# Effect of Gradation and Compactive Effort on the Properties of Bituminous Mixes with Waste Concrete Aggregates

M. A. Sobhan[1], S. A. Mofiz[2] and H. M. Rasel[3]

***Abstract***-- **Waste concrete aggregate (WCA) refers to aggregates that have been used previously in cement concrete structures. After many research it had been concluded that WCA can be used in bituminous concrete. In bituminous concrete mix, there is a wide scope for varying the gradation of aggregate to obtain a good mix without affecting the durability of pavement. Bituminous concrete mixes with WCA in accordance with different gradations were studied. Behavior of bituminous concrete mixes with WCA is also investigated with two different compactive energy, one for medium traffic and another for heavy traffic. The research program concentrated on the Marshall design criteria for bituminous mixes. A dense grading with 25 mm maximum size is found to give the most satisfactory result from the stand point of stability, stiffness, deformation and voids characteristics. Test results reveal that the bituminous concrete with WCA can give satisfactory results when they are constructed using dense gradation and medium compaction.**

***Index Term***- **WCA, Bituminous concrete, Gradation of aggregate, Compactive effort, Marshall design criteria.**

## I. Introduction

Waste concrete originates from demolished concrete element that has 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 and other contaminations contribute to the lower particle density and higher porosity, variation in the quality of the WCA and the higher water absorption. In recent years the use of WCA for road construction has grown spectacularly in many countries of the world. Due to scarcity of natural fresh aggregates, WCA are used for the construction of base and sub-base courses of flexible pavements. Attempts are being made recently in different countries to construct ‘Dense Bituminous Macadam’ (DBM) using WCA.

Paranavithana [1] investigated the effect of recycled concrete aggregates on properties of asphaltic concrete. Test properties of recycled concrete aggregates asphaltic concrete compared with those of fresh aggregate asphaltic concrete.
The results found in his study are encouraging. The quality and durability of a bituminous mixes is influenced by many factors including gradation of aggregates and compaction energy. Aggregates which are well graded from coarse to fine are generally sought in high type bituminous paving mixtures.

Bissada [2] reported that, resistances to compaction of bituminous mixes are affected by mix variables (filler content, binder content and type of asphalt binder). Higher the resistance of the mix to compaction, higher it’s measured stiffness value and consequently better resistance to permanent deformation performance is expected in the pavement. Higher the percent of fines in the mix, higher is the measured stiffness of mix at a lower value of resistance to compaction.

Bose [3] reported that, permanent strain decreased with increased aggregate size in large stone mixes. Large size aggregate has led to lower binder content, high density, satisfying voids in mineral aggregate.

Effective compaction is an essential pre-requisite for obtaining the best performance bituminous mixes for greater load spreading ability and improved resistance to deformation and fatigue cracking. Material compaction includes interlocking of the aggregate framework, displacement of the binder from the aggregate particles to the air voids within the aggregate frame work and reduction in air voids within the material.

In present study, two compactive energies (50 blows for medium traffic and 75 blows for heavy traffic) and three types of aggregate gradation selected from the specifications of some renowned and well established agencies in this field were used for designing dense bituminous concrete mix. Volumetric properties and performance evaluation of the bituminous mixes using both compactive energies were analyzed.

## II. Laboratory Study and Test Results

*Materials:*

For the present study previously used cement concrete in which crushed basalt was coarse aggregates were manually crushed to desired sizes and sieved to different fractions known as waste concrete aggregate. Particles retained on 2.36 mm sieve were regarded as coarse aggregate. Fine aggregate portion of the aggregate blend (2.36 mm to 0.075 mm) was taken from coarse sand. Non-plastic sand finer than 0.075 mm sieve was used as filler material for different gradations and

[1]Associate Professor, Department of Civil Engineering, RUET, Rajshahi-6204, Bangladesh, E-mail: msobhan@yahoo.com.
[2]Professor, Department of Civil Engineering, RUET, Rajshahi-6204, Bangladesh, E-mail: samofiz@yahoo.com.
[3]Lecturer, Department of Civil Engineering, RUET, Rajshahi-6204, Bangladesh, E-mail: hmrruet@yahoo.com.

 

compaction energies. Properties of mineral matter obtained from laboratory tests, are summarized in Table I.

The binder material used for this investigation was of 85-100 penetration grade bitumen and collected from Eastern refinery, Chittagong. Routine tests as per AASHTO were performed on the bitumen sample and get the following properties: sp.gr. 1.022; penetration value (0.1mm), 98; ductility value, 100+ cm; solubility value, 99.75% and Flash & Fire point, $295^0/320^0$C.

TABLE I
PROPERTIES OF MINERAL MATTER

| Properties | Coarse aggregate | Fine aggregate | Mineral filler |
|---|---|---|---|
| Bulk specific gravity | 2.36 | 2.46 | --- |
| Apparent specific gravity | 2.76 | 2.66 | 2.63 |
| Water absorption | 5.74 | 3.10 | --- |
| L. Angeles Abrasion value, percent | 30 | --- | --- |
| Flakiness index, percent | 15 | --- | --- |
| Soundness (MgSO4, 5 cycles), percent | 18 | --- | --- |
| 10% fines value, kN | 100 | --- | --- |

*Gradations:*

Three types of aggregate gradation given in Table II ([4], [5], [6]) used in present study were designated as A-50, C-50 and S-50 when designed using 50 blows and A-75, C-75 and S-75 when designed using 75 blows respectively. The centre lines of these three gradation types are shown in Fig. 1 for comparison.

TABLE II
COMBINED GRADATION OF AGGREGATES

| Sieve size mm | Percent passing | | |
|---|---|---|---|
| | Grading-A | Grading-C | Grading-S |
| 25.00 | 100 | 100 | 100 |
| 20.00 | 90 | 90 | 97 |
| 12.50 | --- | 72 | --- |
| 10.00 | 70 | 66 | 72 |
| 4.75 | 56 | 55 | 52 |
| 2.36 | 42 | 47 | 37 |
| 0.60 | 24 | 25 | 20 |
| 0.30 | 18 | 20 | --- |
| 0.15 | 11 | 15 | --- |
| 0.075 | 4 | 7 | 5 |

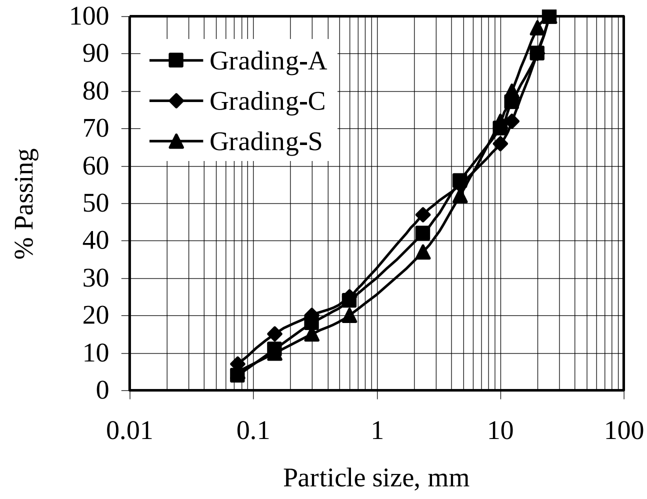


Fig. 1. Grain size distribution of three gradations

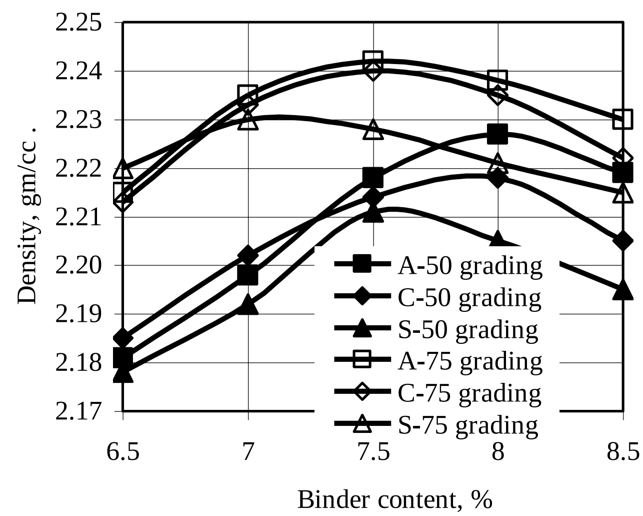


Fig. 2. Relation between density and binder content

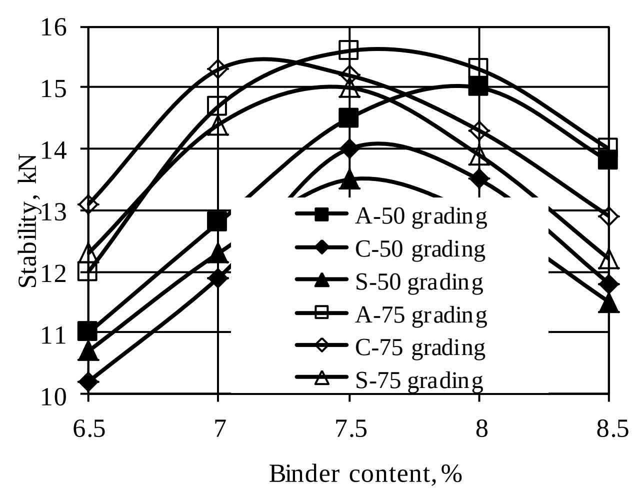


Fig. 3. Relation between stability and binder content

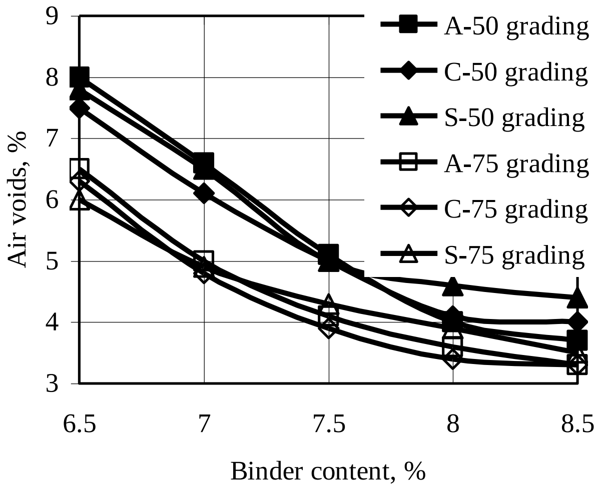


Fig. 4. Relation between air voids and binder content

*Laboratory Investigation:*

At each gradation, Marshall test specimens of 101.6 mm diameter and 63.5 mm thick were prepared as per AASHTO T245-82 by varying bitumen content to study the effect of gradation and compactive energies on the behavior of bituminous mixes. The specimens were then subjected to specific gravity, stability, flow tests as per Marshall mix design procedure. For 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, 3 and 4 respectively. At optimum bitumen content, the values of bulk density, Marshall stability, flow, percentage of voids in total mix ($V_a$, %), percentage of voids in mineral aggregates (VMA, %), percentage of voids filled with bitumen and Marshall stiffness for different gradation types using both compactive energies are shown in Table III.

TABLE III
PROPERTIES OF MIXES AT OPTIMUM BITUMEN CONTENT

| Properties | Aggregate gradation types | | | | | |
|---|---|---|---|---|---|---|
| | A-50 | C-50 | S-50 | A-75 | C-75 | S-75 |
| OBC,%(mix) | 7.9 | 8.0 | 7.8 | 7.4 | 7.3 | 7.5 |
| Bulk density, gm/cc | 2.227 | 2.218 | 2.210 | 2.242 | 2.238 | 2.228 |
| Marshall stability, kN | 15.0 | 13.5 | 13.2 | 15.6 | 15.3 | 15.0 |
| Flow(0.25 mm) | 14.2 | 14.5 | 14.0 | 15.2 | 15.6 | 15.3 |
| Air voids, % | 4.0 | 4.1 | 4.7 | 4.1 | 4.2 | 4.3 |
| VMA, % | 15.3 | 16.0 | 16.0 | 14.3 | 14.6 | 14.8 |
| VFB, % | 73.8 | 74.4 | 70.6 | 71.3 | 71.2 | 70.9 |
| Filler/Binder ratio | 0.50 | 0.88 | 0.64 | 0.53 | 0.96 | 0.67 |
| Marshall stiffness, kN/mm | 4.2 | 3.7 | 3.8 | 4.1 | 3.9 | 3.9 |

## III. ANALYSIS AND DISCUSSIONS

*Effect of Gradation:*

Results shown in Fig. 2 and 3 indicates that the densities and stabilities of the compacted specimens for all the gradations, increase initially with an increase in bitumen content, reach a maximum value and then decrease. It is also seen that the optimum bitumen contents are almost same (7.8 to 8 %) for three gradations.

The void records of the mix with different gradations reported in Fig. 4 shows that the percentage of voids in the total mix decreases with increase in bitumen content. It is seen from Table III that for three gradations the percentage of voids in total mix at optimum bitumen contents are satisfy the limits (3 to 5 %) specified by the Asphalt Institute [7].

The ratio of stability to flow gives a measure of what is termed the stiffness of the mix which can be related to tyre 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 (120 lb/.01") for the design tyre pressure of 100 psi, reported by Lees [8]. The Marshall stiffness for all the gradations shown in last row of Table III is much above the required value of 2.1 kN/mm.

From test results reported in Table III it is seen that the gradation type-A offers the best result regarding unit weight, Marshall stability, percentage of air voids in comparison to these values obtained for the other two gradation types.. This superiority of grading type-A is principally due to the well grading characteristic of this type. A close study of the test results reveals that each of the gradation types as studied satisfy the limits specified by the Asphalt Institute. Out of these three gradations, type-A offers the best values for bituminous mixes with WCA.

*Effect of Compactive Efforts:*

Results shown in Fig. 2 and 4 indicates that the density of the compacted specimens increase with increasing compaction efforts because the percentage of voids in the total mix decreases with the increase of compaction efforts.

Fig.3 shows that the Marshall stability of the compacted specimens increases with the increase of compaction efforts. Densities increases significantly with increasing compaction efforts but there are small increase in stability. Separation of cement paste from the aggregate surface occurs when specimens are prepared by higher compaction energy as a result the interlocking actions between aggregates are decreased. Also these increased fine particles in the bituminous mix affects the load resisting capacity. Excess fine particles in the bituminous mix also promote the rutting of the mix. Marshall Stiffness for compaction efforts of 50 blows in three gradations is nearly equal to that for compaction efforts of 75 blows.

## IV. CONCLUSIONS

On the basis of experimental results of this investigation the following conclusions are drawn:

1. The effects of aggregate gradation type – A, which is taken from The Asphalt Institute, on the behavior of bituminous mixes is reasonably good from the considerations of Marshall test properties. This gradation can be selected for bituminous mixes with WCA.

2. For better 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.

3. Medium traffic compaction energy can be used for design of bituminous mixes with waste concrete aggregate using dense gradation.

## REFERENCES


[1] Paranavithana S, (2006). "Effects of recycle concrete aggregates on properties of asphalt concrete." Resources, Conservation and Recycling 48 (2006), 1-12.

[2] Bissada A F, (1984). "Resistance to compaction of asphalt paving mixtures and its relationship to stiffness." ASTM STP 829, USA.

[3] Bose S, (2001). "Development of design procedure for bituminous macadam mixes for roads and highways. Highways Res Bull, No. 65, 93-102.

[4] The Asphalt Institute, (1974). "The Asphalt Handbook." College Park, Maryland, USA.

[5] The Indian Road Congress, (1988). "Recommended practice for 2 cm thick bitumen and tar carpets."

[6] Standard Specifications, (1975). Department of Transportation, State of California, Sacramento, USA.

[7] The Asphalt Institute, (1984). "Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types." Manual Series No. 2, 6th Ed. Lexington, KY.

[8] Lees G, (1973). Lecture notes, Department of Transportation and highway Engineering of B'ham, UK.



**M. A. Sobhan**

**Mohd. Abdus Sobhan** was born in Chilmari, Daulatpur in the district of Kushtia, in Bangladesh on January 1959. He obtained the degree of Bachelor of Science in Civil Engineering from Rajshahi University, Bangladesh in the year 1982 and secured First Class Fifth Position out of One Hundred and Twenty Students. Just after getting his B.Sc. Eng. Degree, he joined as a faculty member (Lecturer) in the Department of Civil Engineering, Rajshahi Engineering College, Bangladesh. He also obtained the degree of Masters of Science in Civil Engineering from Bangladesh University of Engineering & Technology, in the year 1987. His major field is Transportation Engineering. From July 2000 he is a faculty member (Associate Professor) in the Department of Civil Engineering, Rajshahi University of Engineering & Technology, Bangladesh. At present he is doing his Ph.D. research in the field of Transportation engineering at Rajshahi University of Engineering & Technology, Bangladesh.

**H. M. Rasel**

**Mr. H. M. Rasel** was born in Chapra, Kumarkhali in the district of Kushtia, in Bangladesh on December 1984. He obtained the degree of Bachelor of Science in Civil Engineering from Rajshahi University of Engineering & Technology in the year 2007 and secured First Class First Position with Honors out of One Hundred and Twelve Students. He obtained the University Gold Medal from the president of Bangladesh for the best overall performance in the four years degree of Bachelor of Science in Civil Engineering. He also got the best student awards in the year of 2004 and 2006. His major field is Civil Engineering. Just after getting his B.Sc. Eng. Degree; he joined as a faculty member (Lecturer) in the Department of Civil Engineering, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh. At present he is doing his masters research in the field of water resources engineering at Saitama University, Japan.