American Journal of Traffic and Transportation Engineering
2018; 3(4): 57-61
http://www.sciencepublishinggroup.com/j/ajtte
doi: 10.11648/j.ajtte.20180304.11
ISSN: 2578-8582 (Print); ISSN: 2578-8604 (Online)

Marshall Characteristics of Bituminous Mixes Using Reclaimed Asphalt Pavement

G. M. Harun-Or-Rashid*, Bulbul Ahmed, Mohd. Abdus Sobhan, Nafiur Rahman

Department of Civil Engineering, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh

Email address:

gmharun.ruet11@gmail.com (G. M. Harun-Or-Rashid), bulbulruet@gmail.com (B. Ahmed), msobhan@yahoo.com (Mohd. A. Sobhan), rnafiur92@yahoo.com (N. Rahman)

*Corresponding author

To cite this article:

G. M. Harun-Or-Rashid, Bulbul Ahmed, Mohd. AbdusSobhan, NafiurRahman. Marshall Characteristics of Bituminous Mixes Using Reclaimed Asphalt Pavement. *American Journal of Traffic and Transportation Engineering*. Vol. 3, No. 4, 2018, pp. 57-61.
doi: 10.11648/j.ajtte.20180304.11

Received: August 4, 2018; **Accepted**: October 22, 2018; **Published**: October 31, 2018

Abstract: Recycling is the running trend through all over the world. To save money and keep environment pollution free recycling of waste materials is the best way. Reclaimed Asphalt Pavement (RAP) is such type of waste materials, which are obtained huge amount from spoiled pavement. During this investigation an attempt is made to study the behavior of RAP materials for reuse in road construction. Aggregate Crushing Value, Aggregate Impact Value, Loss Angeles Abrasion Value and Ten percent fine value tests are also performed to determine the strength properties of coarse aggregate. Standard Marshall Mix Design procedure is followed in the design and testing of those mixes. The study reveals that untreated RAP materials are not good as a bituminous mix, but it can be acceptable with additional 1% bitumen content for use in the surface course of bituminous pavement. The investigation also indicates the possibility of adding coarse aggregate from RAP materials in the bituminous mixes with fresh aggregates, which gives satisfactory results. In our Indian subcontinent like Bangladesh, the rate of using RAP materials is very low. For that reason, the findings of the study will help in the development of sustainable road infrastructure for recycling in Indian Subcontinent.

Keywords: Bituminous Road, Reclaimed Asphalt Pavement, Marshall Mix Design, Aggregate Grading, Optimum Bitumen Content

1. Introduction

The usual method of providing bituminous surfacing on flexible pavements require a significant amount of energy for production of bituminous binder, drying aggregates and subsequent production of bituminous mix at Hot Mix Plant (HMP). For example, approximately 6 liters of fuel is used for drying and heating one ton of aggregates, which would expand to massively huge quantities considering lakhs of tons of aggregates that are used for road construction every year. The heating of bituminous binder, aggregates and production of huge quantities of Hot Mix Asphalt (HMA) releases a significant amount of greenhouse gases and harmful pollutants. The amount of emissions becomes twofold for every 10°C increase in mix production temperature and increasingly, higher temperature is actually being used for the production of HMA with modified binders. Also, there is a problem due to the scarcity of quality aggregates, which derives transportation of materials from long distance. The use of diesel for running trucks leads to emission of pollutants. Therefore, an attempt has to be made to develop and adopt alternative technologies for road construction and maintenance to reduce consumption of fuel and aggregates [1-3].

The process in which required asphalt pavement materials are combined with new materials, sometimes along with recycling agent, to produce hot mix asphalt (HMA) mixtures is called Recycling Asphalt Pavement. In order to obtain better performance recycled mixtures must be designed properly. Material Evaluation and mix design are the two steps involved in the mix design procedure. The main purpose of the material evaluation process is to find out the important properties of the constituent materials to make an optimum blend of materials to meet the mix requirements. Determination of the type and percentage of bituminous binder with the help of results from compacted test mixtures is the main objective of the mix design step.

The use of reclaimed asphalt pavement (RAP) in the construction of new hot-mix asphalt (HMA) pavements has increased in recent years. Because pavement industry has long emphasized the need to reuse RAP materials obtained from deteriorated roads as these materials still possess desirable properties to be used for the surfacing layers [4]. Deployment of RAP in construction of flexible pavements may lead to economic savings and preservation of natural resources [5]. RAP is old asphalt pavement that is milled up or ripped off the roadway [6]. But use of RAP in Bangladesh is very low. There are no remaining data for using RAP material in surface course. However, I think that the use of RAP will increase with time. For this reason, it is the presentneed to study the use of RAP for road constructions.

In the past a number of research work has been done to make use of RAP materials into the bituminous mix to make it cost effective. Some researchers have been performing researches by using different percentages of RAP with the fresh mixes to improve the physical property of bituminous mixes. A study shows that the bituminous mixes with RAP especially at 50% to 100% replacement ratio provide better performance than the new mixtures. Mechanical properties, durability performance and stripping resistance also increases with the increasing percentages of RAP. Using RAP has a great impact on improving the indirect tensile strength where 50% RAP content showed the highest values [1]. Mohamady et al., 2014 represented that 30% RAP guaranteed longer field performance after construction [7]. Tambake et al., 2014 represented that the optimum binder content is reduced by increasing the percentage of RAP content and the recommended percentage of RAP mix is 20% [8]. Pradyumna et al., 2013 represented that the addition of RAP improves all the properties of the bituminous mixes. This indicates that mixes with 20% RAP perform better than the fresh mixes under similar condition [2]. Hussain and Yanjum, 2012 represented that mixtures show significant variability increases with the increase in RAP content. According to several studies, generally 10 to 30% RAP are used in hot recycled bituminous mixes [9]. Utilization of 35% RAP ensure same physical and strength parameter as virgin mixes [10]. Also some recent researches have established that RAP replacement at proportions above 50 % is feasible to produce new HMA mixtures, obtaining satisfactory results in the mechanical properties [11]. An article presents that with adequate mixture design for 100% recycled asphalt mixtures can perform equally to conventional asphalt mixes. In this case it is found that, reduction of harmful emission by 35% as well as reducing the costs of materials by half for using 100% RAP material [12]. Actually suitable percentage of RAP depends upon the composition of reclaimed bituminous material and category of layer in which it is to be used [13].

2. Laboratory Investigation

For this investigation the RAP sample was collected from Laxmipur to Court Road in Rajshahi. ASTM D2172-01E01 method was followed for quantitative extraction of bitumen from bituminous paving mixtures [14]. After extraction of bitumen from RAP, the aggregate appearance is displayed in Figure 1. After separating RAP materials 59% coarse aggregates, 31% fine aggregates, 5% mineral filler and 5% bitumen were found. The gradation of aggregate is shown in Figure 2. After that the RAP materials were gone through various tests and their suitability were checked. The test results of the fresh coarse aggregate and coarse aggregate from RAP are shown in Table 1. The aggregates from RAP were found to satisfy the requirements as per LGED (2005) [15].

Table 1. *Strength properties of coarse aggregate.*

Properties	Coarse Aggregate		Limiting Value
	Fresh	RAP	
Los Angeles Abrasion Value(Grade-A), Percent	18	22	≤ 40
Aggregate Impact Value, Percent	7	10	≤ 40
Aggregate Crushing Value, Percent	16	20	≤ 35

2.1. Mix Design

In order to investigate the behavior of asphalt mixes with different aggregates, continuously graded asphalt macadam is essential. The aggregate blend is designed to be evenly graded from coarse to fine in the continuously graded bituminous macadam so as to arrive at a dense mix with a controlled void content, in order to get sustainable paving mix.

In the first phase, objective of the study was to investigate the suitability of untreated RAP materials and also to characterize RAP material by the increment of 0.5% additional bitumen content through the determination of Marshall Mix properties.

Mix contains RAP materials + (0%, 0.5%, 1%, 1.5%) additional bitumen content.

In the second phase, objective of this investigation was to make a comparative study of asphalt mixes with RAP materials in varying percentages with fresh aggregate. Five types of mixes were analyzed and these were designated as mix types A, B, C, D and E

Mix A: in which Fresh CA is 100%

Mix B: in which Fresh CA is 90% and 10% CA from RAP

Mix C: in which Fresh CA is 80% and 20% CA from RAP

Mix D: in which Fresh CA is 70% and 30% CA from RAP

Mix E: in which Fresh CA is 60% and 40% CA from RAP

Figure 1. *Appearance of Coarse Aggregate from RAP.*

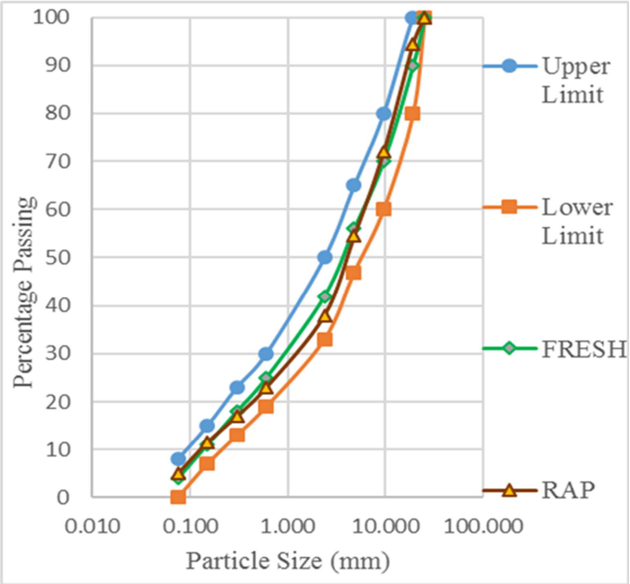

Figure 2. *Particle size distribution curve ofAggregates as per AASHTO gradation.*

2.2. Marshall Properties

Maximum load carried by a compacted specimen at a standard test temperature of 60°C is called Marshall Stability test. The deformation of the Marshall Test specimen is called the flow value which undergoes during the loading upto the maximum load in 0.25 mm units [8]. Marshall Stability test is suitable for hot mix design using bitumen and aggregates. The Stability, flow value, unit weight, total voids in a mix, voids in mineral aggregates and voids filled with bitumen were obtained for different percentages bitumen and RAP content. The Bitumen content due to maximum stability, maximum unit weight and 4% air voids were obtained from these graphs. According to Ministry of Road Transportation Highways (MORTH), the maximum acceptable limit of air voids is 4% [16]. The optimum bitumen content (OBC) is the average value of bitumen content obtained from these 3 plotted graphs. The Marshall Test results of first phase is tabulated in Table 2. Marshall test results and OBC values for different percentages RAP content of second phase is represented in Table 3.

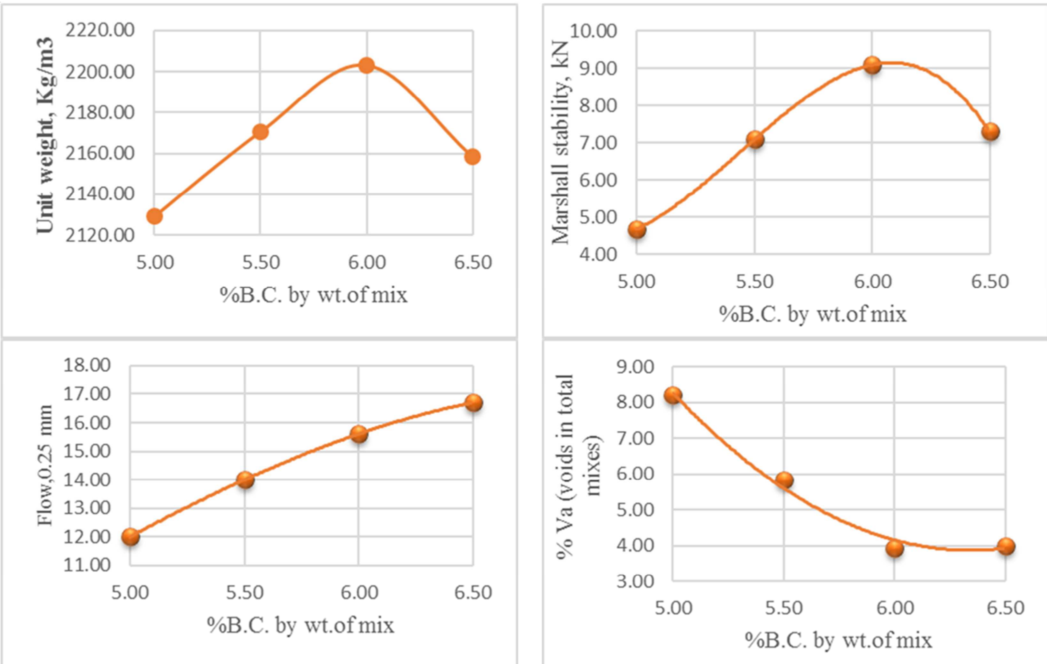

Figure 3. *Graphical representations of Marshall Test results for first phase.*

3. Analysis of Results

Based on Marshall Test results presented in Table 2 it is seen that the unit weight and the Marshall stability value of the compacted specimen is increasing initially with an increase in additional bitumen content upto 1% and then decrease. As bitumen is a binder, with the increase in bitumen content density and stability values are also increased. After reaching to the maximum value, the density decreases because the specific gravity of the excess bitumen is less than that of the mineral aggregates. And shear resistance also decreases due to this excess bitumen. The increasing rate of flow value isgreater for higher proportion of bitumen. Because the thick film of bitumen surrounding the aggregates of RAP help to increase the deformation. For 100% RAP (untreated), $\%V_a$is 8.2 which is very much higher than the limiting value and it is the reason of weak and unstable pavement. On the other hand, untreated RAP contains old bitumen, some rounded shape and nearly smooth surfaced aggregates. The ductile and viscous property of the old bitumen are lost and due to the presence of some rounded shape and smooth surfaced aggregates interlocking capacity and shear resistance of the bituminous mixes are also reduced. For that reason only untreated RAP materials is not suitable for bituminous surface construction.

Table 2. *Marshall test results for first phase.*

%BC	Bulk specific gravity	Unit weight (kg/m^3)	Marshall stability (kN)	Flow (0.25mm)	% Voids in total mix.	% Voids in mineral aggregate	%Voids filled with bitumen
5+0.0=5.0	2.130	2130	4.7	12	8.2	21.0	61
5+0.5=5.5	2.170	2170	7.1	14	5.8	19.9	71
5+1.0=6.0	2.200	2200	9.1	15.6	3.9	19.2	80
5+1.5=6.5	2.160	2160	7.3	16.7	4.0	21.1	82

Table 3. *Marshall Test results for second phase.*

Aggregate Types	O.B.C. (%)	Unit Weight (kg/m^3)	Marshall Stability (kN)	Flow Value (0.25mm)	Air voids (%)	VMA (%)	VFB (%)	Marshall stiffness (kN/mm)
A	5.57	2344	15.8	14.7	3.7	13.7	74	1.14
B	5.50	2333	15.2	14.8	3.6	15.2	76	1.07
C	5.43	2320	14.7	15.0	3.5	16.0	77	0.98
D	5.33	2305	13.5	15.3	3.2	16.5	79	0.88
E	5.10	2290	11.8	15.4	3.0	17.2	81	0.61

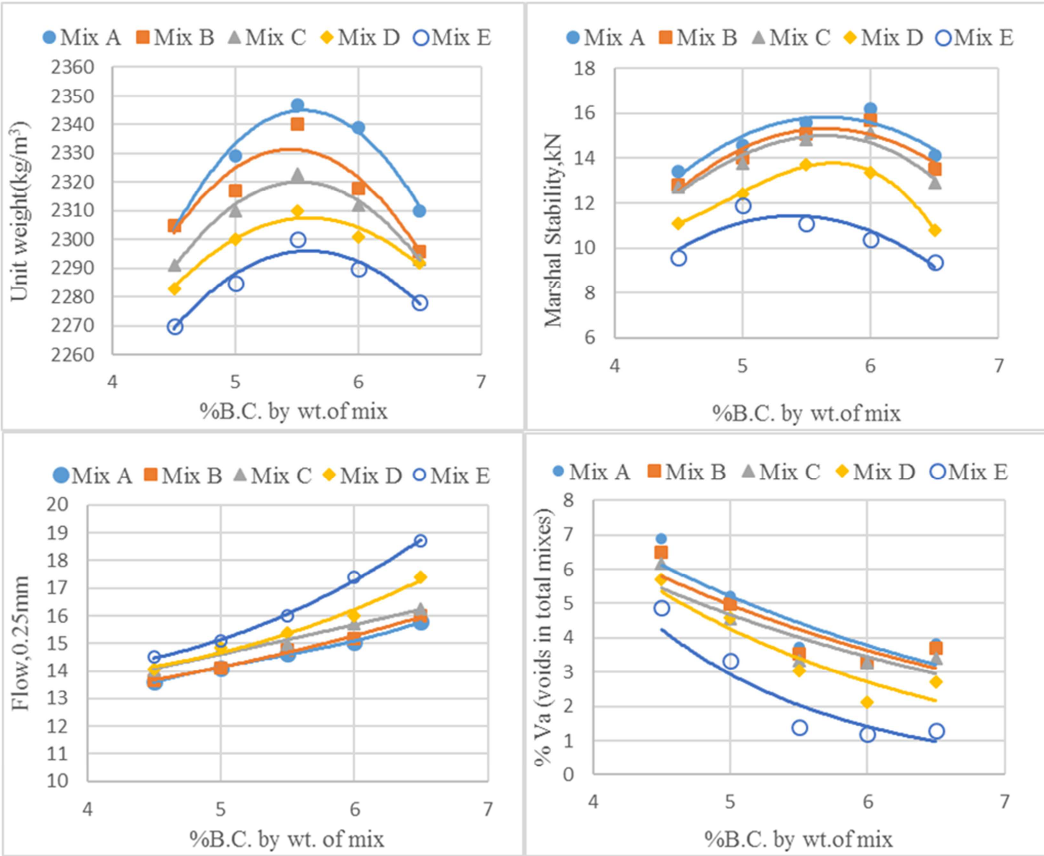

Figure 4. *Comparative analysis of Marshall test results for second phase.*

Based on Marshall Test results presented in Table 3 it is seen that the optimum bitumen content is decreased as the RAP percent increase. With the increasing percentages of RAP, OBC is decreased due to the old bitumen filled the pores of the RAP. As the presence of some amount of rounded shape coarse aggregates in RAP, it may also occurs. Rounded shape particles quickly slips to gain stability and for that reason amount of OBC reduced. Besides, increasing RAP percent from zero to 40% decreases the OBC from 5.57% to 5.1%. It means that saving in OBC by about 9%.

With the increasing percentages of RAP, unit weight is decreased gradually. Increasing RAP percent from zero to 40% that reduces the unit weight by only 2.3%. From the Table 3 it is found that, the mix stability is decreased as RAP percent increases. The mix shear resistance decreases due to the presence of some smooth and round shape aggregates in the mix, which ultimately results in decrease in stability. It is also mentioned that with the increasing RAP from zero to 30% decrease the stability value from 16.8 to 13.5 kN i.e. decreased by about 15%. When the recycled percent reaches 40%, the stability value reaches 11.8 kN i.e. decreased by about 26%. The mix flow value also increases due to the RAP percent increases. With the increasing percentages of RAP from zero to 40%, the flow value increases from 14.7

(0.01 inch) to 15.4 (0.01 inch).

During bituminous mix design the total air voids in a mix is considered as an important parameter. The limiting of the total air voids in a mix is about 3% to 5 % of the total mix volume. If air voids are lower than 3% bleeding of bitumen will occur. Moreover, for air voids percent greater than 5% of the mix, the pavement will be weak and unstable. For that reason, the bituminous binder is a very sensitive element. From the Table 3 it is found that with the increasing percentages of RAP, decrease the corresponding air voids ratio. The reason behind this problem is the presence of old bitumen filled the aggregate pores which minimize the voids percent. Increasing the RAP percent from zero to 40% decreases the air voids percent from 3.7% to 3%.

From the Table 3 it is discovered that the voids in mineral aggregate and voids filled with bitumen are increased as the RAP percent increases. This happens due to the ineffective old bitumen in the aggregate pores which prevent the new bitumen from occupying deeply the aggregate pores.

4. Conclusions

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

(1) From the consideration of aggregate properties, aggregates collected from RAP known as waste aggregates are suitable for the bituminous mixes.

(2) Untreated RAP material is not suitable for bituminous surface course because its stability value 4.68 kN, which is less than the limiting value of 5 kN.

(3) Bituminous mix from the RAP materials with 1% additional bitumen content gives the maximum stability and satisfy the Marshall Design criteria.

(4) Although stability gradually decreases with the increase of RAP aggregates in the bituminous mixes with fresh stone aggregates, the nature of mixes satisfy the Marshall Design criteria.

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