Journal of Civil Engineering
The Institution of Engineers, Bangladesh
Vol. CE 29, No. 1, 2001

EXPERIMENTAL BEHAVIOUR OF BITUMINOUS MACADAM MIXES WITH BRICK AGGREGATE

M. A. Sobhan[1] and M. Zakaria[2]

ABSTRACT: A laboratory investigation was carried out to study the behaviour of bituminous macadam mixes with brick aggregate. Attempts were made to study and compare the mix properties of brick aggregate bituminous macadam with those of natural aggregate bituminous machadam. Behaviour of dense graded bituminous mixes with picked brick aggregate were investigated for different compacting energies. Study on the effect of soaking period on the compressive strength, different mix type is also included. Dense graded (with 28 mm maximum size) picked brick aggregate bituminous mixes are as good as crushed stone aggregate bituminous mixes for use in the base course of bituminous pavements, from the stand point of stability, stiffness, deformation and voids characteristics. Test results reveal that bituminous macadam base course with picked brick aggregate can give satisfactory results when they are constructed using dense grading, good compaction and subjected to lower soaking period.

KEYWORDS: Brick aggregates, Bituminous macadam, Marshall stability, Compacting energies, Soaking period.

INTRODUCTION

In recent years, the use of bricks for road construction has grown spectacularly in many countries of the world, Especially in developing countries of south-east Asia, crushed bricks are being used in many civil engineering works including roads. Due to scarcity of conventional natural aggregates in Bangladesh, crushed bricks are used for the construction of base and sub base courses of flexible pavements. Good quality brick aggregate in unbound condition has found to be satisfactory from strength considerations, provided they are compacted in a dense grading applying appropriate compacting energy (Zakaria and Rauf, 1986).

Bituminous Macadam : The term "Btuminous Macadam" refers to a type of macadam pavement in which the aggregates are bounded together by bituminous material. The use of bituminous macadam for base course is increasing in developed countries. Base course is an important structural part of the flexible pavement. Natural stones are generally used as building materials. Brick an brick aggregates are in use for a long time in the construction of base and sub base courses of highway pavement in Bangladesh. Little research has been carried out on

1 Department of Civil Engineering, BIT, Rajshahi-6204, Bangladesh.
2 Department of Civil Engineering, BUET, Dhaka-1000, Bangladesh.

bituminous macadam and attempts are being made recently in Bangladesh to construct 'Dense Bitumen Macadam' (DBM) using brick aggregates. In some western countries, the trend towards dense mixes took place because of the reduced life of open textured macadams with the increased traffic in the post second world war years (Lees, 1983).

The quality and durability of a bituminous macadam is influenced by many factors including types of aggregate mix, compacting energies and water soaking periods. For road constructions, locally available aggregate having angular particles, rough texture and having affinity for bitumen should be used. Because, natural aggregate (gravel and boulder) are not available in Bangladesh.

The influence of the amount of compacting energy and soaking period (effect of water) upon the quality of bituminous macadam has been subject of active interest in many countries. Due to heavy compacting energy, brick aggregate may be crushed which reduces the stability and stiffness of bituminous mix. Presence of water in the bituminous mix causes stripping. Stripping is considered a great economic loss and engineering failure in terms of proper mix design.

Present Status of Bituminous Macadam : Limited information is found on the use of brick aggregate in hot mix hot-laid bituminous mixes. Most information in this regard is for conventional stone aggregate. However, information is available on lightweight aggregates in plant mixed bituminous pavements. Asphaltic concrete mixtures with brick aggregates were reported to be suitable from the standpoints of stability, stiffness and deformation characteristics (Hoque, 1976). No research has yet been conducted on bituminous macadam mixes with brick aggregate.

Specifications regarding grading of aggregate for bituminous macadam mixes are available for conventional natural aggregates. Separate grading requirements are usually given for separate aggregate components of the mixture: coarse aggregate, fine aggregate and filler. An overall specification is then given pertaining to the composition of the paving mixture itself, including the bituminous material. For bituminous base construction, dense aggregate mixes are specified by the Asphalt Institute (TAI: 1984), British Standard Institute (BSI: 1973) and Calfornia Division of Highway (USA: 960).

The index of retained strength of the specimen immersed in water for 24 hours are 88.2 percent and 89.4 percent for asphaltic mixes with stone aggregate and with brick aggregates, respectively (Hoque, 1976). The index of retained strength for the original asphaltic mixes (100% reclaimed materials) varied between 73-78 percent whereas that for the recycled asphaltic mixes varied between 83-93 percent, which compares favorably with that for fresh mix of 92 percent (Hoque, 1987).

Aggregates and Gradings used in the present study: In this investigation, four types of mixes were studied and these were designated as mix type A, B, C and D. Mix type-A contains Shingles, Sylhet sand and Non-plastic sand. Mix type-B contains Crushed stone Sylhet sand and Non plastic sand. Mix type-C contains Picked brick aggregate, Sylhet sand and Non-plastic sand. Mix type-D contains First class brick aggregate, Sylhet sand and Non-plastic sand. Aggregate grading for dense macadam base course (28 mm nominal size) as per B. S. 4987:1973 was found suitable for bituminous macadam mixes with brick aggregates (Sobhan, 1987). Details of this grading is shown in Table 1, which was selected for the present study.

Table 1. Aggregate Grading for 28 mm Nominal Size Dense Base-course Macadam.

Sieve size (mm)	Percent passing by weight	
	Spaces	Blend
37.50	100	100
28.00	90 – 100	95
20.00	71 – 95	83
14.00	58 – 82	70
6.30	44 – 60	52
3.35	32 – 46	39
0.30	7 – 21	14
0.075	2 – 8	5

LABORATORY STUDY AND TEST RESULTS

Materials : For the present study, Shingles, Crushed stone, Picked brick aggregates and First class brick aggregate were taken as course aggregate and sieved to different fractions, Particles retrined on 2.36 mm size were regarded as coarse aggregate. Fine aggregate portion of the aggregate blend (2.36 mm to 0.075 mm) was taken from coarse Sylhet sand. Non-plastic sand finer than 0.075 mm size was used as filler material for different mix types. Non-plastic sand was used particularly to effect economy and it can be obtained from locally available silty soil. The specific gravity and absorption characteristics of coarse aggregates, fine aggregates and filler materials are shown in Table 2. Table 3 shows the strength characteristics of coarse aggregates.
The binder mateial used for this investigation was of 85-100 penetration grade asphalt cement. Routine tests as per ASTM and AASHTO were performed on the bitumen sample and results are reported in Table 4.

Table 2. Specific Gravity and Absorption Characteristics of Coarse Aggregate, Fine Aggregate and Filler.

Properties	Coarse Aggregate			Fine Aggregate	Filler
	Crushed stone	Crushed brick Picked	First Class	Sylhet sand	Non-plastic sand
Unit weight, dense kg/m^3	1645	1210	1055	1580	1425
Unit weight, loose kg/m^3	1460	1075	930	1430	1185
Apparent Specific gravity	2.70	2.53	2.30	2.69	2.78
Bulk Specific gravity	2.65	2.00	1.73	2.39	-
Absorption of water (%)	0.92	8.95	17.82	2.76	-

Table 3. **Strength Characteristics of Experimental Aggregates.**

Properties		Shingle	Crushed stone	Crushed brick	
				Picked	First class
Los Angeles Abrassion:					
Grade A,	%	24.0	28.2	31.3*	38.5*
Grade B,	%	27.0	30.8	34.7*	40.5*
Aggregate Impact Value,	%	9.0	10.0	16.0	25.0
Aggregate Crushing Value,	%	20.0	22.0	29.0	39.0
Ten Percent Fines Value, (kN)		180	175	90	75
Crushig Strength (kN/m2)	-	-		37700	32800

* Values are determined as per modified Abrasion test for lightweight aggregates

Table 4. Properties of Bitumen

Test	Designation No.		Test
	ASTM	AASHTO	value
Penetration, 100gm, 5 sec, 25°C	D 5	T 49	95
Specific gravity, 25°C/25°C	D 70	T 228	1.013
Solubility in CCL_4, percent	D 2042	T 44	99.8
Loss on heating, 163°C, 5 hrs, percent	D 6	T 49	0.16
Ductility, 5 cm/min, 25°C, cm	D 113	T 51	100+
Ring and Ball softening point, °C	D 36	T 53	52
Cleveland open cup method	D 92	T 48	
Flash point °C			300
Fire pint °C			340

Laboratory Investigation

Marshall test specimen of 10.16 cm diameter and 6.35 cm thick were prepared to investigate the effect of the type of coarse aggregate on the behaviour of bituminous mixes. For this investigation, mix type A, B, C and D were used separately according to selected grading. The specimen were then subjected to specific gravity, stability, flow test as per Marshall mix design procedure. The variations of Marshall stability and voids in total mix with asphalt contents are shown in Fig. 1 and Fig 2, respectively, At optimum asphalt content, the values of unit weight, Marshall stability, flow value, percentage of voids in total mix and percentage of voids in mineral aggregates for different mix types are shown in Table 5.

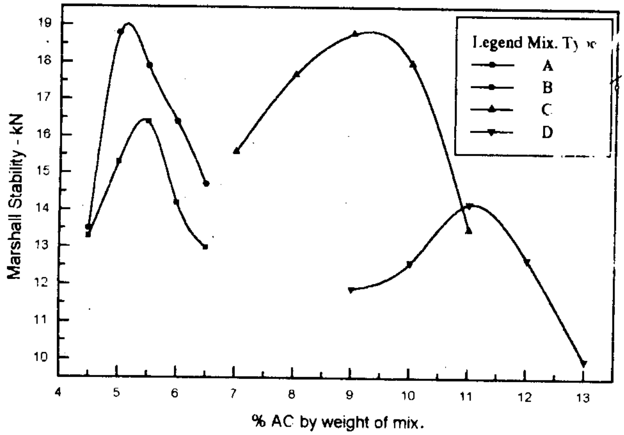

Fig 1. Relationship between Marshall stability and Asphalt content for different Aggregate mixes.

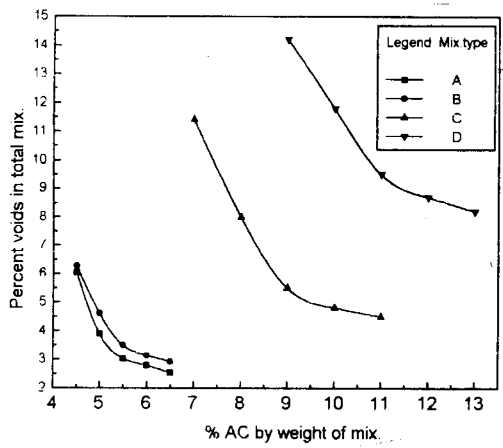

Fig 2. Relationship between percent air voids in total mix and Asphalt content for diffetent Aggregate mixes.

Table 5. Characteristics of Bituminous Mixes for Different Mix types.

Mix type	O.A.C* (%)	Max. Unit wt. Kg/m³	Max. Stability kN	Flow 0.25 mm	V%**	VMA%#	Marshall Stiffness kN/mm	Bitumen kg/m³
A	5.2	2402	16.0	11.7	3.5	15.7	5.5	124.90
B	5.3	2398	18.5	11.5	3.8	16.0	6.4	127.09
C	9.0	2147	18.8	12.4	5.5	24.6	6.1	193.23
D	12.0	1918	12.7	15.7	8.7	31.0	3.2	230.16

* Optimum Asphalt Content ** Voids in total mix # Voids in Mineral Aggregate

By different compaction energy, Marshall test specimen were prepared in order to investigate the effect of compaction on the behaviour of bituminous macadam mixes. In these specimen, the material was mix type-C according to selected grading. In this study, the percentage of asphalt content was kept constant at 9.0 percent by weight of total mix in order to achieve higher stability and specimen were compacted by 30 blows, 50 blows, 75 blows and 90 blows, respectively.

For comparison, the relationships of unit weight and stability value with different number of blows are shown in Fig. 3 and Fig 4, respectively. The characteristics of bituminous mixes for different compaction are contained in Table 6.

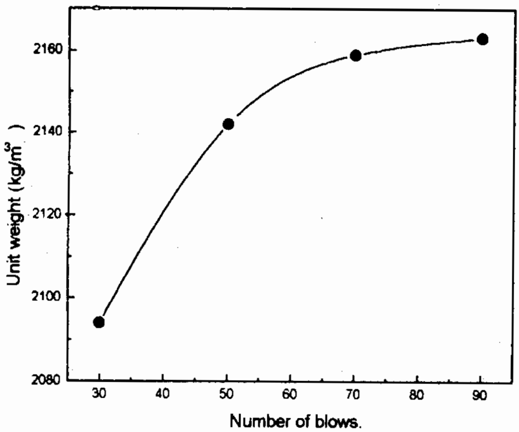

Fig 3. Relationship between Unit weight and Number of blows.

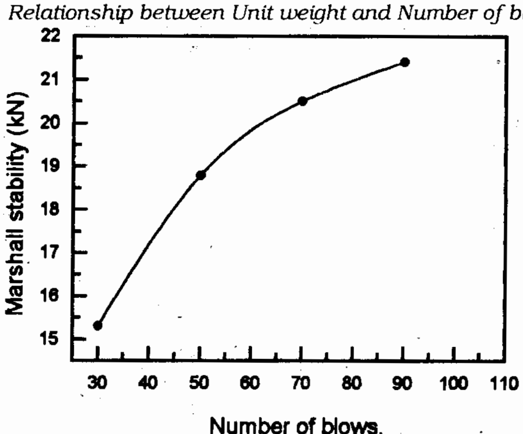

Fig 4. Relationship between Marshall stability and Number of blows.

Table 6. **Characteristics of Bituminous Mixes for Different Number of Blows**

Number of Blows	Asphalt content (%)	Unit wt. Kg/m³	Marshall Stability, kN	Flow 0.25 mm	Marshall Stiffness kN/mm
30	9.0	2094	15.3	12.7	4.8
50	9.0	2142	18.8	12.4	6.1
75	9.0	2159	20.5	13.4	6.1
90	9.0	2163	21.4	14.4	6.0

Specimen of 80 mm diameter and approximately of the same height were prepared and tested according to ASTM specification D 1074 in order to investigate the effect of water on the compressive strength of bituminous mixes for different mix types with selected grading for 2 hours soaking periods. The index of retained strength for different mix types are summarized in Table 7.

Table 7. The Index of Retained Strength for Different Mix types

Mix types	B	C	D
Compressive Strength, kN/m² (before soaking)	1810	1940	1305
Compressive Strength, kN/m² (after soaking)	1630	1765	1145
Index of Retained Strength, percent	90.05	90.98	87.74

In order to investigate the effect of soaking period on the compressive strength of bituminous mixes, the test specimen made from mix type-C with selected grading were immersed in water at 60°C for 12 hrs, 24 hrs 48 hrs and 96 hrs. and then compressive strengths were determined. Test results are given in Table 8. The relationship of index of retained strength and soaking period are shown in Fig. 5.

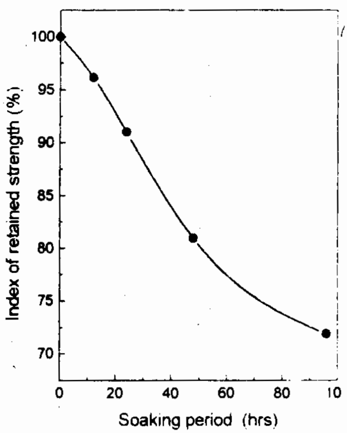

Fig 5. Relationship between Index of retained strength and Soaking period.

Table 8. Compressive Strength of Specimen (Mix type-C) for Different Soaking Periods.

Soaking Period (hrs)	00	12	24	48	96
Compressive Strength (kN/m^2)	1940	1865	1765	1570	1395
Index of Retained Strength, %	100	96.13	90.98	80.93	71.90

ANALYSIS AND DISCUSSION

Effect of Aggregate Types

Results reported in Table 5 and Fig.1 show that the unit weights and Marshall stabilities of the compacted specimen for all aggregated types, increase initially with an increase in asphalt content, reach a maximum value and then decrease. It is also seen that the optimum asphalt contents are different for different mix types. OAC for brick aggregate is about double that for stone aggregate.

The void records of the mix for different mix types show that the percentage of voids in the total mix decreases with increase in asphalt content Figure 2 represents the relationship of percentage of voids in total mix with asphalt content. It is seen from Table 5 and Figure 2 that for mix type A, B and C the percentage of voids in total mix at optimum asphalt contents are 3.5, 3.8 and 5.5, respectively. All these values satisfy the limits 3-8, specified by The Asphalt Institute (TAI-1984).

In order to prevent permanent deformation of the mix under high stress, the Marshall stiffness (ratio of stability value to flow value) should not be less than 2.1 kN/mm/(120 lb/0.01") i.e., 1.2 times the tyre pressure (assuming the design type pressure is 100 psi). It is seen from the last column of Table 5 that the Marshall stiffnesses for all mix types are much above the required value of 2.1 kN/mm.

Effect of Compactive Efforts

Results reported in Table 6 and Fig. 3 and Fig. 4 show that the unit weight and Marshall stability of the compacted specimen increased smoothly with increase of number of blows. The unit weights increase with increasing compactive efforts because the percentage of voids in the total mix decreases with increasing compactive 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 increase with increase of compactive efforts.

Effect of water

Results reported in Table 7 shows that the index of retained strength for different mix types with selected grading satisfy the limiting value of 75% specified by the ASTM (D 1075).

Effect of soaking Period

Results reported in Table 8 and Fig. 5 show that the index of retained strength decrease with the increase of soaking period. As the soaking period increases, more water is absorbed by the aggregates and this absorbed water weaken the cohesive bonds within the asphalt aggregate system. From the above results it is seen that prolonged soaking period reduces the strength of bituminous mixes.

CONCLUSION

On the basis of experimental results of this investigation, it can be concluded that bituminous macadam mix with mix type-C (in Table-1) satisfies all the requirements for 690 kPa (100 psi) type pressure. It was found that compaction energy of 75 blows can be selected for brick aggregate bituminous macadam mixes. It was also found that bituminous macadam mixes with brick aggregate retain satisfactory strength for 24 hrs. soaking period. Brick aggregate bituminous mixes were found to retain lower strength than the required 75% when soaked for more than 72 hrs.

REFERENCES

British Standard Institution (1973), Coated Macadam for Roads and other Paved Areas BS 4987, BSI, London.

Department of Public Works Division of highway (1960), Standard Specification, State of California, USA

Hoque, A. M. (1976), Behaviour of Brick-Aggregate Asphaltic Concrete for Road Pavement. M. Sc. Engineering Thesis, Civil Engineering Department, BUET, Dhaka.

Hoque, S. (1987), Behaviour of Recycled Bituminous Mixes. M. Sc. Engineering Thesis, Civil Engineering Department, BUET, Dhaka.

Less, G. (1983), Lecture Notes, Department of transportation and Highway Engineering. University of B'ham, UK.

Sobhan, M.A. (1987), Characterisation of Bituminous Macadam for Road Construction in Bangladesh. M.Sc. Engineering Thesis, Department of Civil Engineering, BUET, Dhaka.

The Asphalt Institute (1984). Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types. Manual Series No. 2 (MS-2), USA.

Zakaria. M. and Rauf, A.F.M. (1986). Behaviour of Brick Aggregates in Base and Sub-base Courses. Journal, The Institution of Engineers, Bangladesh. Vol. 14, 1986.