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Recycling of bituminous pavement materials in Bangladesh condition

Md. Shamsul Hoque, Md. Alamgir Mojibul Hoque and Md. Asif Imran

Department of Civil Engineering
Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh

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Abstract

Frequent rehabilitation of roads in the form of overlaying consumes a large amount of costly road materials and the consequent rise of road level causes various problems in cities including water logging. Recycling of used road materials has the potential to conserve fund and natural resources. In this study, an attempt has been made to study and compare the properties of recycled bituminous mixes with those produced from salvaged materials only and a conventional fresh mix. In order to achieve this, eleven bituminous mixes including five recycled, five fully salvaged and one fresh were studied, following the Marshall method in the design and testing of these mixes. Effect of water on the compressive strength of these mixes was also investigated in this study. The results revealed that recycled bituminous mixes are suitable for use in the rehabilitation and reconstruction of weathered pavements in Bangladesh from the viewpoint of stability, durability, deformation and voids characteristics. The test results also show that recycling of weathered pavements reduces the bitumen requirement by 30 to 70 percent and aggregate requirement by a maximum of 70 percent as compared to fresh mixes.

Keywords: Recycling, reclaimed asphalt pavement (RAP), Marshall method.

1. Introduction

Due to the effects of traffic and weathering, bituminous road surfaces wear out within a short period of its construction. Maintenance and rehabilitation at the right time can extend the useful life of pavements. In Bangladesh, traditionally an overlay of two to three inches, which does not last long, is provided to strengthen the distressed pavements. Such frequent application of overlays in connection with the rehabilitation of roads not only consumes huge quantity of naturally occurring road building materials but also causes severe problems especially within the built up areas. For example, when the road level goes up gradually due to frequent application of overlays, drainage problem becomes more serious and cause water logging leading to expensive rebuilding of footpaths to prevent the adjacent properties from flooding. Also, there is possibility that the riding quality of the road may deteriorate and the safety of drivers and pedestrians is hampered. However, the most serious implication is that the gradual rise of road level gradually reduces the available vertical clearance of grade separated facilities like flyovers and footbridges, which may inhibit large vehicles to move freely on roads. Although, some of the aforementioned problems can be solved by readjusting the road elements with respect to the new level of road surface, it incurs unnecessary cost of road maintenance. Further, it is to be noted that the aggregates suitable for road construction such as gravels and boulders are not widely available in Bangladesh except in small quantities in Sylhet and Dinajpur. The hauling cost of the materials from these places to the construction sites is often too high. Furthermore, with increased and continued consumption of these naturally occurring aggregates, supply sources are being depleted, which may lead to degradation of the environment. It is therefore desirable to use the available aggregates more judiciously. On the other hand, bitumen is quite expensive and has to be imported from abroad to meet the need of the country. Therefore, for economical use of our limited resources, search has to be intensified for seeking more cost effective approaches for maintenance and rehabilitation of distressed pavements. Recycling of existing pavement materials is one approach towards conservation of resources.

Table 1
Water, mineral aggregate and bitumen contents in reclaimed asphalt pavement samples

Sample Designation	Water Content (%)	Mineral Aggregate Content (%)	Bitumen Content (%)
RAP-1	0.85	94.11	5.08
RAP-2	0.00	96.60	3.40
RAP-3	1.04	93.55	5.47
RAP-4	1.02	94.07	4.96
RAP-5	0.95	93.90	5.20

Table 2
Aggregate grading of reclaimed asphalt pavement samples

Sieve Designation and Size	Percent Finer by Weight					Range of Percent Finer	Average Percent Finer
	RAP-1	RAP-2	RAP-3	RAP-4	RAP-5		
1½ in. (37.5 mm)	100.0	100.0	100.0	100.0	100.0	100	100.0
¾ in. (19 mm)	99.18	97.72	99.08	98.04	100.0	100-97	98.5
⅜ in. (9.5 mm)	86.11	57.8	83.77	76.82	73.64	87-57	72.0
No. 4 (4.75 mm)	67.22	36.54	58.55	52.55	47.48	68-36	52.0
No. 8 (2.36 mm)	44.68	31.71	41.16	34.88	38.39	45-31	38.0
No. 50 (0.3 mm)	16.72	7.19	12.57	8.59	14.79	17-7	12.0
No. 200 (0.075 mm)	2.47	0.92	2.2	1.07	2.15	3-0	1.5

In bituminous pavement recycling, materials reclaimed from old pavement structures are reprocessed along with some new materials to produce bituminous mixtures meeting all normal specification requirements. The recycled mixtures may not only be placed on the same roadbed from which they came, but also they can be used anywhere the bituminous mixtures are needed. Usually recycling is considered where the pavements have been in service for a long period of time and is no longer adequate for the current and future traffic.

The pavement may exhibit notable structural distress necessitating high maintenance costs. Recycling permits to redesign the pavement to suitable standards and reconstruct the pavement at reduced costs.

Recycling of weathered pavements has gained considerable interest in the developed countries because of an awareness of the need to conserve fund, energy and natural resources. This need for conservation should be more evident in Bangladesh condition because of the limitation of financial resources that can be used for other development programmes. It implies that optimum use of aggregates, binders, equipment, manpower, energy, and funds, for rehabilitation purpose is very essential to Bangladesh. It is, therefore, important to study the recycling of weathered pavement which has potential to conserve fund as well as materials.

Table 3
Specific gravity and absorption of aggregates in reclaimed samples and fresh mixes

Sample Designation	Specific Gravity of Coarse Aggregate			Specific Gravity of Fine Aggregate			Specific Gravity of Mineral Filler	Absorption (%)	
	Apparent	Bulk (SSD)	Bulk (OD)	Apparent	Bulk (SSD)	Bulk (OD)		Coarse Aggregate	Fine Aggregate
RAP-1	2.675	2.603	2.511	2.883	2.800	2.722	2.847	3.65	2.85
RAP-2	2.702	2.632	2.571	2.859	2.778	2.688	2.828	2.36	3.34
RAP-3	2.678	2.605	2.502	2.836	2.758	2.693	2.792	4.10	2.41
RAP-4	2.712	2.663	2.588	2.871	2.791	2.708	2.820	2.87	3.05
RAP-5	2.698	2.627	2.534	2.851	2.771	2.708	2.838	3.68	2.32
Fresh	2.741	2.689	2.608	2.885	2.798	2.725	2.853	3.10	2.67

This study aims to collect worn out and weathered bituminous pavement materials from different locations in Dhaka city and examine their composition and properties followed by preparation of mixes using them with modification of their composition with fresh materials with a view to reusing them in pavement constructions. The specific objective of the study is to compare the properties of modified mixes with those of a suitable fresh mix and mixes prepared with weathered materials only.

2. Methodology

In order to achieve the objective of examining the feasibility of recycling worn out pavement materials under local conditions, it is necessary to follow a systematic procedure, which involves procedures ranging from collection of Reclaimed Asphalt Pavement (RAP) samples to preparation of various types of samples including procurement of precisely specified materials followed by testing of samples.

2.1 Collection of reclaimed asphalt pavement samples

In this study, efforts were made to collect fully weathered materials from the wearing course of pavements for the purpose of recycling. From a total of seven roads in Dhaka city, at least two representative samples were collected per mile on each road. Since the labour cost is relatively low in Bangladesh and expensive milling machines are not available, the pavements were reclaimed manually with locally available indigenous cutting tools such as hammer, chisel etc. All the samples were collected in suitable pieces. In the laboratory, these samples were broken down and sized manually in a process similar to the one used for producing khoa (brick chips) from bricks. It was observed that on an average 0.8-1.6 kg of fines (passing No. 200 sieve) was produced during breaking down 40 kg of Reclaimed Asphalt Pavement (RAP) sample. Thus, the percent fines produced (2-4 percent) during manual crushing operation is less than the percent fines produced (8-13 percent) by the mechanical milling method as stated by Servas, V.P. (1980).

The thickness of the reclaimed pavement samples varied from 3 inch to 5 inch. It was observed that the aggregates of each reclaimed sample were rounded in nature. However, a part of the larger sized (3/4 inch and 3/8 inch) aggregates were fragmented possibly due to the fact that they are continuously subjected to high volume of heavy traffic. After visual inspection in the laboratory, two samples were found to be relatively less weathered and were discarded from subsequent analysis. The remaining five reclaimed samples used in the investigation were designated as follows:

- RAP-1: Collected from the road section between Bangla Motor and Farmgate intersection.
- RAP-2: Collected from the road section between Bangladesh Bank and Dainik Bangla intersection.
- RAP-3: Collected from the road section between Kakrail and Malibag intersection.
- RAP-4: Collected from the road section between Fulbaria and GPO intersection.
- RAP-5: Collected from the road section between DoelChattar and Shahbag intersection.

2.2 Determination of water content and bitumen content

The water contents of all the Reclaimed Asphalt Pavement (RAP) samples were determined by distillation with a water immiscible volatile solvent in accordance with ASTM D95. The test method specified by ASTM D2172 was followed for the quantitative determination of bitumen contents in all the Reclaimed Asphalt Pavement (RAP) samples. The water contents and bitumen contents along with aggregate contents of all five Reclaimed Asphalt Samples are presented in Table 1. However, the sum of the three quantities may not be 100 percent possibly due to experimental errors.

2.1 Aggregate evaluation

Sieve analysis was performed separately on the aggregate portion of the Reclaimed Asphalt Pavement (RAP) samples in accordance with ASTM C136 to determine their grain size distribution. The aggregate grading of the five reclaimed samples is given in Table 2. A graphical presentation of aggregate grading is shown in Figure 1.

After sieve analysis, the aggregate was separated into three sizes viz. coarse aggregate (retained on No. 8 sieve), fine aggregate (passing No. 8 sieve but retained on No. 200 sieve) and mineral filler (passing No. 200 sieve). Their specific gravities were determined in accordance with ASTM test methods C127, C128 and C188 respectively. Various specific gravities and absorption of different sizes of aggregates of five reclaimed samples are presented in Table 3, which also includes those of fresh aggregates used in the study.

In hot mix recycled pavements, the aggregate blend is designed to be well graded from coarse to fine so as to obtain a dense mix with a controlled void content and thereby producing a stable and durable paving mixture. At first, a typical aggregate grading (Table 4) recommended by the California Department of Transportation (Cal Trans, 1984) for wearing course was selected and both recycled and fresh mixes were prepared with this grading. It can be observed from Figure 2 that the grading curve obtained by averaging the grading of collected samples is quite similar to the selected grading. This grading was considered to be the standard aggregate grading for comparing the properties of recycled and fresh mixes.

2.2 Proportion of reclaimed samples in recycled mix

One of the objectives of this study is to examine the feasibility of recycling worn out pavement materials under Bangladesh condition. For this purpose, Marshall Test specimens of recycled mixes were prepared. As discussed later, a specially designed sand bath was used for indirect heating of Reclaimed Asphalt Pavement (RAP) samples and a gas burner was used for superheating fresh aggregates. From several trials it was found that when the proportion of Reclaimed Asphalt Pavement (RAP) exceeded 70 percent in the recycled mix, the fresh aggregates required to be heated to very high temperature.

Due to this reason, the proportion of Reclaimed Asphalt Pavement (RAP) in the recycled mixes was restricted to 70 percent in this study.

Table 4
Grading requirements of combined aggregates for wearing course

Sieve Designation and Size	Percent Finer by Weight	Average Percent Finer
1½ in. (37.5 mm)	100	100.0
¾ in. (19 mm)	95-100	97.5
⅜ in. (9.5 mm)	65-85	75.0
No. 4 (4.75 mm)	45-60	52.5
No. 8 (2.36 mm)	30-45	37.5
No. 50 (0.3 mm)	5-20	12.5
No. 200 (0.075 mm)	3-7	5.0

On the other hand, analysing the grading of Reclaimed Asphalt Pavement (RAP) samples it was observed that one or more critical sieve sizes restricted the use of higher proportion of RAP samples in the recycled mixes.

In this case, using higher proportion of RAP samples in recycled mixes caused the grading of the resulting aggregates (RAP plus fresh aggregates) to fall outside the band selected for aggregate grading. For example, the percentage of aggregates finer than No. 4 sieve in sample RAP-1 restricted higher proportion of it to be mixed with fresh aggregates to prepare a recycled mix. From Table 5 and grading of sample RAP-1, it can be revealed that if 50% of RAP-1 is used in a recycled mix, it will merely fall inside the band selected for aggregate grading as shown in Table 4. Therefore, 50% was selected as the maximum limit of RAP in the recycled mix comprising sample RAP-1. Similarly, proportion of RAP for other recycled mixes were calculated and presented also in Table 5.

Table 5
Proportion of reclaimed asphalt pavement (RAP) samples to prepare recycled mixes

Sieve Designation	Percent Finer by Weight										
	Fresh	RAP-1	50% RAP-1 50% Fresh	RAP-2	45% RAP-2 55% Fresh	RAP-3	70% RAP-3 30% Fresh	RAP-4	50% RAP-4 50% Fresh	RAP-5	70% RAP-5 30% Fresh
1½ in.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
¾ in.	97.5	99.18	98.34	97.72	97.6	99.08	98.61	98.04	97.77	100.0	99.25
⅜ in.	75.0	86.11	80.56	57.8	67.26	83.77	81.14	76.82	75.91	73.64	74.05
No. 4	52.5	67.22	59.86*	36.54	45.32*	58.55	56.74	52.55	52.53	47.48	48.99
No. 8	37.5	44.68	41.09	31.71	34.89	41.16	40.06	34.88	36.19	38.39	38.12
No. 50	12.5	16.72	14.61	7.19	10.11	12.57	12.55	8.59	10.55	14.79	14.1
No. 200	5.0	2.47	3.74	0.92	3.16*	2.2	3.04	1.07	3.04*	2.15	3.01

** = Values Corresponding to Critical Sieves*

2.3 Designation of different mixes

In this study, three different types of mixes (original, recycled and fresh) were analysed. Original mixes contained 100% reclaimed materials and neither fresh aggregates nor fresh bitumen. Recycled mixes contained reclaimed materials as well as fresh aggregates and bitumen from laboratory stack in varying proportions. Fresh mix contained 100% fresh aggregates and bitumen from the laboratory stack but no reclaimed material. In total, five original mixes, five recycled mixes and one fresh mix were analysed in this study. Only rounded aggregates were selected in procuring fresh aggregates from laboratory stack. Fresh aggregates having larger sizes such as ¾ inch and ⅜ inch were crushed to obtain results comparable to reclaimed materials and to take into account of the fact that the reclaimed aggregates were not totally rounded but the larger sized aggregates were fragmented during the manual reclamation and crushing operations and also by the stress induced by traffic before reclamation. Different types of mixes with their designation and mix proportion are shown in Table 6.

Table 6
Designation and proportion of different mixes

Mix Type	Designation	Mix Proportion
Original	AO	100% RAP-1 + 0% Fresh
	BO	100% RAP-2 + 0% Fresh
	CO	100% RAP-3 + 0% Fresh
	DO	100% RAP-4 + 0% Fresh
	EO	100% RAP-5 + 0% Fresh
Recycled	AR	50% RAP-1 + 50% Fresh
	BR	45% RAP-2 + 55% Fresh
	CR	70% RAP-3 + 30% Fresh
	DR	50% RAP-4 + 50% Fresh
	ER	70% RAP-5 + 30% Fresh
Fresh	F	0% RAP + 100% Fresh

Table 7
Properties of fresh bitumen

Property	Value
Specific Gravity (at 25^{o}C)	1.015
Penetration (0.1 mm, 100 gm, 5 sec., 25^{o}C)	100
Solubility in CCl_4 (%)	100
Ductility (cm, 5 cm/min, 25^{o}C)	100+
Loss on Heating (%)	0.15
Flash Point (^{o}C)	305
Fire Point (^{o}C)	345

2.4 Specification of bitumen

In this study AC-10 or 85-100 penetration grade bitumen, supplied by the Jamuna Oil Company Limited, was used for all the mixes. The properties of the bitumen are presented in Table 7.

2.5 Bitumen requirements in recycled and fresh mixes

For each of the recycled mixes the approximate bitumen requirement of the combined aggregates was determined by the following equation specified by TAI (1997):

$$P = 0.035a+0.045b+Kc+F \tag{1}$$

In the above equation:
P = Approximate bitumen content of mix (percent by weight of mix).
a = Percent of mineral aggregate retained on No. 8 sieve.
b = Percent of mineral aggregate passing the No. 8 sieve and retained on the No. 200 sieve.
c = Percent of mineral aggregate passing No. 200 sieve.
K = 0.15 for 11-15 percent passing No. 200 sieve.
0.18 for 6-10 percent passing No. 200 sieve.
0.20 for 5 percent or less passing No. 200 sieve.
F = 0 to 2.0 percent (based on absorption).

Table 8
Requirements of fresh bitumen in recycled mixes

Mix Designation	Bitumen Demand (%)	Bitumen Content in Reclaimed Sample (%)	Proportion of Reclaimed Sample in Mix (%)	Requirement of Fresh Bitumen in Mix (%)
AR	4.65	5.08	50	2.11
	5.15	5.08	50	2.61
	5.65	5.08	50	3.11
	6.15	5.08	50	3.61
	6.65	5.08	50	4.11
BR	4.65	3.4	45	3.12
	5.15	3.4	45	3.62
	5.65	3.4	45	4.12
	6.15	3.4	45	4.62
	6.65	3.4	45	5.12
CR	4.65	5.47	70	0.82
	5.15	5.47	70	1.32
	5.65	5.47	70	1.82
	6.15	5.47	70	2.32
	6.65	5.47	70	2.82
DR	4.65	4.96	50	2.17
	5.15	4.96	50	2.67
	5.65	4.96	50	3.17
	6.15	4.96	50	3.67
	6.65	4.96	50	4.17
ER	4.65	5.2	70	1.01
	5.15	5.2	70	1.51
	5.65	5.2	70	2.01
	6.15	5.2	70	2.51
	6.65	5.2	70	3.01

The grading of combined aggregates (fresh) indicates the values of a, b and c to be 62.5, 32.5 and 5 respectively. Using K = 0.2 and F = 1, the calculated expected design bitumen content is 5.65 percent from equation (1). Therefore, using 0.5% increment of bitumen content, the recycled specimens were prepared with 4.65%, 5.15%, 5.65%, 6.15% and 6.65% of binder.

The quantity of fresh bitumen to be added to prepare the recycled mixes is simply equal to the bitumen demand minus the bitumen content in the Reclaimed Asphalt Pavement (RAP) samples multiplied by the proportion of RAP samples in the recycled mixes. The requirement of fresh bitumen in addition to the bitumen present in RAP samples for the recycled mixes is presented in Table 8. Unlike the recycled mixes, the fresh mix was prepared with bitumen contents of 5%, 5.5%, 6%, 6.5% and 7%.

Table 9a
Weights of various constituents for each recycled marshall test specimen

Mix Designation	Proportion of Reclaimed Materials (%)	Proportion of Fresh Aggregates (%)	Weight of Reclaimed Materials (gm)	Weight of Fresh Aggregates (gm)	Total Weight of Specimen (gm)
AR	50	50	600	600	1200
BR	45	55	540	660	1200
CR	70	30	840	360	1200
DR	50	50	600	600	1200
ER	70	30	840	360	1200

Table 9b
Weights of various constituents for each recycled compression test specimen

Mix Designation	Proportion of Reclaimed Materials (%)	Proportion of Fresh Aggregates (%)	Weight of Reclaimed Materials (gm)	Weight of Fresh Aggregates (gm)	Total Weight of Specimen (gm)
AR	50	50	460	460	920
BR	45	55	414	506	920
CR	70	30	644	276	920
DR	50	50	460	460	920
ER	70	30	644	276	920

2.6 Preparation of test specimens

In this study, Marshall Method of mix design (TAI, 1997) was adopted to carry out a comparative study on different types of bituminous mixes involving worn out pavement materials as well as fresh materials. For this purpose, three different types of test specimens namely original (using 100% reclaimed materials), recycled (using both reclaimed and fresh materials) and fresh (using 100% fresh materials) were prepared. For the preparation of fresh specimens conventional procedure depicted in TAI (1997) was followed, whereas for the preparation of original and recycled specimens a special heating arrangement was adopted.

In order to prepare original and recycled specimens, direct method of heating is unacceptable because during direct heating, the loss of volatile contents due to evaporation is immensely increased and the binding properties of the reclaimed bitumen is substantially deteriorated. This is why the recycling of bituminous weathered pavements requires the reclaimed materials to be heated by indirect methods. The method of indirect heating adopted by developed countries is expensive and currently not available in Bangladesh. As a result, expensive methods like drum in drum mix, batch plant mix, split feed mix etc. could not be used in this study. So, a new experimental setup of indirect heating was developed, using locally available and low cost materials. The newly developed mechanism was named ‘Bowl in Bowl Sand Bath’. The ‘Bowl in Bowl Sand Bath’ method is similar to the drum in drum method. In this method, an aluminium bowl with a diameter of 8 inch was placed over another bowl with a diameter of 20 inch. In this method, sand was used as the heat transferring media. It was observed that sand is a good heat conductor and its temperature can easily be increased to about 800^{o}F. Such a high temperature facilitates indirect heating of the reclaimed pavement materials. The reclaimed materials should be placed in the inner bowl. Thus heat applied at the bottom of the bigger bowl is transmitted to the reclaimed materials by convection method. However, total duration of heating depends on bowl size, amount of material, moisture content in the reclaimed material and source of heat energy, all of which should be fixed by trial method. The use of a cover above the bowls showed encouraging results because it minimised the loss of heat energy.

Table 10
Properties of original mixes at in situ bitumen content

Mix Designation	Bitumen Content (%)	Unit Weight (pcf)	Stability (lb)	Flow (Hundredth of inch)	Air Voids (%)	VMA (%)	VFA (%)
AO	5.08	138.32	3974	15.00	6.71	17.54	61.7
BO	3.40	139.23	3234	12.8	5.63	16.63	66.2
CO	5.47	138.09	3899	14.8	5.37	17.01	68.4
DO	4.96	140.71	4374	11.2	5.93	16.68	64.5
EO	5.20	138.15	3155	16.0	6.38	17.44	63.4

Table 11
Properties of recycled and fresh mixes at optimum bitumen content

Mix Designation	Optimum Bitumen Content (%)	Demand of Fresh Bitumen (%)	Unit Weight (pcf)	Stability (lb)	Flow (Hundredth of inch)	Air Voids (%)	VMA (%)	VFA (%)
AR	5.09	2.55	149.28	5890	12.1	4.0	16.04	74.9
BR	5.08	3.55	149.29	5300	12.8	4.0	16.00	74.7
CR	4.93	1.48	148.79	5020	13.0	4.0	15.53	74.4
DR	4.82	2.34	149.15	7170	14.0	4.9	16.25	69.9
ER	5.07	1.60	149.42	5250	12.8	4.0	15.93	74.9
F	5.08	-	150.81	5630	10.6	4.0	15.99	74.8

TAI (1997) mentions that approximately 1200 gm of RAP sample was required to prepare each test specimen with a diameter of 4 inch and height of 2½ inch for mix types AO, BO, CO, DO and EO. Three specimens were prepared for each mix. The RAP samples were heated in the specially designed 'bowl in bowl sand bath' for about 45 to 60 minutes to attain the required temperature. Following the conventional specimen preparation procedures depicted in TAI (1997), the original test specimens were prepared with indirectly heated Reclaimed Asphalt Pavement (RAP) samples. Seventy five blows of hammer were applied to compact the test specimens and this number of blows was maintained throughout the study for comparing the performance of different mixes.

Recycled specimens were nothing but a blend of RAP samples and fresh materials. In order to prepare recycled specimens, fresh aggregates ware superheated with the help of a gas burner for 2-3 hours depending on the proportion of reclaimed material in the mix. On the other hand, the reclaimed portion of the mix was heated in the specially designed 'bowl in bowl sand bath' for 25-35 minutes. The fresh aggregates and reclaimed portion were then transferred to a hot mixing bowl and thoroughly mixed. A crater was formed in the middle of the blended mix and the required amount of fresh bitumen was added, which was heated to a steady temperature of 163^{o}C. The blended mix and fresh bitumen were rapidly mixed to yield a mixture having a uniform distribution of bitumen. Weights of reclaimed materials as well as fresh aggregates for the preparation of each recycled specimen, which total approximately 1200 gm, are presented in Table 10.

Table 12
Results of compressive strength test

Mix Designation	Test Bitumen Content (%)	Average Dry Compressive Strength (psi)	Average Immersed Compressed Strength (psi)	Index of Retained Strength (%)
AO	5.08	732	537	73.4
BO	3.40	524	385	73.5
CO	5.47	700	550	78.6
DO	4.96	836	652	78.0
EO	5.20	700	543	77.6
AR	5.09	993	828	83.4
BR	5.08	782	711	90.9
CR	4.93	926	861	93.0
DR	4.82	1065	976	91.6
ER	5.07	856	741	86.6
F	5.08	1021	930	91.1

2.7 *Testing of specimens*

After the preparation of specimens, the ‘Marshall Stability-Flow Test’ was conducted on compacted specimens to determine Marshall Stability and Flow values of different mixtures as per TAI (1997).

For volumetric analysis of compacted specimens, the bulk specific gravity as well as maximum specific gravity of each specimen was determined after the completion of Stability-Flow test as per ASTM D2726 and ASTM D2041 respectively. In the ‘Density-Void Analysis’, calculations were made to determine the Air Voids (V_a), Voids in Mineral Aggregate (VMA) and Voids Filled with Asphalt (VFA).

2.8 *Effect of water on compressive strength of mixes*

Once the ‘Marshall Stability-Flow Test’ was done on all three type of mixes and the optimum bitumen content being determined for recycled and fresh mixes, it is necessary to determine the compressive strength and assess the effect of water on compressive strength of all types of mixes. Similar to the ‘Marshall Stability-Flow Test’, three types of mixes namely original, recycled and fresh were prepared. Unlike the ‘Marshall Stability-Flow Test’, the recycled and fresh specimens were prepared only at the optimum bitumen content. It was observed that about 920 gm of materials (reclaimed plus fresh as shown in Table 9a and 9b) were required to prepare each test specimen of 3⅛ inch diameter and approximately of the same height. Preparation and curing and testing of specimens were performed in accordance with ASTM D1074 and D1075, which are applicable for compacted bituminous mixes (hot-mix hot-laid) for use in pavement wearing courses and base courses.

From the tests, the dry compressive strength and immersed compressive strength were known and finally, the ‘Index of Retained Strength’ was determined by dividing the latter with the former and multiplying the value by 100.

3. Analysis of test results

The main objective of this study was to examine the performance of original, recycled and fresh bituminous mixes under Bangladesh condition. To achieve this, 'Marshall Stability-Flow Test' including 'Density-Void Analysis' and 'Compressive Strength Test' were carried out on all three types of bituminous mixes. The test results were tabulated and most of them were plotted against bitumen content and the effect of using recycled bituminous mixes on various criteria was observed.

3.1 Marshall test results

Table 10 shows the results of 'Marshall Stability-Flow Test' and 'Density-Void Analysis' for the original mixes AO, BO, CO, DO and EO. These values indicate the in situ condition of weathered pavements at the time of collection of samples. From Table 10 it can be observed that the bitumen content of the original mixes lies between 3.40 to 5.47 percent and the unit weight of the compacted specimens lies between 138.09 to 140.71 pcf.

Study of the results reveals that all the original mixes satisfy the stability criteria but most of them fail to satisfy the flow criteria recommended by TAI (1997). However, the percentage of air voids of all the original mixes was found to be far above the specified limit, which indicates that the original mixes were less durable. This deviation is possibly due to presence of insufficient amount of mineral fillers in the original mixes. This statement is further substantiated by the previous grading analysis (Table 2). Therefore, in order to satisfy all the limits specified by TAI (1997), these observations justify the necessity of recycled mix design.

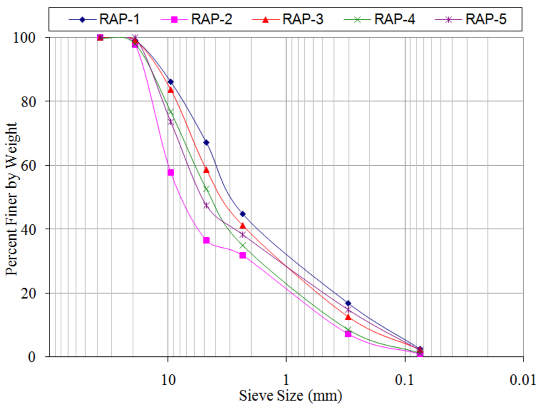

Fig. 1. Grain size distribution of aggregates in different reclaimed samples.

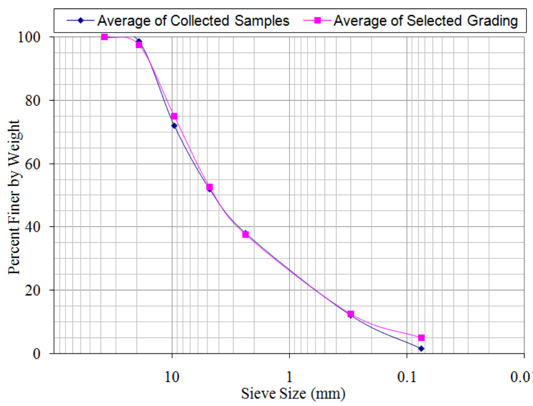

Fig. 2. Average grain size distribution of collected samples and selected grading.

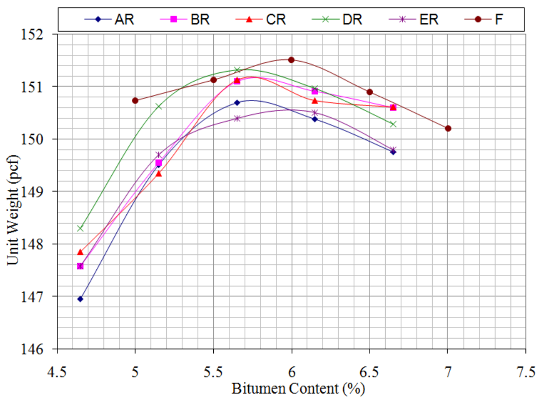

Fig. 3. Variation of unit weight with bitumen content for recycled and fresh mixes.

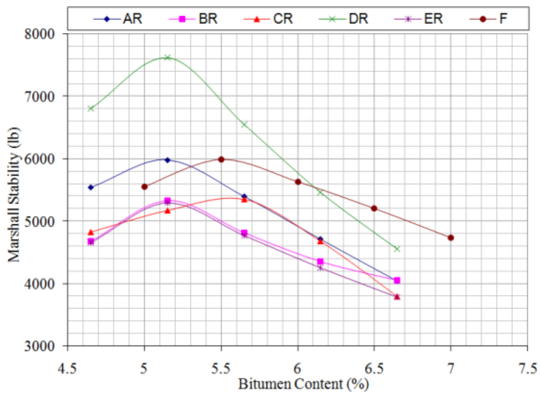

Fig. 4. Variation of stability value with bitumen content for recycled and fresh mixes.

In case of recycled and fresh mixes, a total of six curves were drawn to show the relationships between bitumen content with Unit Weight, Stability, Flow, Air Voids (V_a), Voids in Mineral Aggregate (VMA) and Voids Filled with Asphalt (VFA) as shown in Figure 3 to 8. A close study of the curves reveals that there are similarities between the curves of recycled mixes and those of fresh mix, which in turn are simply the replication of the pattern of typical curves. From the curves, the optimum bitumen content was determined for each mix following the guidelines depicted in TAI (1997). Various properties of the recycled mixes AR, BR, CR, DR, ER and the fresh mix F corresponding to optimum bitumen content are summarised in Table 11. The table reveals that the recycled and fresh mixes satisfy all the design criteria including percentage air voids in the mix. A close observation of the table also reveals that there is little difference between the fresh and recycled mixes with respect to all the criteria shown in the table including optimum bitumen content.

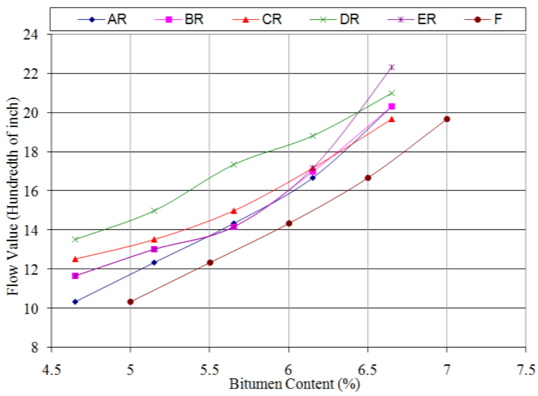

Fig. 5. variation of flow value with bitumen content for recycled and fresh mixes.

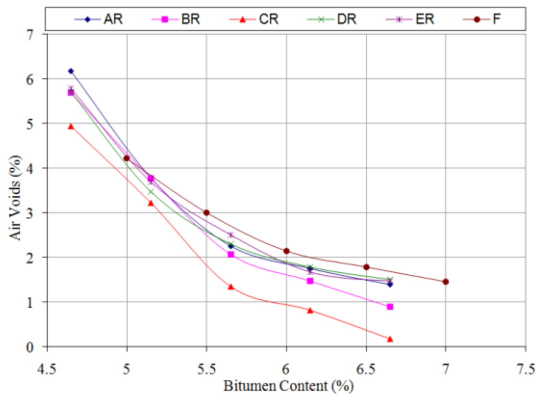

Fig. 6. Variation of air voids results with bitumen content for recycled and fresh mixes.

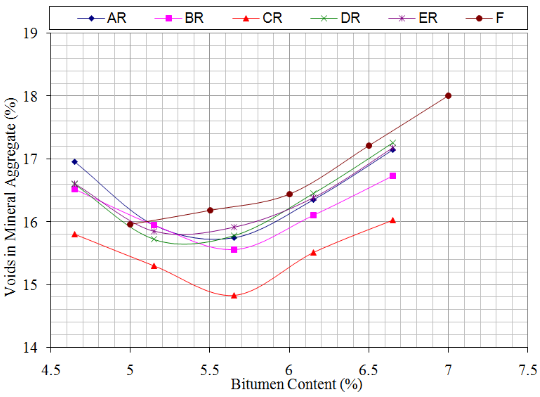

Fig. 7. Variation of VMA results with bitumen content for recycled and fresh mixes.

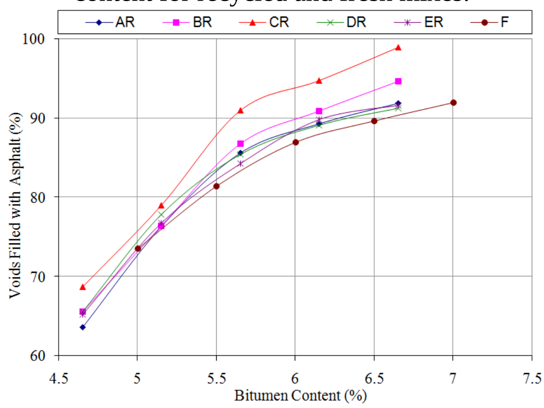

Fig. 8. Variation of VFA results with bitumen content for recycled and fresh mixes.

From Table 10 and 11, a comparison of stability between recycled and original mixes shows that due to recycling the stability of mixes AO, BO, CO, DO and EO has increased by 48, 64, 29, 64 and 66 percent respectively. From Table 11, it is apparent that the requirement of fresh bitumen for recycled mixes AR, BR, CR, DR and ER are 2.55, 3.55, 1.48, 2.34 and 1.60 percent respectively. On the other hand, for fresh mix F this value is 5.08 percent. Thus, recycling reduces the bitumen requirements of the pavement by 30 to 70 percent. Also, depending on the grading of reclaimed material, recycling has the potential to reduce the aggregate requirements in pavement construction by a maximum of 70 percent. Figure 4 shows that the variation of Marshall Stability with bitumen content is similar in nature to that of Unit Weight, except that the maximum value of stability was attained at slightly lower bitumen content than that corresponding to the maximum unit weight. From Figure 4 it can also be found that the stability and unit weight of the mix type DR is higher than the other recycled mixes. A visual examination revealed that the aggregates of the mix DR were more angular and had rougher surface texture compared to the aggregates of other mixes.

3.2 Compressive strength test results

In Table 12, the average values of compressive strength test results (dry and immersed) on original, recycled and fresh mixes are presented including the indices of retained strength. In can be observed from the table that the 'Index of Retained Strength' of original mixes remain in the range of 73.4 to 78.6 percent. According to TAI (1997) the 'Index of Retained Strength' should be greater than 75 percent. It can be observed that in case of original mixes, this index is either less than or slightly greater than the specified limit. This indicates that the current condition of the reclaimed pavement is not good as far as the effect of water on compressive strength is concerned. In case of recycled mixes, the 'Index of Retained Strength' remains in the range of 83.4 to 93.0 percent. These values are significantly above the specified limit of 75 percent. It can also been found that, due to recycling, the 'Index of Retained Strength' of original mixes improved by 12 to 24 percent. The 'Index of Retained Strength' for the fresh mix is 91.1 percent. This value is nearly same as that of recycled mix BR, CR and DR but slightly larger than that of recycled mix AR and ER. A comparison of the results of compressive strength test shows that the compressive strength (both dry and immersed) of recycled mixes AR, BR, CR, DR and ER are greater than that of original mixes AO, BO, CO, DO and EO respectively but nearly same as that of fresh mix F. So, it is found that by recycling old pavements, an improved pavement can be made as far as the effect of water on compressive strength is concerned. The results in Table 12 also indicate that the recycled mix DR has the highest compressive strength among all the recycled mixes.

4. Conclusions and recommendations

The primary objective of this study was to compare the properties of recycled mixes with those of a suitable fresh mix and mixes prepared with weathered materials only. The reclaiming procedure and indirect heating method of weathered pavement materials applied in this study were examined and the improvement of the recycled pavement mix was evaluated by comparing the properties with a fresh mix prepared by conventional method. The observations, evaluations and results were critically examined and the following conclusions were drawn:

- On the basis of experimental results with respect to temperature and duration of heating, an upper limit of 70 percent of salvaged materials in recycled mixes can be incorporated.
- The 'Bowl in Bowl Sand Bath' method, developed by using locally available low cost equipments, can successfully heat RAP samples.
- Test results on mixes produced with only weathered materials prove that generally, they satisfy the stability criteria but contain amount of air voids larger than acceptable value.
- Stable and durable bituminous mixes satisfying all the design criteria recommended by the Asphalt Institute for Marshall Method can be produced by recycling pavements materials.
- In case of road construction and rehabilitation, recycling can reduce the requirement of bitumen in the range of 30 to 70 percent and that of aggregates to a maximum of about 70 percent compared to that required for a fresh mix.
- Recycling can produce a durable pavement in the sense that the 'Index of Retained Strength' of original mixes varied between 73.4 and 78.6 percent, whereas that for the recycled mixes varied between 83.4 and 93.0 percent, which compares favourably with that for fresh mix of 91.1 percent.

The objectives of this study were limited in their scope with respect to the range of variables investigated, the type of test employed and the nature or number of specimens tested. However, the following recommendations can be made:

- Plant mix recycling system should be developed by modification of the conventional mixing plant using locally available and low cost equipment.
- Automated mechanical methods of removing and crushing weathered pavements suitable in local situation should be tried.
- Cold mix recycling of weathered pavement should be experimented to reduce the wastage of fossil fuel and save the environment.
- A study on the effect of aging on the behaviour of recycled pavement mix should be carried out.
- In order to assess whether recycling of worn out pavements is suitable in Bangladesh condition or not, an economic feasibility study should be carried out.

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