Performance Evaluation of Brick Chips as Coarse Aggregate on the Properties of Bituminous Mixes

H. M. Rasel[1*], M. A. Sobhan[2] and M. N. Rahman[3]

ABSTRACT

In Bangladesh there is large area where stone aggregates are not available in the vicinity of road construction. Due to excessive cost on transportation of stone aggregates, road construction becomes expensive. This leads to search of alternative materials for road construction in place of stone aggregate. The locally available over burnt brick-bats are the best alternative material against stone aggregates in bituminous mixes. The demand of natural stone aggregates can be reduced by fresh brick and waste brick from brick-kiln and demolished building respectively. But a very few researches have been carried out to investigate their suitability and limited information's is available about their performances. Thus, this paper describes the technical feasibility on application of the brick aggregates in road construction as an alternative against natural aggregate. An experimental investigation is carried out to evaluate the possible application of fresh brick and waste brick as coarse aggregate in bituminous concrete pavement design and to find out its design characteristics. The research program concentrated on the existing practices relating to use of bricks in road construction, use of crushed bricks in substitution of whole bricks and replacement of stone aggregate with crushed brick wherever economically feasible. The strength properties of coarse aggregate, fine aggregate and Marshall Design properties of bituminous mixes were performed according to the test procedure specified by AASHTO. Dense bituminous mixes using compacted brick aggregate with 50 blows is found a feasible option from the standpoint of stability, stiffness, deformations and voids characteristics.

Keywords : *Brick aggregate, bituminous mixes, stability, stiffness, crushed coarse aggregate, Marshall Design criteria.*

1. INTRODUCTION

Natural stone are not available locally in Bangladesh. Due to the scarcity of the natural stone and their high price urge the development of the locally available materials used as a coarse aggregate in bituminous mixes for the development of the road pavement. In recent years, the use of bricks for the road construction has grown spectacularly in many countries of the world. Especially in the developing countries in the south-east Asia, crushed brick are being used in many civil engineering works including road construction. The quality and durability of a bituminous mix is influenced by many factors including types of aggregate mix, compacting energies and water soaking periods.

For road construction, locally available aggregate having angular particle, rough texture and having affinity for bitumen should be used. Paranavithana, S. (2006) 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. Test results found in this study are encouraging [1]. Sobhan, M.A. (2001) reported that bituminous macadam base course with picked brick aggregate can give satisfactory result when they are constructed using dense grading, good compaction and subjected to lower soaking period [2].

Zakaria and Rauf, (1986) reported that, good quality brick aggregate in unbound condition has found to be satisfactory from strength consideration, provided they are compacted in a dense grading applying

1*. Assistant Professor, Department of Civil Engineering, Rajshahi University of Engineering and Technology, Rajshahi-6204, Bangladesh, e-mail: hmrruet@yahoo.com.

2. Associate Professor, Department of Civil Engineering, Rajshahi University of Engineering and Technology, Rajshahi-6204, Bangladesh, e-mail: msobhan@yahoo.com.

3. Undergraduate student, Department of Civil Engineering, Rajshahi University of Engineering and Technology, Rajshahi-6204, Bangladesh, e-mail: mnrahmanruet@gmail.com.

appropriate compacting energy [3]. Haque, A.M. (1976) studied and compare the properties of brick-aggregate asphaltic concrete with those of natural aggregate asphaltic concrete. He reported that, brick-aggregate asphaltic concrete mixes are suitable for use in the surface courses of asphaltic concrete pavements from the stand points of stability, stiffness and deformation characteristics but the asphalt content requirements of brick-aggregate asphaltic mixes are much higher than those of natural aggregate mixes [4]. The prime objectives in our investigation is to determine the brick as coarse aggregate in bituminous mix is suitable or not as well as to investigate and compare the characteristics of the bituminous mix using brick chips and natural stones.

2. MATERIALS AND METHODS

2.1 Coarse aggregates :

Coarse aggregates were collected from the brick-kiln and demolished building in Rajshahi city of Bangladesh. The collected samples were broken into pieces manually in 25.00 mm down grade [5]. The aggregate were tested for engineering properties related to flexible pavement. Three types of coarse aggregates were used in this study and these were fresh stone, fresh brick and waste brick aggregates. Fresh stone aggregate were collected from sylhet, Bangladesh and then broken in to 25.00 mm downgrade size. Fresh brick aggregate consists of brick chips to the sizes of 25.00 mm and less, which were collected from AKC Bricks Manufacturer Company Ltd. Natore, Bangladesh. Waste brick aggregate consists of that aggregate which were collected from demolished buildings in Rajshahi city of Bangladesh. Then aggregates were crushed to obtain 25.00 mm downgrade size [6]. Unit weight, specific gravity and water absorption of coarse aggregates were determined according to the procedure specified by AASHTO 133, AASHTO T19 and AASHTO T84 respectively. The abrasion value, soundness and ten percent fines value for different aggregates were determined by following test methods AASHTO T104 and BS 812 (part 3) respectively. All the test results are shown in Table 1.

Table 1: Properties of coarse aggregates

Properties	Coarse Aggregates		
	Fresh stone	Fresh brick	Waste brick
Bulk specific gravity	2.62	1.92	1.91
Apparent specific gravity	2.73	2.45	2.43
Absorption of water, percent	1.45	11.30	11.34
Aggregate impact value, %	10	18	14
Aggregate crushing value, %	22	30	34
Los Angeles Abrasion, %	26	38	45
Flaking index, %	17	17	18
Soundness($MgSO_4$,5 cycle), %	6	24	27
Ten percent fines value, kN	190	100	50

2.2 Fine aggregates and filler :

Fine aggregate portion of the aggregate passing through 2.36 mm and retained on 0.075 mm sieves were taken from coarser sand. Non-plastic sand finer than 0.075 mm sieve taken as mineral filler in different mix types [7], [8]. Specific gravity and water absorption of fine aggregates were determined according to the procedure specified by AASHTO T19 and AASHTO T84 respectively. The Unit weights of filler were ascertained by following the test method specified by AASHTO T133. Test results are given in following Table 2.

2.3 Gradation of aggregates :

To investigate the behavior of bituminous mixes with different aggregates, continuously graded bituminous macadam is essential. In the continuously graded bituminous macadam, the aggregate blend is designed to be evenly graded from coarse to fine so as to arrive at a dense mix with a controlled void content, hence producing a stable and durable paving [5], [9]. The gradation of aggregates in bituminous mixes of the present investigation is given in the following Table 3.

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Table 2: Properties of fine aggregate and filler

Properties	Fine Aggregate	Mineral Filler
Unit weight, dense, (kg/m^3)	1138.60	1200
Unit weight, loose, (kg/m^3)	1026.32	990
Bulk specific gravity	2.33	…
Apparent specific gravity	2.80	1.87
Absorption of water, percent	7.23	…

Table 3: Gradation of aggregates in bituminous mixes

Sieve mm	% passing by wt		Cumulative retain %	Individual retain %	% of C.A, F.A & M.F	Individual wt. for 1200 gm
	Specification	Blend				
25.0	100	100	00	00	C.A = 58%	00
19.0	80-100	90	10	10		120
9.50	60-80	70	30	20		240
4.75	48-65	56	44	14		168
2.36	35-50	42	58	14		168
0.60	19-30	25	75	17	F.A = 38%	204
0.30	13-23	18	82	07		84
0.15	7-15	11	89	07		84
0.075	0-8	4	96	07		84
					M.F = 4%	48

C.A.= Coarse Aggregate, F.A.= Fine Aggregate & M.F.= Mineral Filler.

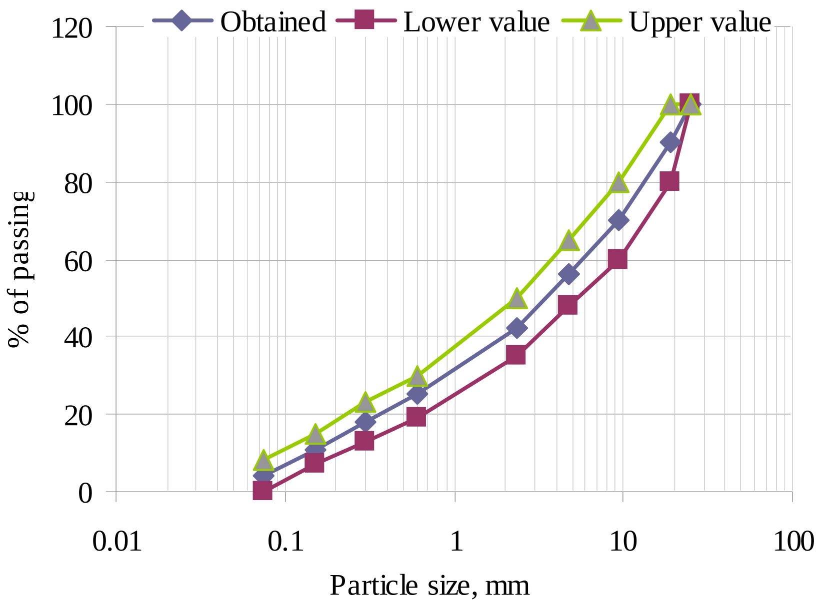

Figure 1: Grain size distribution of aggregate gradation

2.4 Bituminous materials :

The binder material used for this investigation was of 80-100 penetration grade bitumen and collected from Eastern Refinery, Bangladesh. Routine test as per AASHTO were performed on the bitumen sample and get the following properties: specific gravity, 1.022; penetration value (0.1mm), 84; ductility value, 100^{+} cm; solubility value, 99.85% and flash & fire point, 290°C/310°C.

2.5 Preparation of Marshall specimen :

To investigate the Marshall stability of bituminous mixes with different aggregates, 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 1200 gms of aggregates were required to prepare one specimen of 101.6 mm (4 inch) diameter and 63.5 mm (2.5 inch) thick for different aggregates respectively. Three specimens were prepared for each bitumen content and at least 5 bitumen contents were used with increments of 1.0 percent for different aggregates by weight of total mix. Initially 10 percent bitumen was present in bituminous mix. Specimens were prepared with increments of 1.0 percent 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 sizes 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 dry 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 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 101.6 mm 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 4.5 kg 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 (100 psi) 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 safe 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 minutes and extruded from 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 [10], [11].

2.6 Testing procedure :

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

2.6.1 Determination of the bulk specific gravity*:* The bulk specific gravity test was performed as soon as the freshly compacted specimens have cooled to room temperature. The test was performed according to AASHTO (1983) T 166, ASTM (1979) D 2726 bulk specific gravity of compacted bituminous mixtures using standard dry specimens.

2.6.2 Determination of Marshall Stability and flow value : 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 dried 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 was 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 (4.75 kg) of the proving ring gave the load at failure. This value was then adjusted for specimen thickness/volume and corrected stability was obtained. The flow meter reading at the maximum reading of the load dial was recorded and expressed in units of 0.25 mm (1/100 inch) [10], [11].

2.6.3 Determination of optimum bitumen content: In this investigation for the bituminous mixes of all types of aggregate, a set of six curve were drawn showing the relationships of unit weight, Marshall stability, flow value, percentage of voids in total mix, percentage of voids in mineral aggregates and percentage of voids filled with bitumen with percentage of bitumen content. Optimum bitumen content (OBC) for compacted bituminous mixes was calculated from the equation (1) as shown below [5], [12].

$$OBC\ (\%) = \frac{BC\ for\ max.unit\ wt. + BC\ for\ max.\ stability + BC\ for\ max.\ 4\%\ air\ voids}{3} \qquad (1)$$

3. RESULTS AND DISCUSSION

Results shown in Figures 2 and 3 indicates that the unit wt. and stabilities of the compacted specimens for all the mix types, increase initially with an increase in bitumen content, reach a maximum value and then decrease. With the increment of bitumen content, the better compaction was done as a result the density and stability increased. For further increment of bitumen, the thickness of the bituminous film increased as a result the density and stability decreased. From the Figure 2 and Table 4, Marshall stability are 14, 12.5 and 12.3 for fresh stone, fresh brick and waste brick respectively which are greater than the minimum value of Marshall stability according to the Wright, P. H. (1996) [13] shown in Table 5.

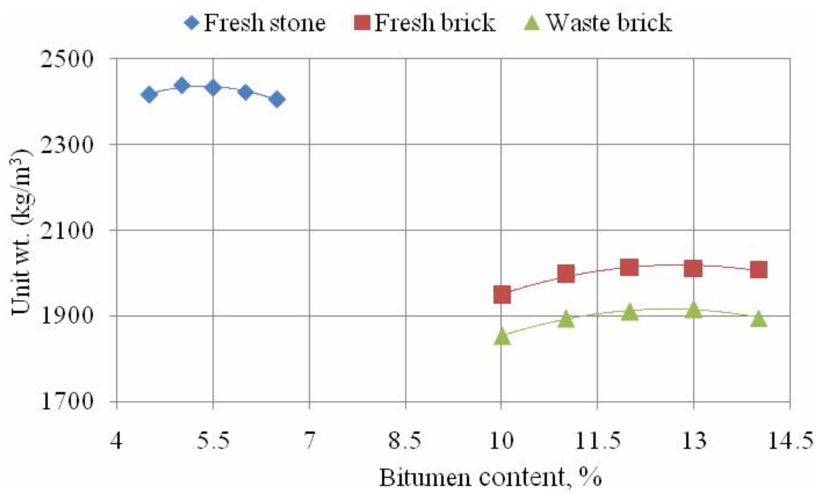

Figure 2: Relationships between unit wt. and bitumen content for different aggregate types

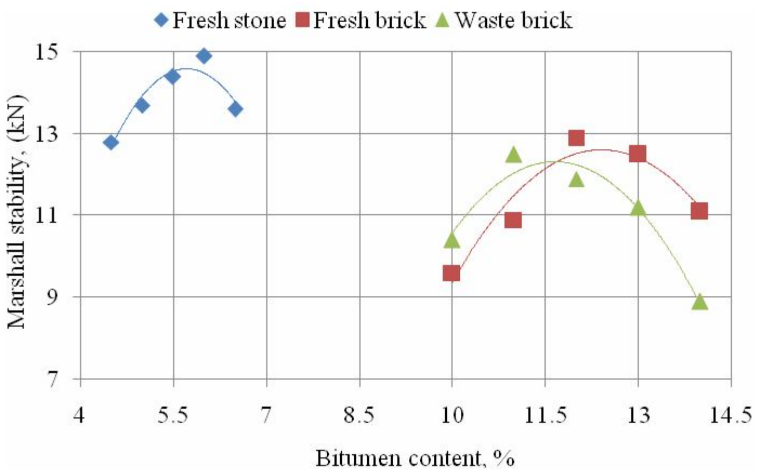

Figure 3: Relationships between Marshall Stability and bitumen content for different aggregate types

The void records of the mix with different aggregates reported in Figure 4 shows that the percentage of void in the total mix decreases with increase in bitumen content. This is due to the increase in bitumen content the air voids in the mix decreases and slowly filled with bitumen. In case of waste aggregates, air voids is less than the fresh aggregate this is because the waste aggregates contain cement paste around it so that the voids in waste aggregate filled with cement paste. It is seem from Table 4 that the percentage of voids in total mix at optimum bitumen content for all the mix types are satisfy the limiting value (3 to 5%) specified by The Asphalt Institute (1984) [14] shown in Table 5.

Figure 5 shows that the flow value increases with increase in bitumen content. With the increment of bitumen in all types of mix, the deformation of the specimen increased. For interpretation of Marshall Test results, Lees (1983) considered the stiffness (the ratio of stability to flow) of the mix which can be related to tyre pressure [15]. 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/ 0.01inch) for the design tyre pressure of 100 psi. From Table 4, it is seen the Marshall stiffness are above required value 2.1 kN/mm.

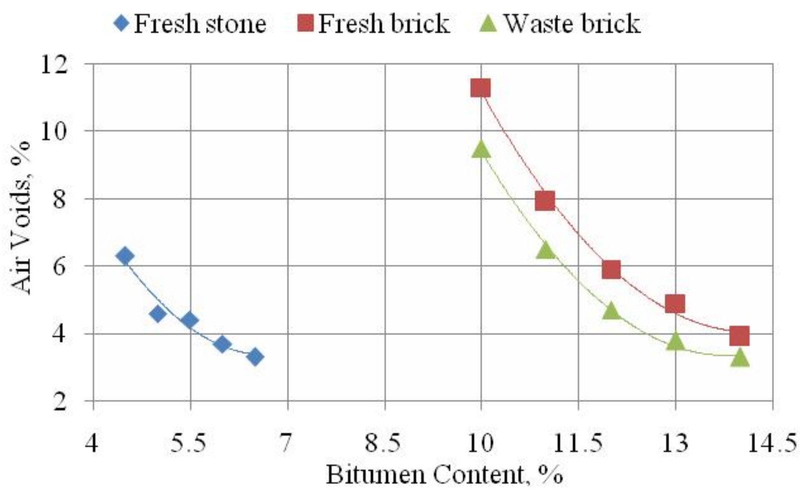

Figure 4: Relationships between percent air voids and bitumen content for different aggregate types

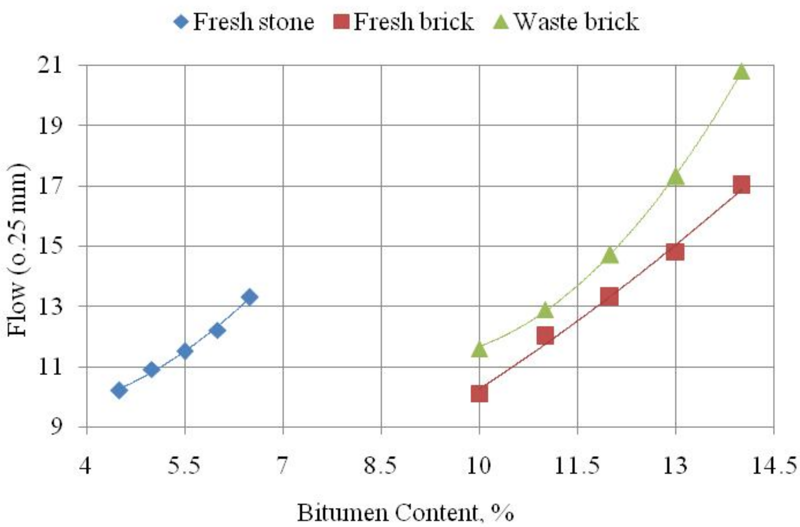

Figure 5: Relationships between flow and bitumen content for different aggregate types

From the Figure 6 it is seen that, the percentage of voids filled with bitumen increases with the increment of bitumen content for different aggregates. Table 4 shows that, %VFB at optimum bitumen content for fresh stone, fresh brick and waste brick aggregates are 68%, 72% and 73% respectively. All these values satisfy the limiting value specified by the Asphalt Institute shown in Table 5 [14].

From the Figure 7 it is shown that the %VMA initially decreases with the increase in bitumen content but after attains certain minimum value it is increases for further increase in bitumen content for all types of mixes. Table 4 shows that the % VMA at optimum bitumen content is 13%, 16.9% and 16.9% for fresh stone, fresh brick and waste brick aggregates. All these values are greater than the minimum value of 12% as shown in Table 6.

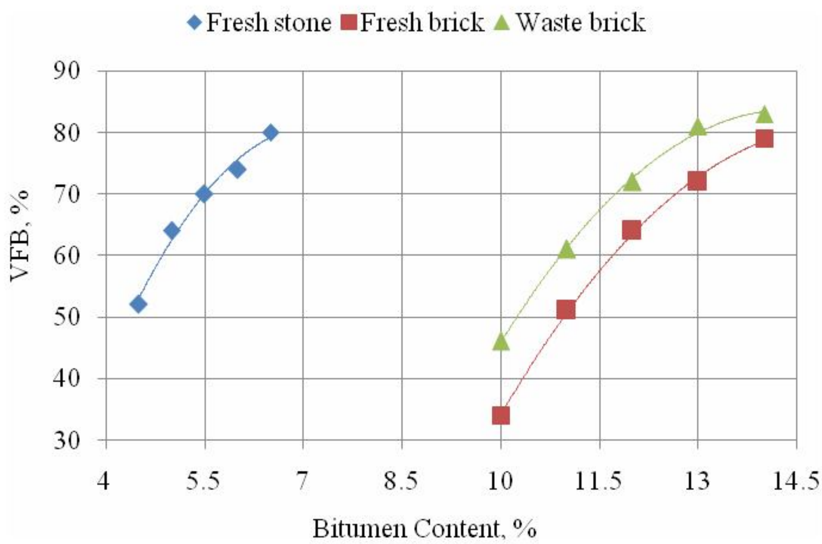

Figure 6: Relationships between percentage of voids filled with bitumen (%VFB) and bitumen content for different aggregate types

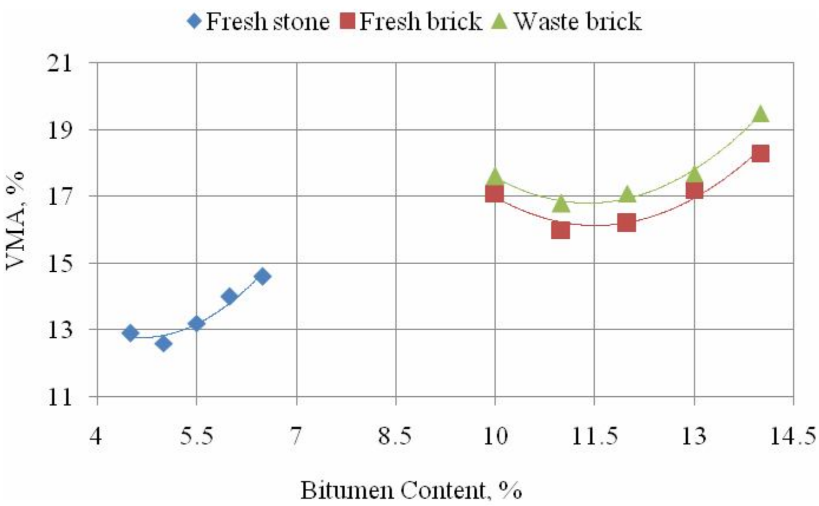

Figure 7: Relationships between percentage of voids in mineral aggregates (%VMA) and bitumen content for different aggregate types

Table 4: Comparison of the Marshall characteristics among various types of aggregates

Types of aggregates	OBC (%)	Unit wt. (kg/m^3)	Marshall stability, kN	Flow (0.25 mm)	% V_a	% VMA	% VFB	Marshall stiffness (kN/mm)
Fresh stone	5.4	2430	14	11.2	3.8	13	68	5.00
Fresh brick	13	2017	12.5	15	4.6	16.9	72	3.33
Waste brick	12	1910	12.3	14.8	4.8	16.9	73	3.32

Table 5: Design criteria for the Marshall method (Wright, P. H. 1996) [13], [14]

Table 6: Minimum %VMA for the Marshall method [14]

Marshall method mix criteria	Light traffic surface & base		Medium traffic surface & base		Heavy traffic surface & base	
	Min.	Max.	Min.	Max.	Min.	Max.
Compaction no. of blows each end of specimen	35		50		75	
Stability, kg (N)	340 (3336)		544 (5338)		816 (8006)	
Flow (0.25 mm)	8	18	8	16	8	14
%V_a	3	5	3	5	3	5
%VFB	70	80	65	78	65	75

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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

Figure 8 shows that the comparison of cost (In BDT) for $1m^3$ various coarse at different divisions of Bangladesh. From the figure, it is shown that the difference of rate of fresh stone aggregate is too high for the transport cost at different part of Bangladesh. On the other hand fresh brick and waste brick aggregate are less costly than stone aggregate because they are locally available. So, it is economical to use fresh brick and waste brick as coarse aggregate in medium and low traffic roads.

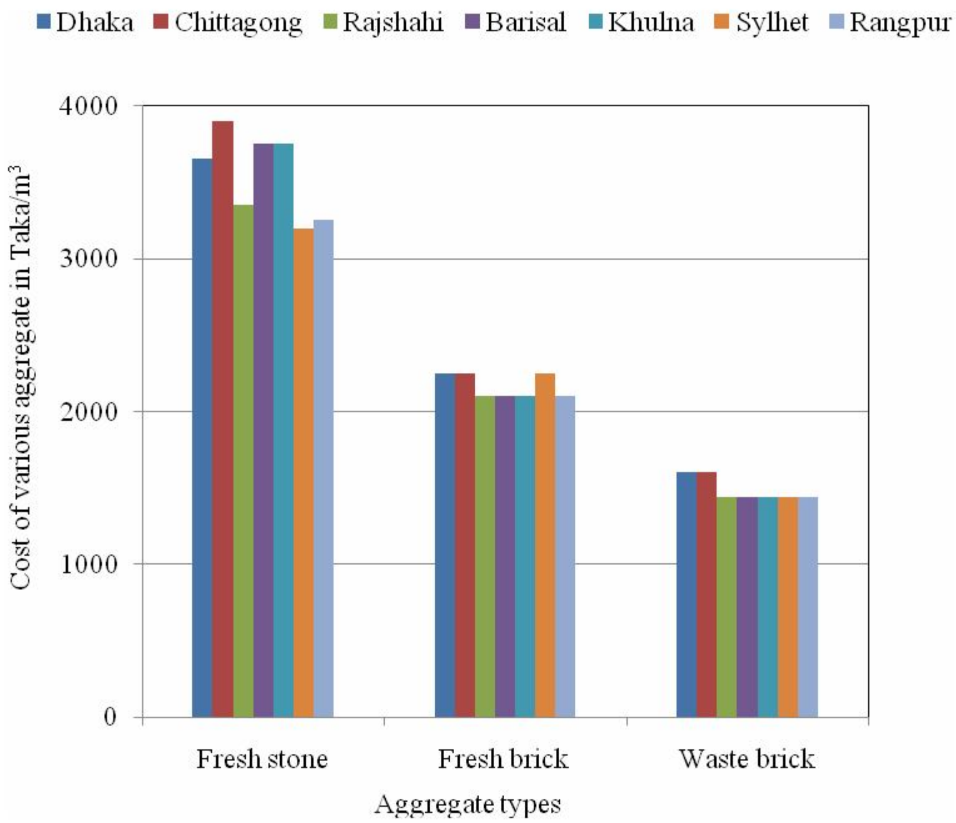

Figure 8: Comparison of cost (In BDT) per cubic meter of coarse aggregates.

4. CONCLUSIONS

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

- The use of fresh brick and waste brick as a coarse aggregate in bituminous mixes is a feasible option.
- Fresh brick and waste brick are suitable for the bituminous mixes as coarse aggregate from the consideration of aggregate properties.
- Bituminous mixes with fresh brick aggregates and waste brick aggregates both satisfy all the requirement of a bituminous binder course for 690 kPa (100 psi) tyre pressure having higher optimum bitumen content (13% and 12% respectively).
- The use of fresh and waste brick in the bituminous mixes required higher amount of bitumen binder compared to the conventional mix because of the high porosity and roughness of brick aggregates.
- Bituminous mixes using fresh and waste brick required less energy for mixing, transporting and laying bituminous concrete due to the lighter in weight compared to the conventional bituminous mix.

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