percentage was selected. Then these RAP percentage specimen was prepared and taken the specimen in water at 0, 5, 10, 15, 20 days. After that optimum days of watering was determined according to Marshall mix design criteria based on medium traffic condition.

3. Results

Table 6. *Marshall test results of bituminous mixes without RAP materials.*

SL NO.	1	2	3	4	5
% BC	4.5	5	5.5	6	6.5
Unit weight (kg/m³)	2311	2311	2349	2332	2321
Marshall Stability (KN)	13.4	14	15.6	14.8	13.7
Flow value	13	13	14	15	16
% Va	6.9	5.4	3.9	3.6	3.8
% VMA	15.5	15.2	15	15.8	17
% VFB	55.5	64.5	74	77.2	77.6

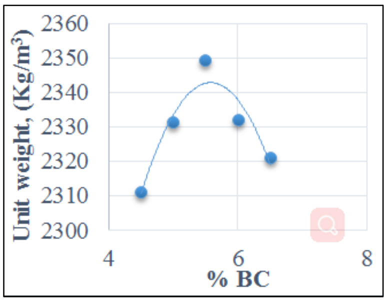

Figure 1. *Relationship between unit weight and bitumen content.*

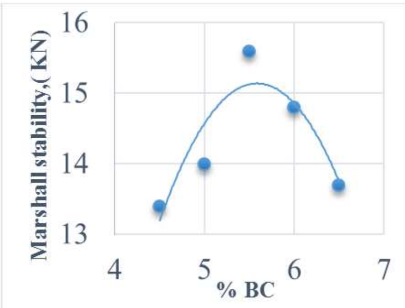

Figure 2. *Relationship between Marshall stability and bitumen content.*

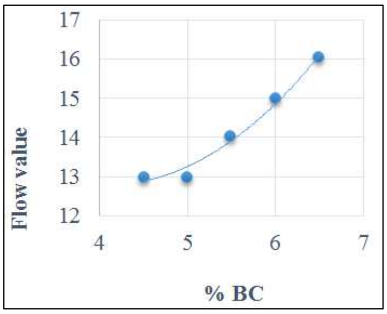

Figure 3. *Relationship between flow and bitumen content.*

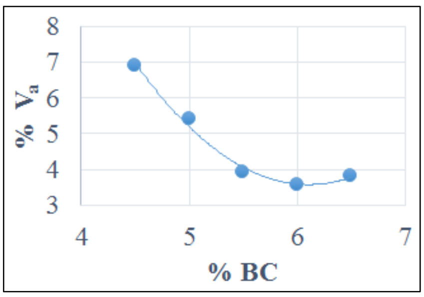

Figure 4. *Relationship between voids in total mix and bitumen content.*

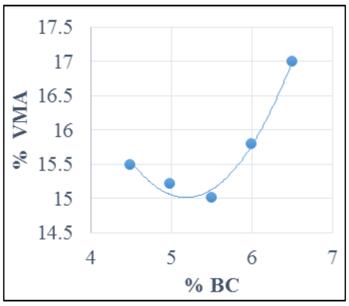

Figure 5. *Relationship between void in mineral aggregate and bitumen content.*

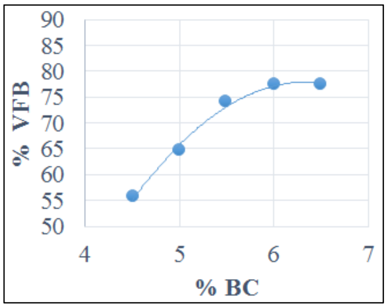

Figure 6. *Relationship between voids filled with bitumen and bitumen content.*

Optimum bitumen content

The optimum bitumen content is the minimum bitumen content at which maximum density of bituminous paving mix is obtained by averaging the bitumen content for maximum unit weight, bitumen content for maximum stability and bitumen content for 4 % air voids.

$$OBC=\left(\frac{5.63+5.6+5.65}{3}\right)\%$$

$$=5.63\%$$

Table 7. *Marshall test results of bituminous mixes with varying RAP percentage.*

SL NO.	1	2	3	4	5
% of RAP	0	10	20	30	40
Unit weight (kg/m³)	2342	2331	2320	2310	2300
Marshall Stability (KN)	15.25	14.95	14.4	13.22	11.68
Flow value, 0.25mm	14	15	15	16	17
% V_a	3.9	3.87	3.7	3.55	2.95
% VMA	15.3	15.74	16.1	16.43	16.76
% VFB	73.3	75.4	77	78.4	82.4

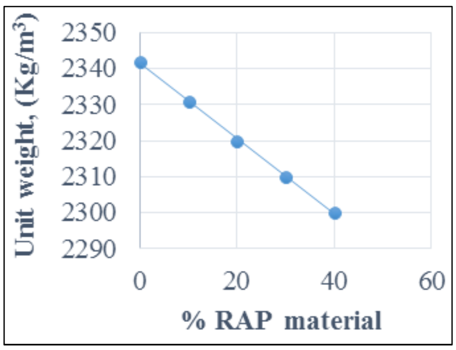

Figure 7. *Relationship between unit weight and RAP material.*

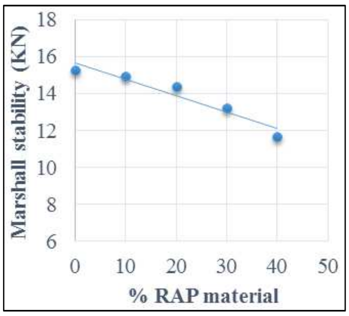

Figure 8. *Relationship between Marshall stability and RAP material.*

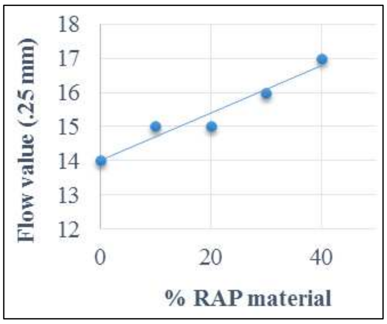

Figure 9. *Relationship between flow value and RAP material.*

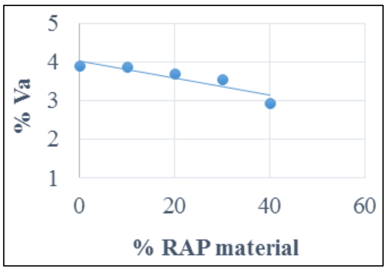

Figure 10. *Relationship between voids in total mix and RAP material.*

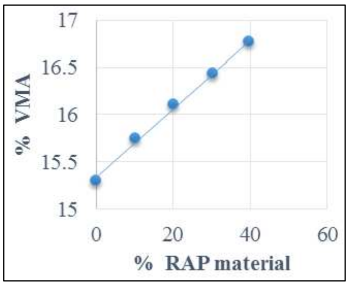

Figure 11. *Relationship between void in mineral aggregate and RAP material.*

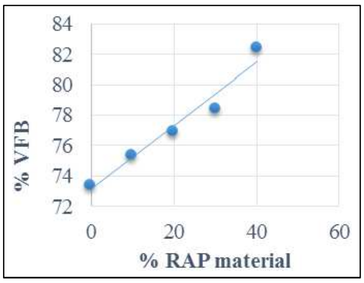

Figure 12. *Relationship between void filled with bitumen and RAP material.*

From the Table 7, it can be shown that 0%, 10% and 20% RAP content satisfy Marshall mix design criteria based on medium traffic condition. There is a failure on void filled with bitumen at 30%. So, 0%, 10% and 20% satisfy traffic requirement. For economical reason 20% RAP content would be selected.

Table 8. *Marshall test results of bituminous mixes taking varying days in water.*

SL NO.	No of Days	Marshall Stability (KN)	Flow value, 0.25mm
1	0	14.4	15
2	5	11.89	15
3	10	9.18	16
4	15	6.63	16
5	20	5.43	17

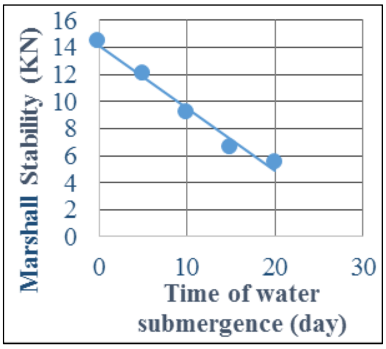

Figure 13. *Relationship between Marshall stability and time of water submergence.*

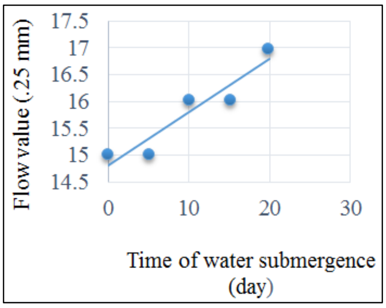

Figure 14. *Relationship between flow value and time of water submergence.*

From the Table 8 it can be shown that for 20% RAP content up to 15 days of watering of bituminous mix all values are satisfied medium traffic condition based on Marshall mix design criteria. At 20 days both Marshall stability and flow failure occurs.

4. Conclusions

On the basis of experimental results of this study, the following conclusions are drawn.

Optimum bitumen content is 5.63% for fresh aggregate.

Although stability gradually decreases with the increase of RAP aggregates in the bituminous mixes with fresh stone aggregates, the characteristics of mixes satisfy the Marshall design criteria.

Up to 20% RAP content, the characteristics of mix satisfy the Marshall mix design criteria.

Up to 15 days of submergence in water, the characteristics of mix satisfy the Marshall mix design criteria

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