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Effect of aggregate shape on the strength of Bituminous Mixes

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Abstract: Bangladesh is a developing country and its road network demands an ever-increasing expansion. Roads in Bangladesh are usually constructed of flexible pavement. The type and quality of aggregates are of prime importance on the design strength of the pavement. A laboratory investigation was made to evaluate the effect of the shape of aggregates as manifested by flakiness and elongation indices on the design strength of the bituminous mixes for flexible pavement construction. Test results revealed that both stability and flow values increased with the decrement of flaky and elongated particles for the aggregate matrix. At a temperature of 3000F and when no elongated or flaky particles were used in the mix, the stability value was 340 kN and the flow value was 4.8. When temperature was increased to 3200F, stability also increased by 18.5% but the flow reduced to 4.4. Stability value reached as high as 598 kN when flakiness index was 34% with no elongated particles in the mix.

Keywords: *Flakiness index; Elongation index; Stability; Flow; Strength*.

1. Introduction:

Economic development of a country is indicated by the development of the communication infrastructure of the country. The present demand of the quick mobility of human and materials depends on the increase of motor vehicles. In Bangladesh, about 36% of the current total road motor vehicles of all types were added just in the last four years at an accelerating annual rate (BRTA, 2013). Consequently, the continual increase of pavement construction and reconstruction is a general need. In Bangladesh, the traffic phenomenon has gained tremendous importance of late. From only 3,600 KM of paved road at the pre-independence 1971 throughout Bangladesh, it is now about 72,000 KM (LGED, 2013). If only the capital city is considered, an area of about 1463 sq. KM is seen to be consisting of 1700 KM of paved roads. It is estimated that the space occupied by paved roads in Dhaka is about 9% of the total area whereas it is ideal to have about 25% of the area covered by the total street network. As a result, traffic jams and accidents happen frequently on the city roads. They are supposedly associated with the meagre space availability for more than 643,000 motorized vehicles in conjunction with over one million rickshaws apart from other non-motorized vehicles of various types (Alam, 2011;BRTA, 2011). A survey conducted for the road accidents showed that more than 25,000 killed and another 12,000 injured apart from huge property damage and social disturbances in the last decade (BRTA, 2008). One of the factors leading to the occurrences of accidents was poor pavement conditions. Maintenance of pavements devoured a huge amount from the national exchequer per year due to surface defects, cracks, deformation, and disintegration. In addition, Bangladesh is not gifted with all the materials required for its infrastructure development; sometimes materials need to be imported from abroad. Therefore, a compromising balance must be made between the selection of materials and their mix design to ensure maximum durability and minimum recurring expenditure, keeping avenues for stage construction as the situation demands. There are still over 218,000 KM of earthen road connected to the paved road network throughout Bangladesh, are expected to be paved in the near future in phase construction (LGED, 2013). Thus the tremendous necessity for pavement construction and renovation in the city in particular as well as throughout the country in general cannot be overemphasized. Construction of flexible pavements is preferred in Bangladesh because of their low initial cost and adaptability for stage construction. A flexible pavement is a layered structure that receives the axle loads directly and transmits the same to the underneath layers without being overstressed. The transfer of load is influenced by the aggregate interlock, particle friction and cohesion for stability (Ioannides and Korovesis, 1990). The aggregates not only support the main stresses occurring within the pavement but also resist wear due to abrasion by traffic and weathering effects as well. The strength and performance of the pavement layer is directly related to the pavement structure which has direct bearing with the inherent properties and qualities of the individual particles and on the means by which they are held together i.e. by interlocking, by cementitious binder, or by both. The coarse aggregates for asphalt concrete should be hard, durable and angular. They are generally crushed rock and gravel. The strength of an aggregate and its resistance to abrasive wear and to polishing are determined largely by the properties of the parent rock from which the aggregate is derived. On the other hand, the overall strength of the compacted bituminous concrete and aggregate-bitumen bond would largely influenced by the aggregate shape and surface texture. The ratio of the least or greatest dimension of an aggregate to its mean size introduces two indices, namely flakiness and elongation, which is an important aspect to determine the stability of a bituminous mix. In order to produce a better mix considering the materials availability and environmental effects, this paper studies the effect of elongation and flakiness indices of the coarse aggregates on the strength of bituminous mixes.

2. Experimental program:

2.1 Materials and mix design:

Aggregates from natural stone may have various shapes after crushing in the stone crusher. The particle shape of aggregates is determined by the percentages of flaky and elongated particles that it contains. Flaky particles are defined as those particles whose least dimension is less that 0.6 of their mean size while elongated particles are those whose greatest dimension is more than 1.8 times their mean size. Thickness gauge and length gauge conforming BS812 were used to determine the flakiness and elongation indices of coarse aggregates. According to the British Standard (BS), single sized road stones and chippings require that maximum permissible flakiness index for 40 and 50 mm single sized stone does not exceed 40 and maximum permissible flakiness index for 10, 14, 20 and 28 mm single sized stone does not exceed 35. The maximum size of coarse aggregate used was 20 mm. The basic properties of the coarse aggregate are shown in Table 1.

***Table 1**: Basic properties of coarse aggregate*

Type of test	Values
Flakiness index	34
Elongation index	27
Aggregate crushing value	36%
Aggregate impact value	25%
10% fines value	250 kN
Los Angeles abrasion	16%

Penetration grade bitumen 80/100 is normally used in Bangladesh for pavement construction, which conforms to the requirements of AASHTO M20-70 penetration grade asphalt cement grade 60-70 (AASHTO, 1970). The basic properties of the bitumen are shown in Table 2.

***Table 2**: Basic properties of bitumen*

Type of test	Values
Penetration	80-100
Flash point	290^0C
Fire point	315^0C
Specific gravity	1.02
Solubility	99.50%
Loss on heating	0.57
Ductility	100 cm

An optimum bitumen content was determined from five trial batches of bituminous mixes having varying bitumen content between 5 and 7%. The optimum bitumen content was then used to prepare six batches of bituminous mixes with varying contents of flaky and elongated coarse aggregates. Three types flaky aggregate content namely 0%, 15% and 34% and three types of elongated aggregate content of 0%, 17% and 27% used to modify and adjust the content of aggregate shape in the mixture gradation. Filler materials of 3% were used in all mixes. The mixture combinations are shown in Table 3.

2.2 Sample preparation and testing procedure:

Correct design and physical testing of bituminous mixtures is important to construct sound, durable and economic pavements and to ensure minimum maintenance during the design life. A good bituminous paving mix should exhibit stability, durability, workability and skid resistance besides economy. Temperature of the mix, mixing procedure, compaction and physical testing all contribute towards the design of a suitable mixture. The Marshall method of mix design was developed by Bruce Marshall in 1948 and subsequently improved by the US corps of engineers (The Asphalt Institute, 1988). The Marshal method uses standard cylindrical test specimens of diameter 102 mm and 64 mm high. The specimens were prepared following a specified procedure for heating, mixing and compaction of the asphalt-aggregate mixtures. The two principal features of the Marshal method of mix design were a density-voids analysis and a stability-flow test of the compacted test specimens. The latter was followed in this research. The stability of the test was determined from the maximum load resistance in Newtons (N) that the standard test specimen would develop at 60^0C when tested. The flow was the total movement or strain, in units of 0.25 mm occurring in the specimen between no load and maximum load during the stability test.

***Table 3:** Aggregate combinations for bituminous mixes*

Batch	Flakiness Index (%)	Elongation Index (%)
M1	0	0
M2	0	27
M3	15	27
M4	34	0
M5	34	17
M6	34	27

The load was applied to the specimen at constant rate of deformation until failure occurred. The point of failure was defined by the maximum load reading obtained. The total force (in N) required to produce failure of the specimen at 60^0C was recorded as its Marshall stability value. While stability was in progress, the flow meter was held firmly in position over guide rod and removed as the load began to decrease; reading was taken and recorded. That reading was the flow value for the specimen expressed in units of 0.25 mm. Two properties were determined – the ultimate load before failure (i.e. Marshall stability) and the amount of deformation at the ultimate load (Marshall flow). The ratio of stability to flow was denoted as the Marshall quotient, which gave a measure of the materials' resistance to permanent deformation.

3. Results and discussions:

3.1 Optimum bitumen content:

Relationship of Marshall stability and flow with five asphalt content of 5.0, 5.5, 6.0, 6.5 and 7.0% are shown in Figure 1. Stability values increased with the increase of asphalt content up to 6.0% and decreased thereafter, while flow of the mixture increased continuously with the increase of asphalt content as expected. Figure 2 shows the relationship of unit weight and amount of void (%) with varying asphalt content. Both the void (%) in total mix and in mineral aggregate decreased with the increase of asphalt content, however, the unit weight of the mix reached its maximum for an asphalt content of 6.5%. Thus the optimum bitumen content was the average of 6.0 and 6.5 i.e. 6.25. The parameters at optimum bitumen content were Marshall stability = 407.5 kN, flow = 0.045 in, unit weight = 2.27 gm/cc, void in total mix = 3.47% and void in mineral aggregates = 21.0%. The objective when designing continuously graded mixes is to achieve a dense mix of high stability but with sufficient voids between aggregates particles ensuring that sufficient bitumen is added to achieve flexibility, durability and workability without sacrificing resistance to permanent deformation.

3.2 Influence of elongation index

Stability-flow relationship with varying elongation index is shown in Figure 3. Both stability and flow value decreased with the increase in elongation index. The particle was said to be elongated when its dimension is greater than 1.8 times the mean size. With higher elongation index of the aggregates the total contact surface area between aggregate and binder got reduced and amount of total void in the mix would be increased, which adversely affected the stability of mix. When there were no elongated particles in mix, the Marshall stability was 589 kN for a fixed flakiness index of 34% at a temperature of 300^0F. With a 17% increase in the elongation index the stability got reduced by 12.5%. However, the rate of strength reduction significantly slowed down with further increase in the elongation index. Only a less than 1% more reduction in stability was observed with further increase of elongation index by 10% i.e. at total of 27%.

Under traffic loading the layers of a flexible pavement structure are subjected to continuous flexing. The magnitude of strain was likely to depend on the overall stiffness and nature of the pavement construction. There are two categories of stiffness namely elastic stiffness under conditions of low temperature or short times of loading and viscous stiffness at high temperatures or long times of loadings. The former is used to calculate stains in the structure and the latter is used to assess the resistance of the materials to deformation. To determine the permanent deformation resistance of a bituminous mix, its response at high temperatures or long loading time was analyzed. Marshall stability at higher mixing temperature (320^0F) was decreased linearly with the increase in elongation index. They were about 3% lower than that at temperatures of 320^0F. It was reported that when the stiffness of bitumen was less than $5x10^6$ Pa, the mix behavior was much more complex than that in the elastic zone (Ehrola and Turunen, 1995).

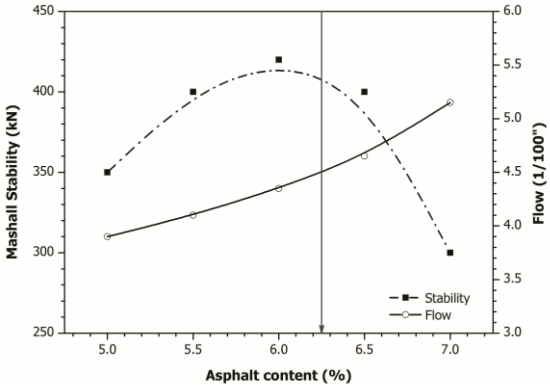

***Figure 1**: Optimum bitumen content from Stability-flow relationship*

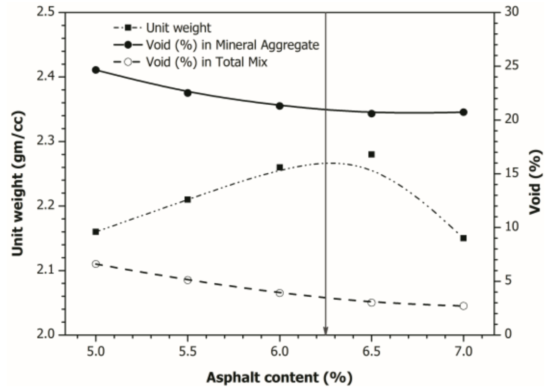

***Figure 2:** Optimum bitumen content from unit weight and void ratio (%)*

Figure 3 shows that the strain values (or Marshall flow in other words) showed negligible changes with the increase in elongation index up to 17%, however, decreased about 18% with further increase of the elongated particles.

3.3 Influence of flakiness index:

The variation of Marshall stability and flow for varying flakiness index with a fixed elongation index of 27% is shown in Figure 4. With the increase in flakiness index Marshall stability of the compact increased steadily. The particle was said to be flaky when its least dimension or thickness was less than 0.6 times the mean thickness. When there was no flaky or elongated particles in the mix the stability values were 438 kN at temperatures of 300^0F. When the flakiness index was increased the total contact surface area also increased and amount of total void in the mix would be reduced. A combination of 34% flakiness index and 27% elongation index, as was the natural properties of the coarse aggregates under study (Table 1), yielded a stability value of 511 kN at 300^0F.

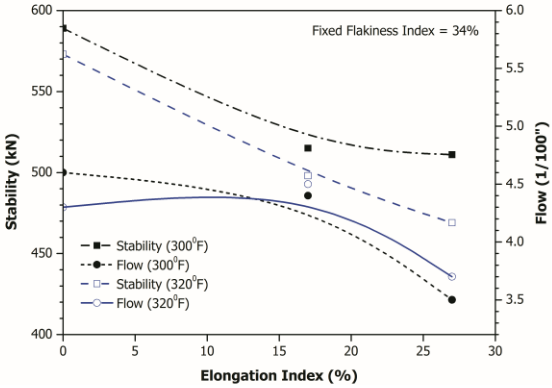

Figure 3: *Marshall stability and flow for varying elongation index (%)*

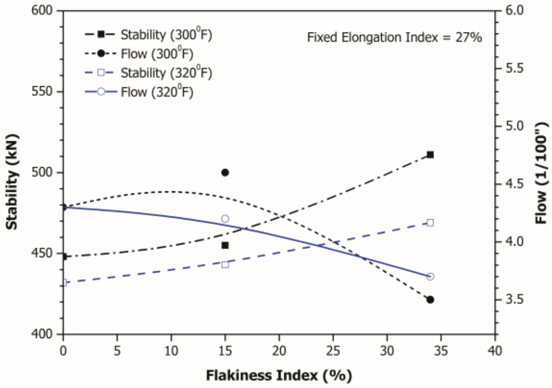

Figure 4*: Marshall stability and flow for varying flakiness index (%)*

Although it was about 13% less than that produced by the mix with no elongated particles (Figure 3), mixes with abnormally high values of Marshall stability and abnormally low flow values are often less desirable because pavements of such mixes tend to be more rigid or brittle and may crack under heavy volumes of traffic. This is particularly true where base and subgrade deflections are such as to permit moderate to relatively high deflections of the pavement. Stability at 320^0F increased linearly with the increase in flakiness index and was consistently 3% lower than that for 300^0F up to a flakiness index of 15%. It reached 469 kN at a flakiness index of 34%.

Flow value of the compact increased slightly with increase in the flakiness index of 15% but started to decrease afterwards. As the flow value increased the mix became unstable, but when the flakiness index increased further, the flow value decreased, which was an indication of a stable mix. However, when more flaky particles were present in the mix, the specimen was initially vertically deformed to a certain amount during the blowing (compaction) period. Thus it is obvious that a certain amount of flaky particles were needed to have a stable mix.

4. Conclusion:

This paper studied the effect of flaky and elongated coarse aggregates on the strength of bituminous mixes for flexible pavement in terms of Marshall stability and flow value. The bitumen content was kept same with 3% filler in all mixes, while temperature was varied between 300 and 320^0F. The following conclusions are drawn:

- Highest stability of 589 kN was obtained from a combination of 0% elongation index with 34% flakiness index, while lowest flow of 0.035 in. was obtained from a combination of 27% elongation index with 34% flakiness index.
- Increasing elongation indices reduced the stability value up to about 13% for a fixed flakiness index.
- Marshall stability was found to increase up to about 14% with the increase in flakiness indices by 34% for a fixed elongation index.
- Elongated particles caused more instability than that by the flaky particles in terms of Marshall flow.
- A flakiness index of higher than 15% deemed necessary to have a stable bituminous mix.
- At higher mixing temperature (320^0F) didn't affect the flow value but reduced the stability 3-8%.

References:

[1] AASHTO (1970). "Standard Specification for Penetration-Graded Asphalt Cement", AASHTO M20-70, American Association of State Highway and Transportation Officials, Washington, DC.

[2] Alam, H., "Rickshaws clog city", in: The Daily Star, Dhaka, Bangladesh, March 29, 2011, http://archive.thedailystar.net/newDesign/news-details.php?nid=179563.

[3] BRTA (2008). "National Road Traffic Accident Report", Bangladesh Road Transport Authority, Dhaka, Bangladesh, http://www.brta.gov.bd/index.php/road-safety.

[4] BRTA (2011). "Registered Vehicles in Dhaka", Bangladesh Road Transport Authority, Dhaka, Bangladesh, http://www.brta.gov.bd/media/com_acymailing/upload/motor_vehicles_dk_06_09_11.pdf.

[5] BRTA (2013). "Registered Vehicles in Bangladesh: 2009 to 2013", Bangladesh Road Transport Authority, Dhaka, Bangladesh.

[6] Ehrola, E. and Turunen, R. (1995). Bituminous pavements: materials design and evaluation. University of Oulu, Oulu, Finland.

[7] Ioannides, A.M. and Korovesis, G.T. (1990) "Aggregate interlock: a pure-shear load transfer mechanism", in: Design and evaluation of rigid and flexible pavements, Transportation Research Record, Transportation Research Board, Washington, DC 20001 USA, pp. 14-24.

[8] LGED (2013). "Road Database", Local Government Engineering Department, Dhaka, Bangladesh, http://www.lged.gov.bd/ViewRoad2.aspx.

[9] The Asphalt Institute (1988). "Mix design methods for asphalt concrete and other hot-mix types", Manual Series No. 2 (MS-2), The Asphalt Institute.