Characterization of Bituminous Mixes using Waste Concrete Aggregate

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Abstract

Waste concrete aggregates (WCA) are produced by crushing demolished concrete elements. The lightweight, porous cement mortar attached to WCA causes crushed concrete aggregates to have a lower specific gravity and higher water absorption than comparatively sized fresh aggregates. Due to the booming of real estate business, the amount of waste generation is increasing day by day in Bangladesh. Initially WCA were used as land filling materials and after many research works it is now being utilized as unbound road base material and in non-structural concrete applications. The demand of stone aggregates for the construction of bituminous pavement can be reduced by recycling of WCA as coarse aggregate. But a few researches have been carried out to investigate their suitability and limited information's are available about their performance. Therefore, this research was carried out to investigate the possibility of using WCA in bituminous mixes. Properties of mineral matters and Marshall test properties of bituminous mixes were ascertained according to the test procedure specified by AASHTO standards. Dense bituminous mixes using WCA compacted with 50 blows is found a feasible option from the standpoint of stability, stiffness, deformations and voids characteristics.

Keywords: *WCA, Recycling, Bituminous Mix, Stability, Stiffness.*

1 Introduction

Waste concrete aggregate (WCA) originates from demolished concrete elements that have been removed from pavements, concrete yards, curbs, bridges or buildings. WCA differ from fresh aggregates due to the cement paste attached to the surface of the original crushed aggregates after the process of recycling. This highly porous cement paste contributes to the lower particle density, variation in the quality of the WCA and the higher water absorption. Torring and Lauritzen reported that at present, the amount of global demolished concrete is estimated at two to three billion tons. A significant amount of natural resource can be saved if the WCA is recycled for new constructions. WCA were initially used as land filling material and after many research works (Huang et al) it is now being utilized as road sub-base material and in non-structural concrete applications. Yanagibashi noted that sixty to seventy percent of demolished concrete is used as sub-base aggregates for road construction [3]. Public Works Technical Bulletin (PWTB) reported that about eighty percent of all cement concrete debris that is recycled is used as road base due to its availability, low transportation cost, and good physical properties [4]. Saeed concluded that recycled concrete aggregate (RCA) has a proven history of use as base, sub-base, land filling and drainage layers within the pavement structure; construction and performance have been excellent.
Limited information is found on the use of WCA in the hot-mixed, hot laid dense bituminous mixes. However, some information are noted on the use of brick aggregate like porous WCA in the hot-mixed dense bituminous mixes.

Rasel et al. (2011) reported that bituminous mixes with fresh brick-aggregates and waste brick-aggregates both satisfy all the requirement of a bituminous binder course for medium traffic road having higher optimum bitumen content (13% and 12% respectively). Biswas (2011) reported that brick aggregates and RCA from brick chips can be used for the construction of surface course of bituminous road at places where stones are very costly and mix subjected to lower soaking periods. Paranavithana and Mohajerani (2006) investigated the effect of RCA on the properties of asphalt concrete. The results of RCA asphalt concrete found in this study are encouraging.

2 Laboratory study and test results

A bituminous mix is normally composed of aggregates and bitumen. Aggregates are generally divided into coarse, fine and filler fractions according to the size of individual particles. Aggregates have to bear load stresses occurring in the roads and have to resist wear due to abrasive action of traffic. Bitumen content in mix ensure proper bond together with durable pavement under suitable compaction. Thus the properties of aggregates and bitumen are of considerable significance for proper bituminous mix design.

2.1 Materials

WCA used in the present investigation were collected from previously used cement concrete in which basalt chips, crushed gravels and brick chips were coarse aggregates respectively. Waste cement concretes were manually crushed to desired sizes and sieved to different fractions. Particles retained on 2.36 mm sieve were taken as coarse aggregates according to the specification of the Asphalt Institute,1984. Fresh basalt chips were also taken as coarse aggregate for comparison. Fine aggregate portion of the aggregate blend (2.36 mm to 0.075 mm sieve) were taken from coarser sand (sp.gr. = 2.46). Mix of stone dust and non-plastic sand (with 1:2) finer than 0.075 mm sieve were used as mineral filler (sp.gr. = 2.63). Properties of coarse aggregates, fine aggregate and mineral filler were determined according to the test procedures specified by American Association of State Highway and Transportation Officials (AASHTO) standards and test results are summarized in Table 1.

Table 1. Properties of mineral aggregates

Properties	Coarse Aggregates			
	Fresh	WCA from		
	Basalt	Basalt	Crushed gravel	Brick chips
Bulk specific gravity	2.79	2.38	2.27	1.94
Water absorption, percent	0.81	5.74	6.38	10.7
Los Angeles Abrasion Value (Grade-A), %	12	30	40	42
Soundness ($MgSO_4$, 5 cycles), percent	3	17	19	23
Aggregate Impact Value, percent	7	19	22	24
Aggregate Crushing Value, percent	11	27	30	33
Ten Percent Fines Value, kN	300	100	90	80

Bituminous binders are the product of petroleum crude oil by refining process. The bitumen binder produced during the refining process can be modified in many different ways to meet the specifying agency's specifications. These different modification methods will change the moisture sensitivity of the binder. Petersen (2002) reported that if the crude oil is not desalted after the caustic treatment, these salts will remain in the crude oil which have caused stripping in asphalt mixtures. The properties such as stability, void content and flow of a bituminous mix are dependent on the type and amount of bitumen.

The binder material used for this investigation was of 80/100 penetration grade bitumen and collected from Eastern Refinery in Bangladesh. Routine tests as per AASHTO test standards were performed on the bitumen sample and get the following properties: Specific gravity, 1.02; Penetration value (0.1mm), 98; Ductility value, 115 cm; Solubility value, 99.8% and Flash point, 290^0C.

2.2 Mix types

One of the main objectives of this investigation was to make a comparative study of WCA bituminous mix with bituminous mix contained conventional aggregates. Four types of bituminous mix used in present study were designated as A, B, C and D. Mix A contained fresh basalt aggregates, Mix B contained WCA from basalt, Mix C contained WCA from crushed gravels and Mix D contained WCA from brick chips. Coarse sand and filler were added with selected coarse aggregates to achieve the required aggregate combination. Sobhan, M.A (2011) reported that aggregate gradation for dense bituminous concrete (25 mm nominal size) recommended by the Asphalt Institute is suitable for WCA bituminous mix [11]. The particle size distribution of this gradation is shown in Fig. 1. This gradation was used for the preparation of selected bituminous mixes.

3 Investigations and Test Results

To investigate the characteristics of WCA bituminous mixes, Marshall test specimens (101.6mm diameter and 63.5 mm thick) were prepared for medium traffic requires 50 blows per side of the specimen as per AASHTO

T245-82. Three specimens were prepared for each bitumen contents and five bitumen contents were used for each mix type. The bulk specific gravities of fresh compacted specimens were determined according to the test procedure specified by AASHTO T166-83. After determination of the bulk specific gravity, the specimens were then subjected to Marshall stability and flow tests as per AASHTO T245-82. Voids analysis were made for each series of test specimens after the completion of the stability and flow tests. For the determination of optimum bitumen content (OBC), the variations of bulk density, Marshall stability and voids in total mix with bitumen contents were plotted and shown in Fig. 2, Fig. 3 and Fig. 4 respectively.

OBC was determined as follows: The bitumen contents at maximum density and at maximum stability were taken from Fig. 2 and Fig. 3 respectively. For bituminous concrete, bitumen content, at 4 percent (median of 3-5 percent range) air voids in total mix was ascertained from Fig. 4. The average of these three bitumen contents was taken as OBC. At OBC, the values of bulk density, Marshall stability, flow, percentage of air voids in total mix (V_a,%), percentage of voids in mineral aggregates (VMA,%), percentage of voids filled with bitumen (VFB,%), Marshall stiffness and bitumen required (kg per m^3 of mix) for four mix type are given in Table 2.

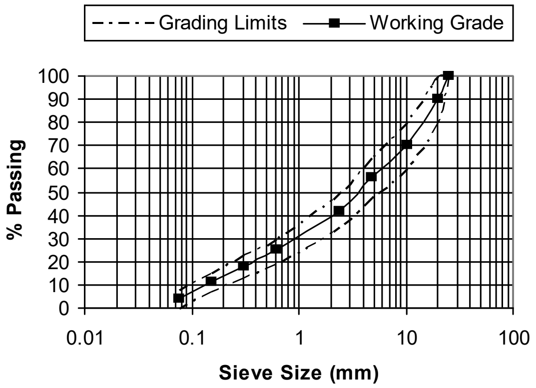

Figure 1. Particle size distribution curve

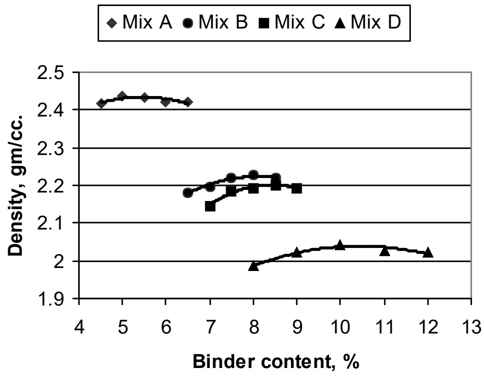

Figure 2. Relation between bulk density and % BC

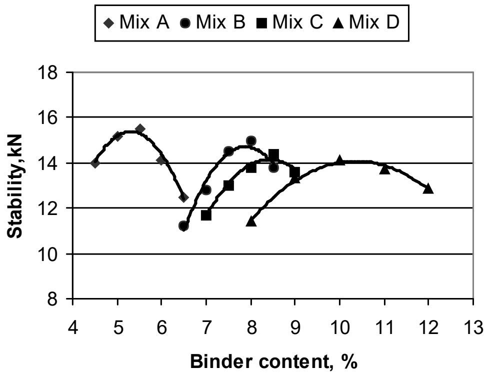

Figure 3. Relation between stability and % BC

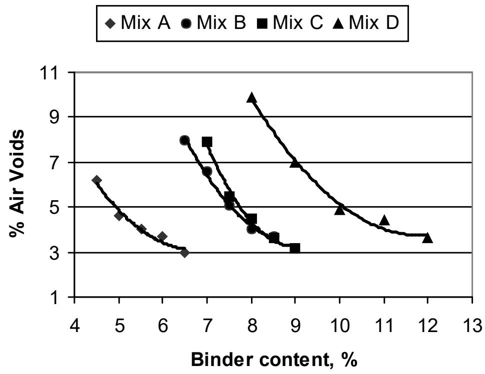

Figure 3. Relation between stability and % BC

Table 2. Characteristics of compacted bituminous mixes at optimum bitumen content

Properties	Mix Types			
	A	B	C	D
OBC, % (by weight of mix)	5.5	8.0	8.5	10.5
Bulk density, gm/cc	2.433	2.225	2.200	2.040
Marshall stability, kN	14.3	14.8	14.1	14.0
Flow (0.25 mm)	12.2	14.0	13.4	12.5
Air voids in total mix, %	4.0	4.1	3.6	4.3
Voids in mineral aggregates, %	13.2	15.4	14.3	14.5
Voids filled with bitumen, %	70	73	75	68
Bitumen required (kg per m^3 of mix)	135	185	192	218
Marshall stiffness, kN/mm	4.7	4.2	4.2	4.5

Compaction of bituminous mix is a mechanical process by which the aggregates are constrained to be packed more closely together by reducing the air voids. Not all mix design methods use the same compaction effort for mixtures. For instance, a mixture designed using the Marshall mix design procedure for heavy traffic requires 75 blows per side of the specimen with the Marshall compaction hammer. The same mix designed for medium traffic and light traffic requires 50 blows per side and 35 blows per side respectively. To study the effect of compaction efforts on the characteristics of bituminous mixes with WCA, specimens were prepared for each mix type using 35, 50 and 75 number of blows respectively. Bitumen content was kept constant at their OBC calculated from Marshall mix design of specimen for 50 blows from the consideration of higher stability. The relation between bulk density and number of blows; Marshall stability and number of blows for four mix types are shown in Fig. 5 and Fig. 6 respectively. Marshall stiffness of compacted specimens with four mixes for three compaction efforts are given in Table 3.

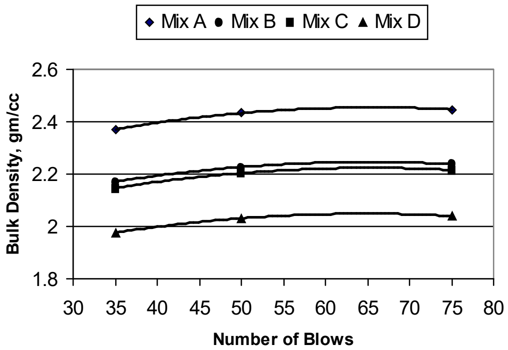

Figure 5. Relation between density and no. of blows

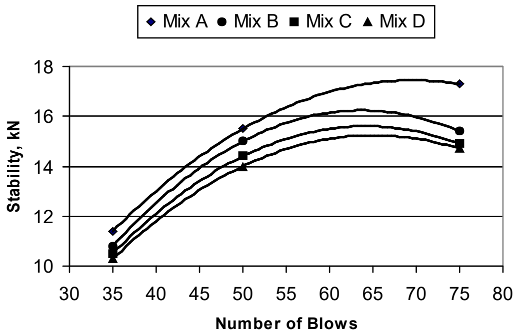

Figure 6. Relation between stability and no. of blows

Table 3. Marshall stiffness of compacted bituminous mixes

No. of blows	Mix type	Marshall stiffness (kN/mm)			
		A	B	C	D
35, for light traffic road		3.5	2.9	2.8	2.8
50, for medium traffic road		4.7	4.2	4.2	4.1
75, for heavy traffic road		5.1	4.1	3.8	4.5

The durability of hot-mixed asphalt (HMA) pavement may degrade at the interface between asphalt and aggregate (loss of adhesion) or within the asphalt binder (loss of cohesion) due to loading and environmental conditions. Failure of the bond already formed, resulting in the displacement of the asphalt cement from the aggregates due to moisture, is referred to as stripping (Kennedy et al. 1983) [12].When this occurs, the asphalt pavement will lose rock particles under traffic loads and the result is raveling. Moisture damage can manifest itself through various failure mechanisms. These include rutting, fatigue cracking, raveling, and potholes. Martin et al. (2003) mentioned that the moisture-induced damage within HMA pavement is a national issue that decreases the lifespan of the nation's highways.

Highly porous cement paste and dusty surface are the main characteristics of WCA. The National Asphalt Pavement Association (NAPA, 1992) recognized that dust coating of the aggregate can inhibit the adhesion of the asphalt binder, thereby allowing water to penetrate to the aggregate surface [14]. This is a problem most associated with WCA produced by crushing demolished concrete.

4 Analysis and Discussions

4.1 Effect of Aggregate Types

Table 1 presents the specific gravities, water absorptions and strength properties of coarse aggregates used in this study. WCA was found to have lower specific gravity and higher absorption values than that of conventional basalt aggregate. Test results indicate that WCA are weak than fresh aggregates due to the easy separation of the mortar attached to WCA under compression, crushing and abrasion. Hansen (1992) reported that Los Angeles abrasion results dependent on the strength of the original concrete, where stronger breaks up less than weaker concrete.

Results shown in Fig. 2 and 3 indicates that the densities and stabilities of the compacted specimens for all the mixes, increase initially with an increase of bitumen content, reach a maximum value and then decrease. With the increments of bitumen content, the batter compactions were done as a result the density and stability increased. For further increments of bitumen, the thickness of bitumen film increased as a result the density and stability decreased. Gallaway and Harper [1968] reported that cohesion of mixtures containing lightweight aggregate (high absorbent) as the coarse fraction generally increases with increasing bitumen content. They further noted that the density of specimen increases with increasing bitumen content reaches a maximum value and then decreases [16]. In this sense, WCA mixtures behave as fresh aggregate mixtures. It is also seen from Table 2 that the required bitumen (kg/m^3) is 1.37 times, 1.42 times and 1.61 times more in bituminous mixes using WCA from basalt, crushed gravels and brick chips respectively than that of bituminous mix contain fresh basalt aggregates due to highly porous mortar attached onto WCA.

The void records of the mix with different aggregates reported in Fig. 4 shows that the percentage voids in the total mix decreases with increase in bitumen content. For same bitumen content, air voids of WCA mixes are considerably higher than that of mix contain fresh basalt aggregate due to the highly porous cement paste attached on the surface. It is seen from Table 2 that for four mixes the percentage of voids at OBC are satisfy the limits (3 to 5 %) specified by the Asphalt Institute, 1984 [16].

The ratio of stability to flow gives a measure of what is termed the stiffness of the mix which can be related to tire pressure. In order to prevent permanent deformation of the mix under high stress the Marshall stiffness should not be less than 2.1 kN/mm (120lb/0.01″) for the design tire pressure of 100 psi, reported by Lees [17]. Marshall stiffness for bituminous mixes with WCA shown in last row of Table 2 is much above the required value of 2.1 kN/mm.

4.2 Effect of Compaction Efforts

Result shown in Fig. 5 and 6 indicates that the densities and stabilities of the compacted specimens for all the mixes increase with the increase of compaction efforts because the percentage of air voids in the mix decrease with the increase of compaction efforts. In highly compacted bituminous mixes, the interlocking of the aggregate particles and their frictional resistance to displacement is very high and as a result the stability increases with the increase of compaction efforts. Densities increases significantly with the increase of compaction efforts but there are slight increase in stability from 50 blows to 75 blows for mix contain WCA. Separation of cement mortar from the aggregate surface occurs due to higher compaction energy which decreases the interlocking of the aggregate particles and their frictional resistance to displacement Excess fine particles in the bituminous mix due to higher compaction energy also promote the rutting in the bituminous surface course at higher temperature. From test results reported in Table 3 it is seen that the Marshall stiffness for compaction efforts of 75 blows are less than that for compaction efforts of 50 blows in mix contains WCA.

5 Conclusions

This paper has presented some of the experimental characteristics of bituminous mixes with WCA. Although densities of the compacted bituminous mixes containing WCA were lower than that for the compacted bituminous mix containing fresh aggregates due to porous mortar attached onto WCA but their stability values were very close. Characteristics of bituminous mixes with WCA from basalt chips, crushed gravels and brick chips are reasonably good from the considerations of Marshall test properties having higher optimum bitumen content of 8.0%, 8.5% and 10.5% respectively.

Marshall stiffness of bituminous mixes containing WCA for compaction efforts of 75 blows were less than that for 50 blows. For batter stiffness and to avoid rutting of the bituminous mix at higher temperatures, compaction efforts for medium traffic (50 blows) can be adopted when WCA are used as coarse aggregates in bituminous mixes.

Compressive strength of bituminous mix decreases due to the presence of water in the mixes. Stripping potential of bituminous mixes with WCA was high but index of retained strengths for 24 hours immersion were satisfactory and the TSR values of bituminous mixes with WCA were within the limiting value for HMA surface.

Due to the highly porous, low dense cement mortar attached onto WCA particles, the strength properties of WCA were relatively lower and absorption of WCA were much higher.

Bituminous mixes using WCA required less energy for mixing, transporting and laying bituminous concrete due to the lighter in weight compared to the bituminous mix with conventional aggregates. The use of WCA as a coarse aggregate in bituminous mixes is a feasible option.

The results found in this investigation are encouraging, however, further study is required to investigate the application of current mix design methods for bituminous mixtures containing WCA.

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