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Experimental Behavior of Bituminous Mixes with Waste Concrete Aggregate

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Abstract

Waste concrete aggregates (WCA) are produced by crushing demolished concrete elements. WCA differ from fresh aggregates due to the cement paste attached to the surface of the original aggregates after the process of recycling. The highly porous cement paste and other contaminations contribute to the lower particle density and higher porosity, variation in the quality of the WCA and the higher water absorption. This paper presents some of the results of an investigation on the possible application of WCA in bituminous pavement. The laboratory investigation was divided into three distinct phases. At first all the physical properties of material such as coarse aggregate, fine aggregate, filler and bitumen were determined. The second phase consists of preparation of Marshall test specimens. The third and last phase consists of testing of specimens to obtain Marshall test properties. At first three specimens were prepared with bitumen content 5% for black stone (Type A), 5.5% for white stone (Type B), and 6.5%for WCA from black stone (Type C) and 7% for WCA from white stone (Type D). Five bitumen contents were used with increment of 0.5% for type A, B, C and D. Then the specimens were tested and Marshall stability were obtained 88.7kN, 10.5kN, 10.1kN and 9.2kN at optimum bitumen content 6.2%, 63.7%, 8.1% and 8.3% for mix type A, B, C, and D respectively. Amount bitumen per cubic meter of mix are 154 kg, 153.4 kg, 188 kg, 175.8 kg for mix type A, B, C and D respectively. Marshall test properties of mixes with WCA are satisfactory but required bitumen are 1.08, 1.31,1.34 times more for mix type B, C, and D than that of time A. Aggregates types C and D are acceptable from the consideration of strength properties. The investigated results indicate that the bituminous macadam base course with WCA from white stone give satisfactory results when they are constructed using dense grading, good compaction for medium traffic road.
Keywords: Aggregates, Marshall Test, Bitumen, Waste concrete aggregate (WCA)

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Introduction

1.1 General

The recycling of crushed aggregate has long been recognized to have the potential to conserve natural resources and to reduce energy used in production. In some countries it is a standard alternative for both construction and maintenance, practically where there is a shortage of aggregate. The objective of this papers to determine the technical feasibility/application of using the recycles aggregate in road construction as an alternative for natural aggregate. A detailed testing program was conducted. The findings of this paper will assist in drawing a clear picture about the applications of crushed recycled aggregate. The results will also provide a technical recommendation to the regulatory agencies to issue the standards and technical specifications for the materials of concern. [Al-Khatib, 1999]

The term 'Waste Aggregate' refers to aggregates that have been used previously in construction. Waste aggregates can comprise construction and demolition wastes, asphalt road planning and used railway ballast. Concrete waste materials generated when a building is torn down. It is the first step in cyclical recycling of concrete. Waste aggregate is produced by crushing concrete, and sometimes asphalt concrete, to reclaim the aggregate.

Concrete, being the most widely used construction material, has been its consumption rise given the growth in population and urbanization in many countries. However, along with an increased consumption, there is also an increased generation of wastes. Concrete waste, which accounts for the largest percentage of construction byproducts. According to a survey of actual conditions carried out, is reached 37% of the total quantity of construction byproducts emitted, or a wright of approximately 3.6 million tons.

As societies progressively move towards more environmentally conscious ones, may aspects which could pose a threat to the environment have become matters of serious considerations. Traditionally, the management of waste concrete has been mainly constituted of land filling and partly, recycling. The proportion of the total waste stream that is recycled also varies from place to place but lies in the range of 0-35%.

However, with the large number of waste comprising this stream and an assured increased of it in the future, land filling has become a major problem, particularly in countries where land is scarce. Besides scarcity of land, others problems facing the landfill option include their sitting, transport costs, tipping fees, and public opposition. Thus, recycling has been gaining wider attention as a variable option for the handling of waste concrete. Promoting the recycling of this waste has become extremely important in terms of environment conservation and resource saving.

The recycling of waste concrete, apart from reducing the volume of waste to be land filled, also offers other benefits. One of the main environmental benefits is the conservation of natural resources, especially in regions where aggregates are scarce. If the recycling plants are centrally located and easily accessible, transport costs can also be minimized. Moreover, there is indication of un-hydrated cement particles in the old concrete which can be triggered to further reacting. If attainable, it would lead to reductions in the use of cement whose manufacture bears large environmental hazards due to the emission of toxic gases and dust. It is therefore inductive that effort be placed by the research community and by the industry to increase the rates of waste concrete recycling as there are serious implication from an environmental standpoint that should be complied with. This is particularly true in industrialized countries where waste volumes are high and resource availability is low. Examples of these are: Germany, Netherlands, Belgium and Japan, where the rates of recycling have reached up to 50%. [Chan, 2004]

1.2 Scope of the Research

Every year many buildings are constructed all over the world. Not only the buildings but also many kinds of concrete structures are constructed. After few years they may be torned out. They may be demolished because of many reasons such as construction of a newer on or destruction during wear. The demolished concrete creates many problems to the authority how to dispose them off or how to recycle or reuse.

The rapid development of the urban areas caused the generation of huge volumes of construction and demolition materials. Every authority is now facing a crisis on how to accommodate these surplus materials. Apart from putting more efforts in minimizing its generation and the setting up of temporary fill banks, recycling is one of the most effective means to alleviate the growing problem. Promoting the recycling of this waste has become extremely important in terms of environmental conservation and resource saving. [Ruhi,2004]

The demand for aggregates in the construction industry has been increasing day be day. Road construction, maintenance and widening activities re the most important consumer of aggregates.

Generally, around two thirds of concrete waste are recycled, mainly as road base or as backfill. However, recycling of concrete in buildings up until now has been restricted to nonstructural sections of building (i.e. not including columns, beams, slabs etc.) apart from experimental cases of applications.

The scope of the study consists of the following applications of waste aggregate:

1. New concrete for pavements, shoulders, median barriers, sidewalks and curbs.
2. Road sub-base and bituminous macadam base course.
3. Construction of pavement of playground.
4. Construction of bank protection blocks.
5. Construction of drainage system.

1.3 Objective of the Research

The construction and demolition materials create many problems. With a view to use them for various purposes the thesis works has done. Prior to use these materials in construction, it is essential to know its behavior and various properties that are needed in design. The investigation and experiments were performed to attain primarily the following objectives:

1. To determine and compare the physical properties of fresh aggregates and waste aggregates.
2. To investigate the behavior of bituminous macadam mixes with respect to-
    i. Different types of fresh aggregate
    ii. Different waste aggregates from fresh aggregates.
3. To establish design criteria for the construction of bituminous macadam courses for flexible pavements with waste concrete aggregate.

1.3 Organization of the Research

As the main purpose of the research is to make use of the waste aggregate in flexible pavement, so the maximum work is related to the making of bituminous mixes by using fresh and waste aggregate. Some work is related to the making of cement concrete cylinder by using fresh aggregate. Before making concrete cylinder and bituminous mixes physical properties of all ingredients of bituminous mixes are determined. The detail activities related to this research project are briefly discussed below. In this project work, at the first chapter, introduction with scope and objectives of the research is briefly described. In the second chapter all the literature related to concrete constituents and bituminous mixes constituents such as aggregate, sand, cement and bitumen are discussed also the process of recycling and the field and laboratory studies of aggregate in bituminous mixes are discussed.

Methodology

2. General

Coarse aggregates were collected from different place of Bangladesh. The collected samples were broken into pieces manually in 25mm down grad. Sand and stone dusts (filler passing 0.075mm sieve) were added to achieve the required aggregate gradation. The aggregate was tested for engineering properties related to flexible pavement. The engineering properties of materials were determined according to the procedure specified by AASHTO, ASTM and BS standards. In order to study the effect of aggregate on the behavior of bituminous mix, Marshall test specimens were prepared for four types of aggregates mix with 50 blows for medium traffic road according to the standard procedure specified by AASHTO.

2.1 Material Properties

A bituminous mixture is normally composed of aggregates and bitumen. The aggregates are generally divided into coarse, fine and filler fractions according to the size of individual particles. The following sections include the description of the coarse aggregate, fine aggregate, mineral fillers and bitumen used in this investigation.

2.2 Materials Collection

One of the main objectives of the research was to make a comparative study of the bituminous mixes with different coarse aggregates. Therefore, the type of fine aggregate, type of filler and type of bitumen were same in all bituminous mixes.

2.3 Properties of Materials

The properties of all ingredients were determined by following the ASTM and AASHTO standard.

However, it is very important to know the physical properties of coarse aggregate, fine aggregate, filler and bitumen as it affect the strength of road pavement. The laboratory test results which reflect the physical properties of ingredients are stated in the following articles.

2.3.1 Intrinsic Properties of Coarse Aggregates

Unit weight, specific gravity and water absorption of coarse aggregates were determined according to the procedure specified AASHTO T19 and AASHTO T185 respectively. Test results of intrinsic properties of coarse aggregates are given in Table 2.1.

Table 2.1 Intrinsic Properties of Coarse Aggregate

Properties	Aggregate Types			
	A	B	C	D
Unit weight, dense, (kg/m^3)	1670	1570	1415	1360
Unit weight, loose, (kg/m^3)	1535	1450	1255	1200
Bulk specific gravity	2.846	2.607	2.351	2.274
Apparent specific gravity	2.949	2.706	2.739	2.665
Absorption of water, %	1.00	1.42	6.03	6.46

2.3.2 Strength Properties of Coarse Aggregates

The abrasion value, soundness, impact value, crushing value and ten percent fines value for different aggregates were determined by following test methods AASHTO T104 and BS 812 (part 3) respectively. Test results of strength properties of coarse aggregates are summarized in Table 2.2

Table 2.2 Strength Properties of Course Aggregate

Properties	Aggregate Types			
	A	B	C	D
L. A. Abrasion Value, (Grade-A), %	12	27	34	42
L. A. Abrasion Value, (Grade-B), %				
Soundness, ($MgSO_4$, 5 cycles), %	2	6	20	21
Aggregate Impact Value, %	6	11	19	22
Aggregate Crushing Value, %	12	22	29	31
Ten percent fines value, (kN)	300	190	95	75

2.3.3 Properties of Fine Aggregate and Filler

Unit weight, specific gravity and water absorption of fine aggregates were determined according to the procedure specified by AASHTO T19 and AASHTO T84 respectively, specific gravity of filler was ascertained by following the test method specified by AASHTO T19 and AASHTO T133 respectively. Test results are given in Table 2.3

Table 2.3 Test Result of Fine Aggregate and Filler

Properties	Fine aggregate	Filler
Unit weight, dense, (kg/m^3)	1570	1200
Unit weight, loose, (kg/m^3)	1440	990
Bulk specific gravity	2.461	-
Apparent specific gravity	2.637	2.436
Absorption of water, %	2.720	-

2.3.4 Properties of Bitumen

Specific gravity, penetration, solubility, loss on heating, ductility flash and fire point of bitumen were determined according to the test procedure specified by AASHTO T229, T49, T44, T47, T51, T48 respectively. Test results of bitumen given in Table 2.4

Table 2.4 Properties of Bitumen

Sl. No.	Description of tests	AASHTO Digestion	ASTM Digestion	Test values
01	Specific gravity (25°C)	T229	D70	1.002
02	Penetration (100gm, 5sec, 25°C)	T49	D5	98
03	Solubility, % (CCl_4)	T44	D2042	99.75
04	Loss on heating, % (163°C, 5 hrs)	T47	D6	1.80
05	Ductility, cm (25°C)	T51	D113	100^+
06	Flash point (°C)	T48	D92	295
07	Fire point, (°C)	T48	D92	320

2.4 Testing Procedure

Each compacted specimen was numbered, their height, diameter was measured and weight in air was recorded. The specimens were then subjected to the following tests.

i. Determination of the bulk specific gravity

ii. Stability and flow tests.

2.5. Instruments

Compaction Pedestal and Hammer, Water Bath, Vacuum Desicator, Marshall Stability Testing Machine.

2.6 Preparation of a Specimen

To investigate the Marshall stability of bituminous mixes with different aggregates 120 number specimens of 101.6 mm diameter and approximately 63.5 mm thickness were prepared. 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 preliminary trials that about 1200gms and 1000gms of aggregates were required to prepare one specimen of 101.6mm (4inch) diameter and 63.5mm (2.5inch) thick for natural stone aggregates and waste cement concrete aggregate respectively. Three specimens were prepared for each bitumen content and at least 5 bitumen contents were used with increments of 0.5% for stone aggregates and waste cement concrete aggregate by weight of total mix. Initially 6.5% bitumen was present in waste bitumen was present in waste bituminous mix. Specimens were prepared with increments of 0.5% for bituminous mixes. The ranges of bitumen contents were determined from trial mixes such that the optimum bitumen contents were within those ranges.

The filler material and aggregate of all sixes were weighted for one test specimen and taken in a pan. The aggregate blend was then heated for four hours in an electric oven maintained at a temperature of 182-188°C (depending on the moisture content of that aggregates). The aggregates were then transferred to a hot mixing bowl and thoroughly mixed. A crater was formed in the middle of the fry blended aggregate and the required amount of bitumen, heated to a steady temperature of 160°C (on the basis of Saybolt Furol Viscosity of Bitumen) was added. The aggregates and bitumen were rapidly mixed to yield a mixture having a uniform distribution of bitumen throughout.

The mould assembly heated in a bath of boiling water was placed on the table and a piece of circular paper of 101.6mm diameter was placed at the bottom of the mould. The entire bath of mixture was then introduced in the mould and the mixture was vigorously spaded with a hot trowel 15 times around the perimeter and 10 times over the interior. Temperature of the mixture was recorded and the mould assembly with the mixture was placed on the standard compaction pedestal and 50 blows were applied with the 4.5kg compaction hammer with a free fall of 45.7cm. The axis of the hammer was kept perpendicular to the base of the mould assembly during compaction.

The number of blows for the preparation of the sample was selected corresponding to 690 kN/m^2 (100psi) tyre pressure. The heavy vehicles which move on the road of Bangladesh have tyre pressure in range of 415-485 kN/m^2 (60-70 psi). So, the assumption of 690 kN/m^2 tyre pressure seems to be sage and appropriate.

The collar of the mould was then removed and the mould with specimen inside was inverted and reset on the base plate. The extension collar was placed in position and 50 blows were applied on the face of specimen with the compaction hammer. The sample was then cooled for about 10 mins and extruded form the mould with the help of a hydraulic jack. The specimen was then transferred to a smooth flat surface and allowed to stand overnight at room temperature. The same procedure was adopted to prepare specimens of all mix types.

2.7 Determination of the Bulk Specific Gravity

The bulk specific gravity test was performed as soon a the freshly compacted specimens have cooled to room temperature. The test was performed according to AASHTO (1983) T166, ASTM (1979) D2726. Bulk specific gravity of compacted bituminous mixtures using standard dry specimens. Bulk specific gravity results of mix types A, B, C, and D are given in Table 2.5 to 2.8

Table 2.5 Bulk Specific Gravity of Compacted Paving Mix Type A

Percent Bitumen Content	Height of Specimen (mm)	Dry Wt. of Specimen = A (gm)	S.S.D Wt. of Specimen = B (gm)	Wt. in water = C (gm)	Bulk Sp. Gr. G_{mb} = A/(B-C)	Average G_{mb}
5.0	66 65 65	1248 1250 1250	1252 1253 1254	721 722 721	2.350 2.354 2.345	2.350
5.5	65 65 65	1256 1255 1257	1260 1260 1260	731 732 733	2.374 2.378 2.385	2.379
6.0	65 64.5 65	1265 1264 1264	1267 1266 1266	744 743 742	2.419 2.417 2.412	2.416
6.5	64 64 64.5	1269 1270 1270	1270 1271 1271	743 744 743	2.408 2.410 2.405	2.408
7.0	65 65 65.5	1276 1275 1275	1276 1275 1275	745 744 745	2.403 2.401 2.406	2.403

Table 2.6 Bulk Specific Gravity of Compacted Paving Mix Type B

Percent Bitumen Content	Height of Specimen (mm)	Dry Wt. of Specimen = A (gm)	S.S.D Wt. of Specimen = B (gm)	Wt. in water = C (gm)	Bulk Sp. Gr. G_{mb} = A/(B-C)	Average G_{mb}
5.5	64.0 63.5 63.5	1158 1157 1157	1160 1159 1159	654 653 654	2.289 2.287 2.291	2.289
6.0	62.5 62.5 62.5	1160 1159 1159	1163 1162 1162	664 663 664	2.325 2.323 2.327	2.325
6.5	62.5 62.5 62.5	1165 1164 1164	1166 1165 1165	666 665 666	2.330 2.328 2.333	2.330
7.0	62.5 62.5 63.0	1170 1169 1169	1170 1169 1169	667 666 667	2.326 2.324 2.329	2.326
7.5	63.0 63.0 63.0	1175 1174 1174	11745 1174 1174	668 667 668	2.318 2.316 2.320	2.318

Table 2.7 Bulk Specific Gravity of Compacted Paving Mix Type C

Percent Bitumen Content	Height of Specimen (mm)	Dry Wt. of Specimen = A (gm)	S.S.D Wt. of Specimen = B (gm)	Wt. in water = C (gm)	Bulk Sp. Gr. G_{mb} = A/(B-C)	Average G_{mb}
6.5	66.0 65.5 65.5	1164 1165 1165	1168 1169 1168	635 636 634	2.184 2.186 2.182	2.184
7.0	65.5 65.5 65.0	1167 1168 168	1169 1170 1169	638 639 637	2.198 2.200 2.195	2.198
7.5	65.0 65.0 65.5	1169 1170 1170	1170 1171 1170	643 644 642	2.218 2.220 2.216	2.218
8.0	65.0 65.0 65.0	1176 175 1175	1177 1176 1175	649 648 648	2.227 2.225 2.230	2.227
8.5	65.5 65.5 65.0	1186 1185 1185	1187 1186 1185	653 652 652	2.221 2.219 2.223	2.221

Table 2.8 Bulk Specific Gravity of Compacted Paving Mix Type D

Percent Bitumen Content	Height of Specimen (mm)	Dry Wt. of Specimen = A (gm)	S.S.D Wt. of Specimen = B (gm)	Wt. in water = C (gm)	Bulk Sp. Gr. G_{mb} = A/(B-C)	Average G_{mb}
7.0	63.0 63.5 63.5	1060 1059 1059	1065 1064 1064	571 570 571	2.146 2.144 2.148	2.146
7.5	63.0 63.0 63.0	1068 1067 1067	1073 1072 1072	579 578 579	2.162 2.160 2.164	2.162
8.0	62.5 62.5 63.0	1072 1071 1071	1073 1072 1072	589 589 589	2.215 2.213 2.217	2.215
8.5	63.0 63.0 63.0	1078 1077 1077	1079 1078 1078	590 589 590	2.204 2.202 2.207	2.204
9.0	63.0 63.0 63.5	1077 1076 1075	1077 1076 1076	587 588 589	2.198 2.205 2.194	2.199

2.8 Marshall Stability and Flow of a Specimen

After determination of the bulk specific gravity of the compacted specimens, the specimen was immersed in thermostatically controlled water bath maintained at a temperature of 140° ± 1.8°F. It was kept in that position for 30 to 40 minutes. The specimen was then removed from the water bath and the surface was died by a piece of cloth.

The specimen was then placed on the lower segment of the Marshall testing head. The upper segment of the testing head was then placed on the specimen and the complete assembly was placed in position on the platform of the testing machine. The loading head was brought just in contact with the breaking head and the flow meter was placed in position over the guide rods and flow meter reading were adjusted to zero.

Load was applied on the specimen at a constant rate of movement of the load jack of 2 inches per minute until the maximum reading on the proving ring dial was reached. This reading multiplied by the calibration factor (4.75kg) of the proving ring gave the load at failure. This value was the adjusted for specimen thickness/volume using Table 2.6 and corrected stability was obtained.

The flow meter reading at the maximum reading of the load dial was recorded and expressed in units of 0.25mm (1/100 inch). Specimen of 101.6mm diameter and 63.5mm thick were made with different types aggregate to investigate the effect of aggregate on the behavior of bituminous mixes. In this investigation similar procedure was applied for Marshall test as discussed above.

Table 2.6 Stability Correlation Ratio

Thickness of Specimen (mm)	55.6	57.2	58.7	60.3	61.9	63.5	65.1	66.7	68.3
Correlation Ratio	1.25	1.19	1.14	1.09	1.04	1.00	0.96	0.93	0.89

Analysis And Discussion Of Test Result

3.1 Effect of Strength Properties of Aggregates

For compaction, aggregate strength values and their limiting values recommended by AASHTO and BS shown in Table 3.1

Table 3.1 Comparison f Test Results with Recommendation Values

Properties of aggregate	Test Values				Recommended Values AASHTO/BS
	Aggregate Types				
	A	B	C	D	
Aggregate crushing value, %	12	22	29	31	35 (max.)
Aggregate impact value, %	6	11	19	22	35 (max.)
Los Angeles abrasion value, %	12	27	34	42	40 (max.)
Soundness, ($MgSO_4$, 5 cycles), %	2	20	20	21	15 (max.)
Ten percent fine value, (kN)	300	95	95	75	100 (min.) (LGED)

From the table 3.1 the aggregate crushing value record shows that the aggregate crushing value of fresh aggregate type A is 12% and type B is 22%, whereas for the waste coarse aggregate the same value for type C is 29% and type D is 31%. This shows that the aggregate crushing value of aggregate type A, B, C, and D satisfied the limiting value 35%.

The aggregate impact value record shows that the aggregate impact value of fresh coarse aggregate type A is 6% and type B is 11%, whereas for the waste coarse aggregate the same value for type C is 19% and type D is 22%. This shows that the aggregate impact value of aggregate type A, B, C, and D satisfied the limiting value 35%.

The Los Angles abrasion value record shows that the Los Angles abrasion value of fresh coarse aggregate type A is 12% and type B is 27%, whereas for the waste coarse aggregates the same value for type C is 34% and type D is 42%. This shows that the Los Angles abrasion value of aggregate type A, B and C satisfied the limiting value 40%, but Los Angles abrasion value of aggregate type D exceeds the limiting value.

The soundness value records show that type A is 2% and type B is 6% which satisfy the limiting value. But the soundness value of type C is 20% and D is 21% which exceeds the limiting value 15%.

The ten percent fine value record shows that the ten percent fine value of fresh coarse aggregate type A is 300kN and type B is 190 kN, whereas for the waste coarse aggregate the same values for type C is 95kN and type D is 75 kN. This shows that the ten percent fine value of fresh aggregate type A and B satisfied the limiting value 100kN.

3.2 Effect of aggregate on the behavior of Bituminous Mixes

Marshall Test results of mix type A, B, C and D are given in Tables 3.2 to 3.5

Table 3.2 Marshall Test Data of Mix Type A CA=58%, FA=38% & MF= 4%

% BC	Specimen Number	Specimen Height (mm)	Bulk Sp. Gr.	Unit Wt. (Kg/m^3)	Marshall Stability (kN)		Flow (0.25mm)
					Measured	Adjusted	
5.0	1	66.0	2.350	2350	7.7	7.0	10.1
	2	65.0	2.354		7.6	7.1	10.2
	3	65.0	2.345		7.5	7.0	10.3
	Av.		2.350			7.1	10.2
5.5	1	65.0	2.374	2379	8.3	7.7	10.8
	2	65.0	2.378		8.2	7.7	10.9
	3	65.0	2.385		8.4	7.8	10.9
	Av.		2.379			7.7	10.9
6.0	1	65.0	2.419	2416	9.9	9.2	11.4
	2	64.5	2.417		9.8	9.1	11.5
	3	65.0	2.412		9.7	9.0	11.6
	Av.		2.416			9.1	11.4
6.5	1	64.0	2.408	2408	9.0	8.6	12.1
	2	64.0	2.410		9.2	8.7	12.2
	3	64.5	2.405		9.1	8.6	123
	Av.		2.408			8.7	12.2
7.0	1	65.0	2.403	2403	8.4	7.8	13.1
	2	65.0	2.401		8.5	7.9	13.3
	3	65.5	2.406		8.6	7.9	13.5
	Av.		2.403			7.9	13.3

Table 3.3 Marshall Test Data of Mix Type B CA=58%, FA=38% & MF= 4%

% BC	Specimen Number	Specimen Height (mm)	Bulk Sp. Gr.	Unit Wt. (Kg/m^3)	Marshall Stability (kN)		Flow (0.25mm)
					Measured	Adjusted	
5.5	1 2 3 Av.	64.0 63.5 63.5	2.289 2.287 2.291 2.289	2289	6.52 6.51 6.50	6.4 6.5 6.5 6.5	11.2 11.3 11.4 11.3

6.0	1 2 3 Av.	62.5 62.5 62.5	2.325 2.323 2.327 2.325	2325	8.91 8.92 8.92	9.1 9.0 9.0 9.0	12.3 12.2 12.4 12.2
6.5	1 2 3 Av.	62.5 62.5 62.5	2.330 2.328 2.333 2.330	2330	10.36 10.35 10.34	10.6 10.6 10.6 10.6	12.9 13.0 13.1 13.0
7.0	1 2 3 Av.	62.5 62.5 63.0	2.326 2.324 2.329 2.326	2326	10.13 10.11 10.12	10.3 10.3 10.2 10.3	13.7 13.8 13.9 13.8
7.5	1 2 3 Av.	63.0 63.0 63.0	2.318 2.316 2.320 2.318	2318	9.85 9.84 9.83	9.9 9.9 9.9 9.9	14.8 14.9 15.0 14.9

Table 3.4 Marshall Test Data of Mix Type C CA=58%, FA=38% & MF= 4%

% BC	Specimen Number	Specimen Height (mm)	Bulk Sp. Gr.	Unit Wt. (Kg/m^3)	Marshall Stability (kN)		Flow (0.25mm)
					Measured	Adjusted	
6.5	1 2 3 Av.	66.0 65.5 65.5	2.184 2.186 2.182 2.184	2184	7.96 7.97 7.98	7.2 7.3 7.3 7.3	9.8 9.7 9.6 9.7
7.0	1 2 3 Av.	65.5 65.5 65.0	2.198 2.200 2.195 2.198	2198	9.23 9.25 9.27	8.5 8.5 8.6 8.5	12.0 12.1 12.2 12.1
7.5	1 2 3 Av.	65.0 65.0 64.5	2.218 2.220 2.216 2.218	2218	10.51 10.53 10.55	9.8 9.8 9.9 9.8	13.2 13.1 12.9 13.1
8.0	1 2 3 Av.	65.0 65.0 65.0	2.227 2.225 2.230 2.227	2227	10.85 10.87 10.89	10.1 10.1 10.1 10.1	15.3 15.4 15.5 15.4
8.5	1 2 3 Av.	65.5 65.5 65.0	2.221 2.219 2.223 2.221	2221	10.11 10.12 10.13	9.3 9.3 9.4 9.3	15.6 15.7 15.8 15.7

Table 3.5 Marshall Test Data of Mix Type D CA=58%, FA=38% & MF= 4%

% BC	Specimen Number	Specimen Height (mm)	Bulk Sp. Gr.	Unit Wt. (Kg/m^3)	Marshall Stability (kN)		Flow (0.25mm)
					Measured	Adjusted	
7.0	1 2 3 Av.	63.0 63.5 63.5	2.146 2.144 2.148 2.146	2146	8.26 8.28 8.30	8.3 8.3 8.3 8.3	12.2 12.1 12.0 12.1
7.5	1 2 3 Av.	63.0 63.0 63.0	2.162 2.160 2.164 2.162	2162	8.87 8.89 8.91	9.0 9.0 9.0 9.0	12.8 12.9 13.0 12.9
8.0	1 2 3 Av.	62.5 62.5 63.0	2.215 2.213 2.217 2.215	2218	9.22 9.23 9.24	9.4 9.4 9.4 9.4	13.4 13.5 13.6 13.5
8.5	1 2 3 Av.	63.0 63.0 63.0	2.204 2.202 2.207 2.204	2204	9.56 9.57 9.58	9.6 9.6 9.7 9.6	14.5 14.6 14.7 14.6
9.0	1 2 3 Av.	63.0 63.0 63.5	2.198 2.205 2.194 2.199	2199	8.79 8.80 8.93	8.9 8.9 8.9 8.9	15.4 15.5 15.6 15.5

and the results are summarized in Table 3.2 to 3.5. Each of the Tables 3.6 through 3.9 contains the values of bitumen content, bulk specific gravity, unit weight, Marshall Stability, flow, percent voids in total mix, percent voids in mineral aggregates and percent voids filled with bitumen.

For each mix type a set of 6 curves are drawn showing the relationship of unit weight, Marshall stability, flow, percent voids in total mix, percent voids in mineral aggregates and percent voids filled with bitumen with bitumen with percentage of bitumen content. In figures 3.1 to 3.6 the above-mentioned figures are shown in a consolidated form for comparison.

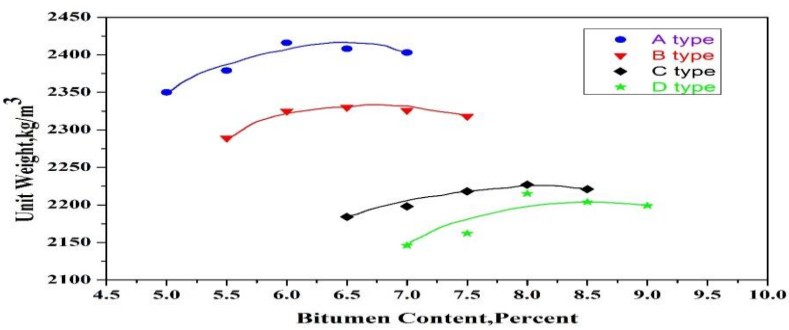

Figure 3.1: Relationship between unit weight and bitumen content for different aggregate types

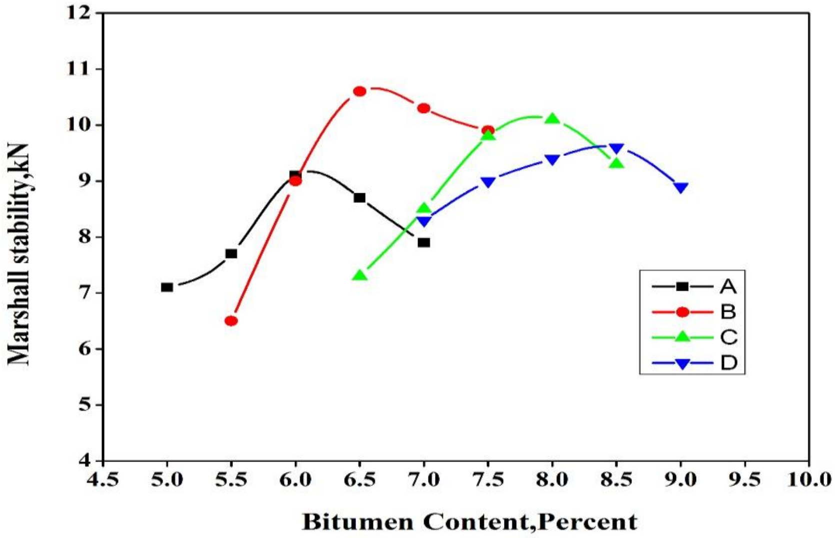

Figure 3.2: Relationship between Marshall stability and Bitumen Content for different aggregate types.

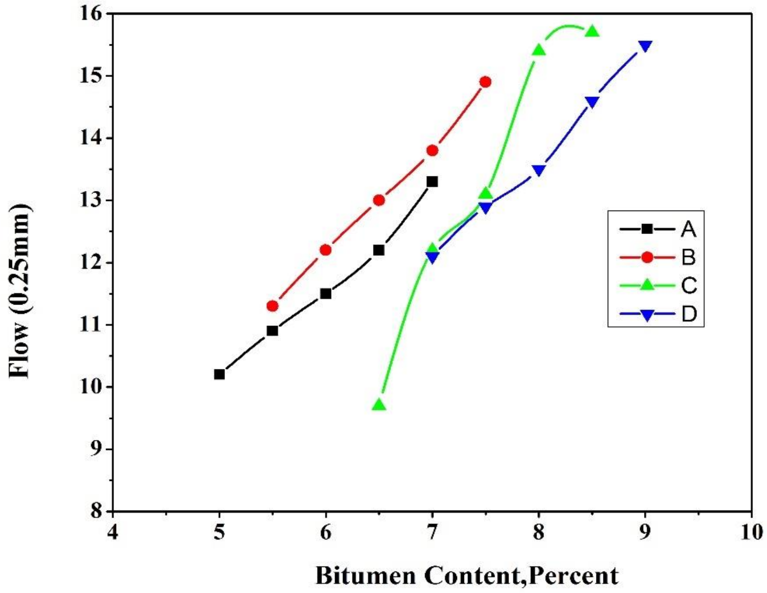

Figure 3.3: Relationship between flow and bitumen content for different aggregate types.

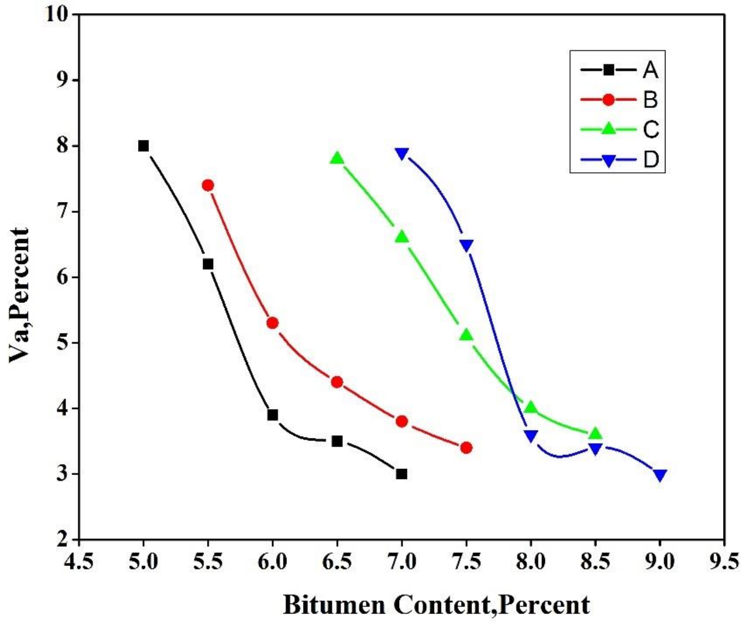

Figure 3.4: Relationship between percent voids in total mix and bitumen content for different aggregate types

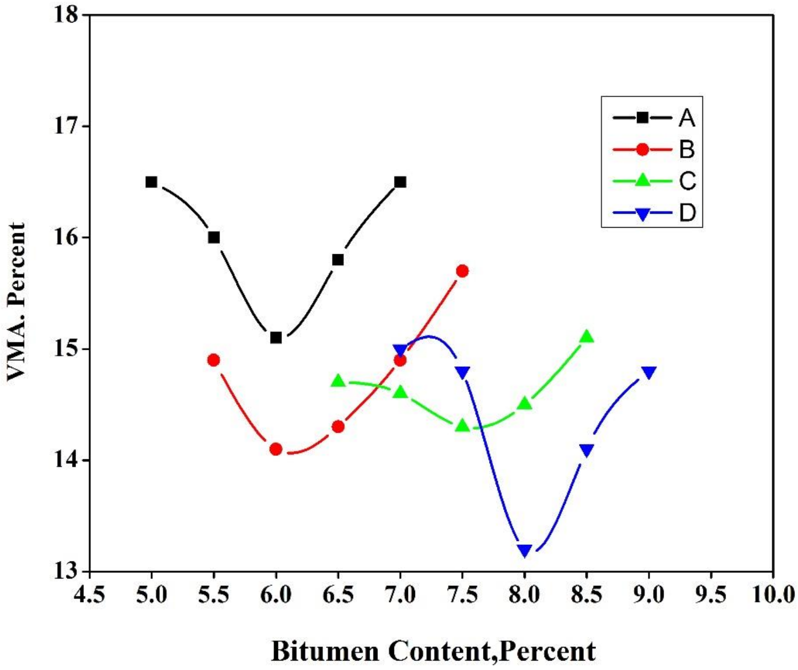

Figure 3.5: Relationship between percent voids in mineral aggregates and bitumen content for different aggregate types

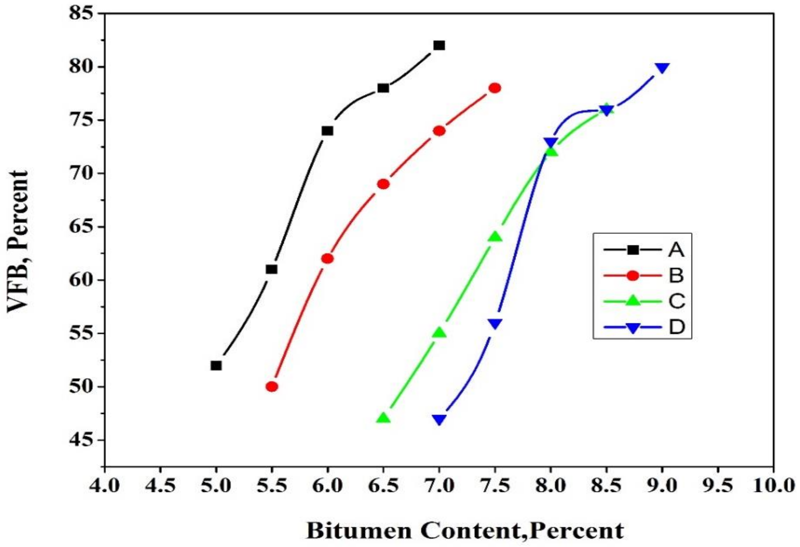

Figure 3.6: Re3lationship between percent VFB and bitumen content for different aggregate types.

A close study of the tables and the figures reveals that there are similarities between the curves of waste aggregate bituminous mixes with those of fresh aggregate bituminous mixes. Curves of Figure 4.1 showing the relationship of unit weight and bitumen content indicate that the unit weights of compacted specimens for all the mixes increases initially with an increase in bitumen content, reach a maximum value and then decreases.

Figures 3.2 shows that the variation of Marshall stability with bitumen content is similar in nature to that of unit weight.

Figure 3.3indicates that the flow values of the specimen increase with increase in bitumen content. The rate of increase being higher for higher proportions of bitumen.

Figure 3.4 shows that the percentage of voids in the total mix decrease with increase in bitumen content.

Figure 3.5 represents the relationship of aggregates with bitumen content. The void records of the mixes show that the percentage of voids in mineral aggregates decreases initially with an increase in bitumen content, reach a minimum value and then increases.

Figure 3.6 indicates that the percent voids filled with bitumen of the specimen increase with increase in bitumen content. The rate of increase being higher for higher proportions of bitumen.

Table 3.6 Marshall Test Results of Bituminous Mix Type A

B. C. (%)	Bulk Sp. gr.	Unit wt. (Kg/m^3)	Marshall Stability (kN)	Flow(0.25mm)	V_a	VMA (%)	VFB (%)
5	2.350	2350	7.1	10.2	8.0	16.5	52
5.5	2.379	2379	7.7	10.9	6.2	16.0	61
6.0	2.416	2416	9.1	11.5	3.9	15.1	74
6.5	2.408	2408	8.7	12.2	3.5	15.8	78
7.0	2.403	2403	7.9	13.3	3.0	16.5	82

Table 3.7 Marshall Test Results of Bituminous Mix Type B

B. C. (%)	Bulk Sp. gr.	Unit wt. (Kg/m^3)	Marshall Stability (kN)	Flow(0.25mm)	V_a	VMA (%)	VFB (%)
5.5	2.289	2289	6.5	11.3	7.4	14.9	50
6.0	2.325	2325	9.0	12.2	5.3	14.1	62
6.5	2.330	2330	10.6	13.0	4.4	14.3	69
7.0	2.326	2326	10.3	13.8	3.8	14.9	74
7.5	2.318	2318	9.9	14.9	3.4	15.7	78

Table 3.8 Marshall Test Results of Bituminous Mix Type C

B. C. (%)	Bulk Sp. gr.	Unit wt. (Kg/m^3)	Marshall Stability (kN)	Flow(0.25mm)	V_a	VMA (%)	VFB (%)
6.5	2.184	2184	7.3	9.7	7.8	14.7	47
7.0	2.198	2198	8.5	12.1	6.6	14.6	55
7.5	2.218	2218	9.8	13.1	5.1	14.3	64
8.0	2.227	2227	10.1	15.4	4.0	14.5	72
8.5	2.221	2221	9.3	15.7	3.6	15.1	76

Table 3.9 Marshall Test Results of Bituminous Mix Type D

B. C. (%)	Bulk Sp. gr.	Unit wt. (Kg/m^3)	Marshall Stability (kN)	Flow(0.25mm)	V_a	VMA (%)	VFB (%)
7	2.146	2146	8.3	12.1	7.9	15.0	47
7.5	2.162	2162	9.0	12.9	6.5	14.8	56
8.0	2.215	2215	9.4	13.5	3.6	13.2	73
8.5	2.204	2204	9.6	14.6	3.4	14.1	76
9.0	2.199	2199	8.9	15.5	3.0	14.8	80

From table 3.2 to 3.5, it is found that or mix type A, B, C and D; the maximum bulk specific gravities are 2.416, 2.330, 2.227 and 2.215 respectively. The maximum unit weights are 2416, 2330, 227 and 2215 Kg/m^3 respectively. The maximum Marshall stabilities are 9.1, 0.6, 10.1, and 9.6 kN respectively. The maximum unit weight of mix type C and D is less than that of mix type A by the amount of 189 Kg/m^3 and 201 Kg/m^3 respectively; because highly porous cement mortar paste attached to the surface of waste aggregates contribute to the lower particle density and higher porosity. The maximum stability of mix type A, B, C and D are very close to each another.

Optimum bitumen content is determined as follows:

The bitumen contents at maximum unit weight and at maximum stability are determined from Figures 3.1 and 3.2 respectively. For base course, bitumen content at 4% (medium of 3-5% range) vids in total mix are determined from Figure 3.4. the average of these three bitumen contents is taken as optimum bitumen content.

At optimum bitumen content, the values of unit weight, Marshall stability, flow, percentage of voids in total mix, percentage of voids in mineral aggregates and percent voids filled with bitumen for different mix types are shown in Table 3.10.

Aggregates types	O. B.C %	Unit wt. (Kg/m^3)	Marshall Stability (kN)	Flow(0.25mm)	V_a	VMA (%)	VFB (%)
A	6.2	2410	8.7	11.9	3.8	15.5	75
B	6.7	2330	10.5	10.8	4.0	14.5	73
C	8.1	2225	10.1	9.8	4.0	14.8	72
D	8.3	2210	9.2	9.5	3.6	13.8	74

Table 3.10 shows that the Marshall stability at optimum bitumen content for mix types A, B, C, and D are 8.7 10.5, 10.1 and 9.2 kN respectively. All these stability values satisfy the limiting value (3.336kN) specified by The Asphalt Institute as shown in Table 3.10. the flow values are 11.9, 10.8, 9.8 and 9.5 respectively. All these flow values satisfy the limiting value 8-16 specified by The Asphalt Institute. From Table 3.10 it is found that at optimum bitumen content % V_a for mix type A, B, C and D are 3.8%, 4.0%, 4.0% and 3.6% respectively. All this value satisfies the limits 3-5% specified by The Asphalt Institute as shown in Table 3.10 shows that for mix type A, B, C and D. the % VMA at optimum bitumen content are 15.5%, 14.5%, 14.8% and 13.8% respectively. All these values are greater than the minimum value 12% shown in Table 3.12. Table 3.10 shown that the % VFB at optimum bitumen content for mix type A, B, C and D are 75%, 73%, 72% and 74% respectively. All these values satisfy the limits 65-78% specified by The Asphalt Institute as shown in Table 3.11.

When interpreting the Marshall test results, it is considered that it is the ratio of stability to flow that is important and not their individual values. This ratio gives a measure of what is the term the stiffness of the mix which can be related to type pressure. In order t prevent permanent deformation of the mix under high stress, the Marshall stability flow ration should not be less than 3.1 kN/mm i.e. 1.2 times tyre pressure.

Table 3.11 Design Criteria for the Marshall Method (Wright, P.H. 1996)

Marshall Method Mix Criteria	Light Traffic Surface & Base		Medium Traffic Surface & Base		Heavy Traffic Surface & Base	
	Min.	Max	Min.	Max	Min	Max.
Flow (0.25 mm)	8	18	8	16	8	14
% V	3	5	3	5	3	5
% VFB	70	80	65	78	65	75
Compaction, No. of Blows each end of specimen	35		50		75	
Stability, Kg (N)	340(3336)		544(5338)		816(8006)	
% VMA	See Table 4.8		-		-	

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 or C. V. > 300/day.

Table 3.12 Minimum % VMA for The Marshall Method

Nominal Particle Size (mm)	Minimum VMA (%)		
	Design Air Voids (%)		
	3.0	4.0	5.0
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

Marshall properties of bituminous mixes for different mix types are shown in Table 3.13

Table 3.13 Properties of Bituminous Mixes

Mix types	O. B.C %	Marshall Stability (kN)	Flow(0.25mm)	Marshall Stiffness (kN/mm)	Amount of Bitumen per Cubic Meter of Mix (kg)
A	6.2	8.7	11.9	2.9	154.0
B	6.7	10.5	10.8	3.9	153.4
C	8.1	10.1	9.8	4.1	188.3
D	8.3	9.2	9.5	3.9	175.8

From Table 3.13, it is found that the stiffness values of the mix type A, B, C and D at optimum bitumen content are 2.9, 3.9, 4.1 and 3.9 kN/m respectively. All these values are above the required value of 2.1 kN/mm. The stiffness values of mix with fresh aggregates are nearly equal to that of mix with west aggregates. The optimum bitumen content of mix types C and D are 8.1% and 8.3%, which are 1.9% and 1.6% more than that of mix types A and B This discrepancy of bitumen content is due to higher bitumen absorption characteristics of cement paste attached to the surface of the fresh aggregate.

The unit weight of mix type A, B, C and D at the optimum bitumen content are 2410, 2330, 2225 and 2210 kg/m^3 respectively. From Table 4.9 it appears that the bitumen requirement of the mixes B, C and D are 1.08, 1.31 and 1.34 times that of mix type A.

As the unit weights of the different bituminous mixes are significantly different, the comparison of the bitumen requirements on the weight basis will not depict the correct picture. So, for comparison, the calculations are made on the basis of kg of bitumen per cubic meter of the mixes. In the practical field, generally the quantity of bitumen is expressed in terms of kg or liter per cubic meter of the mix. The total surface covered on the pavement is dependent on volume and not on the weight of the mix. So, comparison of bitumen requirement in terms of volume is more appropriate. To prepare one cubic meter of the compacted mix of types A, B, C and D; 154, 153.4, 188.3 and 175.8 kg.

Conclusions

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

1. Waste concrete aggregate from white stone chips are suitable for the bituminous macadam base curse from the consideration of aggregate strength properties.

2. Marshall characteristics of bituminous mixes with waste concrete aggregate from white stone at optimum bitumen content satisfy the Marshall design criteria.
3. The ratio of the optimum bitumen requirement of the mix containing WCA from white stone chips to the mix containing black stone aggregate is 1.14 times by volume.
4. WCA from white stone chips are suitable for the construction of bituminous macadam base course for medium traffic road.

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