EFFECTS OF AGGREGATE SHAPE ON THE STRENGTH OF BITUMINOUS MIXES.

A Project Report

by

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ABSTRACT

In Bangladesh, roads are usually constructed of flexible pavement. The most important factors influencing the design of flexible pavements for given traffic and environmental conditions is the type and quality of aggregates used and also the properties of the bitumen incorporated in the bituminous mixes. To ensure satisfactory and desired performance of the pavement it is, therefore, an utmost necessity to have a prior knowledge about the selected aggregates and bitumen properties used in the mix. Since Bangladesh is a developing country and its road network demands an everincreasing expansion, a study was made to evaluate the effects of the shape of aggregates as manifested in flakiness and elongation indices used in conjunction with the bitumen generally used in roads in Bangladesh to achieve a durable and functional bituminous mix in pavement constructions. In the present study, a systematic laboratory investigation was made to evaluate the effects of flakiness and elongation indices of available aggregates in order to examine their influence on the properties of bituminous mixes and also to examine the suitability of using them in road construction. Aggregates with varying shapes in respect of flakiness and elongation were used

with a commonly used grade of bitumen and their effects on the overall performance of the mixes in terms of stability and flow values were determined.

Analysis of data gleaned from laboratory tests tends to indicate that both stability and flow values increase with the decrement of flaky and elongated particles from the aggregate matrix. At a mix temperature of 300° F and when no elongated and flaky particles were used in the mix, the stability value was around 1800 pounds and the flow value was around 19. The highest value (around 3150 pounds) of stability was found when flakiness index of the coarse aggregate was 35% with no elongated particles in mix. The corresponding flow value was around 18. At a mix temperature of 320° F, the stability increased by 18.5% to nearly 2140 pounds and flow values decreased to around 17 when no flaky and elongated coarse aggregate was used in the mix.

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CHAPTER 1

INTRODUCTION

1.1 General

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, at present about 7% annual rate of increase is estimated (Source: Bangladesh Road Transport Authority) in respect of all types of road motor transports. Consequently, the continual increase of pavement construction and reconstruction is a general need. In Bangladesh, the traffic phenomenon has gained tremendous importance of late. It is estimated that about 600 km paved roads were available throughout Bangladesh just after 1947 whereas, though at low profile development in this aspect upto 1971, now it is about 16,000 km (Source: Bangladesh Road Transport Authority). If only the capital city is considered, an area of about 343 Sq km is seen to be consisting of 1967 km roads of all kinds. But traffic jams and accidents are common daily scenarios. They are supposedly associated with the meagre space availability for about 367000 motorized vehicles in conjunction with an estimated 300000 rickshaws apart from other non-motorized vehicles of various types. It is estimated that the space occupied by paved roads in Dhaka is about 8% of the total area whereas it is ideal to have about 25% of the area covered by the total street network (Source: Janakantha 14.2.96). A survey conducted for the road accidents shows that 15326 killed and 26931 injured apart from huge property damage and social disturbances during 1983-93. 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, disintegration and so on. In addition, Bangladesh is not gifted with all the materials required for construction and sometimes materials need be imported from abroad. Therefore, a compromising balance 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, in future with as little time and expenditure possible must be made. So, the tremendous necessity for pavement construction and reconstruction in the city in particular as well as throughout the country in general cannot be overemphasized. We have limited economic resources in one hand and necessity of expanding roadway networks on the other, so we must strike a correct balance to make pavements with such a mix that is durable and requires the least maintenance. It is a continuous process of research to produce a better mix considering the materials availability and also the environmental effects. In this study, among many variables, the effects of elongation and flakiness indices of the coarse aggregates that are used in the asphaltic concrete constructions are investigated.

Construction of flexible pavements is being preferred in Bangladesh (Source: Roads and Highways Department) 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 through its depth and obviously the transfer of load is influenced by the aggregate interlock, particle friction and cohesion for stability. The main function of the flexible pavement is to distribute imposed traffic loads underneath without being overstressed. Therefore the strength and performance of the pavement layer depends on the condition of the structure of the pavement which has direct bearing with the mix design.

1.2 Significance of Aggregates, Bitumen and Mix Properties

Aggregates are the basic materials of pavement construction and they not only support the main stresses occurring within the pavement but also resist wear due to abrasion by traffic as well as effects of weathering agencies . The behaviour of pavement structure depends on the inherent properties and qualities of the individual particles and on the means by which they are held together ie. by interlocking, by cementatious binders, or by both. Bitumen may be said to be a complex organic material that may occur naturally or may be artificially created during a production process. Bitumen is a material that is soluble in carbon disulphide. Bituminous materials are frequently divided on the basis of their consistency into liquid, semisolid and solid materials. The material is sticky, adhesive substances that is dark brown to black in colour, frequently associated with characteristics odors, and that is usually liquid at all the time of its application to mineral aggregates in road construction. Bituminous materials are of value to the highway engineers principally because of their binding or cementing power and their waterproofing properties.

1.3 Factors Influencing the Selection of Aggregates and Bitumen

In general, aggregates may be of natural or artificial and while selecting the aggregates, hardness, attrition, toughness, strength, texture, durability, specific gravity, shape, cementation, hydrophobic characteristics, etc are taken into consideration. In addition the gradation of aggregates need to be emphasized. Aggregate grading for bituminous mixtures and bitumen content is shown in Table 1.1. The resistance to slow crushing and impact, resistance to frost action, swelling and softening and ability to provide a non-skid surface etc are considered before selecting aggregates. The bituminous materials used in road construction must fulfil the expected qualities through the required tests such as consistency tests, composition tests, specific tests, flash and fire point tests etc. The grade and viscosity selected must conform to the local climatic conditions.

Table -1.1

Aggregate Grading for Bituminous Mixtures and Bitumen Content

Sieve size	% by wt passing sieves	
	1" max size	3/4" max size
1" (25.0mm)	100	-
3/4" (19.0mm)	76-100	100
1/2" (12.5mm)	66-86	77-99
3/8" (9.5mm)	57-77	68-88
No.4 (4.75mm)	40-60	48-68
No.8 (2.36mm)	26-46	33-53
No.16 (1.18mm)	17-37	20-40
No.30 (0.60mm)	11-27	14-30
No.50 (0.30mm)	7-19	9-21
No.100 (0.15mm)	6-16	6-16
No.200 (0.075mm)	3-6	3-6
Bitumen percent	4.5-7.0	5.0-7.5

Source : The Asphalt Institute (January 1983).

1.4 Scope of the Study

As the indiscrete selection of aggregates and bitumen properties can severely affect the design life of a pavement and constant maintenance becomes inconvenience, a properly selected aggregates and bitumen properties well in advance can help overcome this inconvenience to a great extent. The available grade mostly used in Bangladesh being 80/100 and varying the flakiness and elongation of the aggregates, a comparative study can be made to evaluate the difference in respect of stability and flow value of a design mix and a suitable design mix may be recommended for the present to apply in the future . In this study , a systematic laboratory investigation has been made to evaluate the characteristics of bituminous mixes differing the aggregates shape to show the marked difference in the performance.

1.5 Objective of the Study

a. The main objective of this study is to investigate the effect of flaky and elongated aggregate particles on the stability of bituminous mixes.

b. To ascertain the additional cost to sift the flaky and elongated particles in respect of flaky and elongated particles while preparing the mix.

1.6 Limitations and Assumptions

1.6.1 Limitations

Following are a few of the limitations within which the laboratory investigation was carried out :

a. No research was done in Bangladesh so far on influence of coarse aggregate properties on bituminous mixes, particularly the influence of flaky and elongated particles on mix properties. Furthermore, research reports on such investigations that might have been carried abroad were not available in libraries.

b. Investigations on bituminous mixes involve a lot of laboratory works and comprehensive laboratory testing. However, the transportation laboratory in which this investigation was carried out remains heavily engaged in different academic activities and availability of time for long sustained reseach in this laboratory posed difficulty in managing and scheduling.

c. Coarse aggregates used in this research was collected from only one source. Exploration of different sources would have given much insight and satisfactory results.

1.6.2 Assumptions

a. A bitumen content of 5.5% by weight using 80/100 penetration grade bitumen used throughout in this research. Due to time limitation, it could not be varied.

b. A filler material of three percent incorporated in all specimens prepared to testing purpose.

c. Stability - flow values were determined by Marshall Method in order to investigate the effect of variations of flaky and elongated particles on the mix properties.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A Review of literature reveals that no work has yet been done in Bangladesh to examine the influence of varying properties of aggregates on bituminous mixes. Works which have been done abroad are conspicuous by their absence on Bangladeshi libraries. As a consequence, it was difficult for this researcher to glean information from previous research and to carry out the investigation as a continuum of past researches on the selected topic.

In the circumstances as stated above brief discussions on the mix material and the mix properties are presented below.

2.2 Aggregates

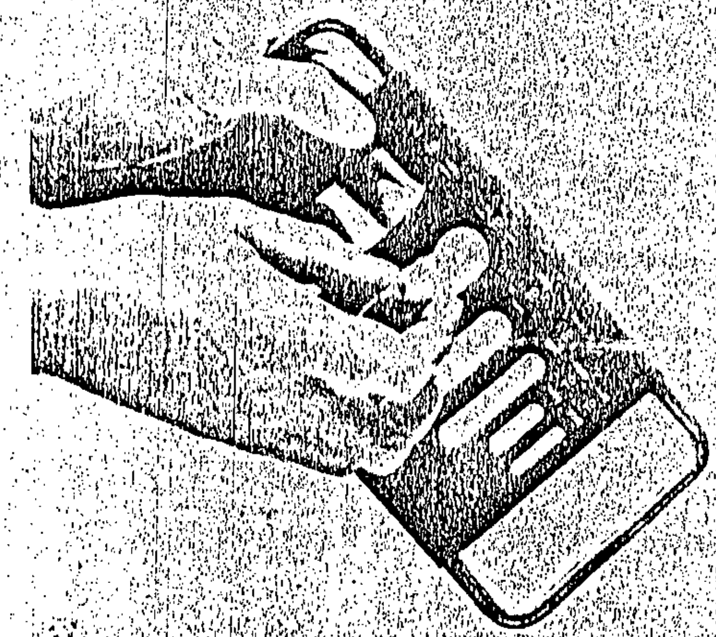
The wide range and type of aggregates available make it essential to select an aggregate that is adequate for a given application. Various mechanical tests are designed to determine different characteristics of aggregates that need to be known in order to select the most economical and suitable type of aggregate. The aggregates support the main stresses occurring within the pavement and resist the wear due to abrasion by traffic as well as the effects of weathering agencies.

The behaviour of the pavement structure depends on 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 binders; or by both. 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 . The particle shape of aggregates is determined by the percentages of flaky and elongated particles that it contains. Flaky and elongated particles are defined respectively as those particles whose least dimension is less than 0.6 of their mean size and whose greatest dimension is more than 1.8 times their mean size. The equipments used to determine the flakiness and elongation indices are shown in Figure 2.1. As per BS (British Standard) single sized road stones and chippings require that : maximum permissible flakiness index for 40mm and 50mm single sized stone does not exceed 40 and maximum permissible flakiness index for 10,14,20 and 28mm single sized stone does not exceed 35.

The most important properties of aggregates are :

a. Particle size and gradation (An aggregate gradation chart is shown in Figure 2.2 and a grading of aggregates for asphalt concrete is shown in Table 2.2). The shape of the aggregate particles plays an important role in the strength of the road pavement. Size and gradation is a vital part of the strength development of pavement mix.

b. Hardness or resistance to wear . Under heavy traffic loads, aggregates of flexible pavement are subjected to continuous slight movements and distortions. The aggregates used therefore should be capable of resisting this abrasive action.

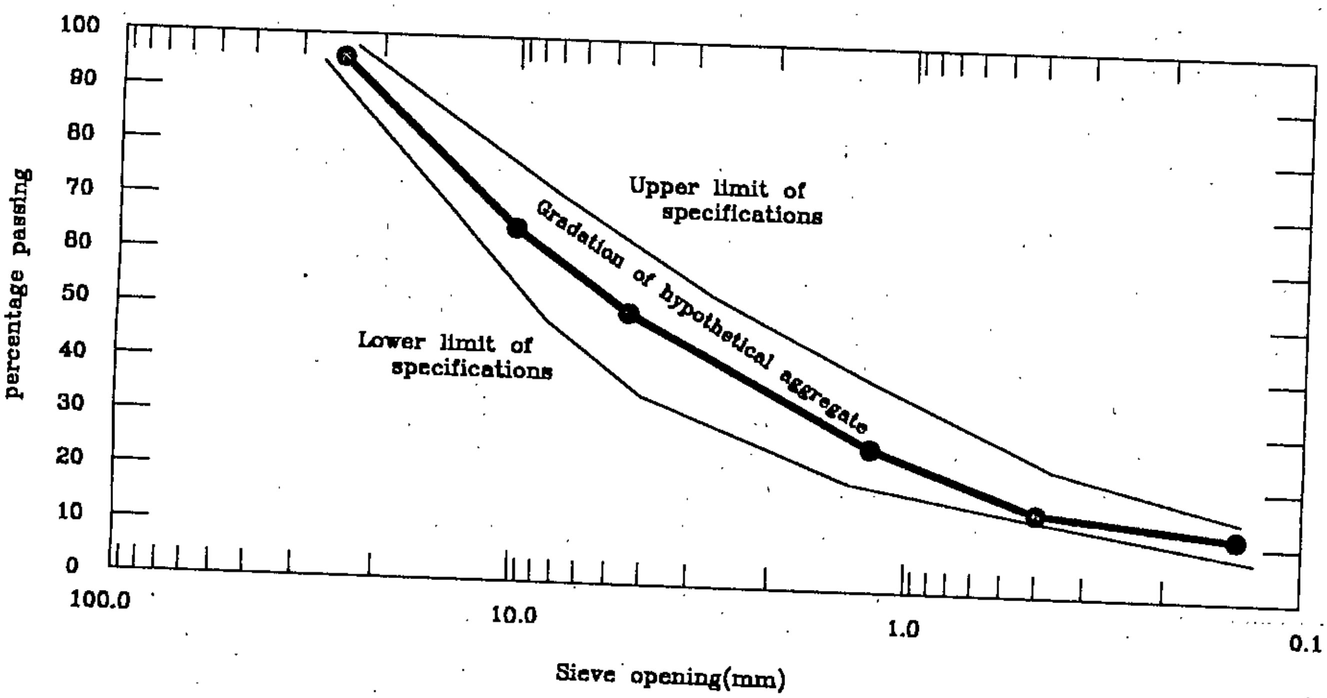


(A) Test for flakiness index.

(B) Test for elongation index.

Source : MOT, UK (1966), Bituminous Material in Road Construction.

Figure 2.1 : Equipment used for Determining Flakiness and Elongation Indices.



Source : Highway Engineering, Fifth edition
Paul H.Wright and Radnor J. Paquette.

Figure 2.2 : Aggregate gradation specification chart

Table-2.2

Grading of Aggregates for Asphalt Concrete

B S Sieve Size(mm)	% by wt passing sieves	
	Base Course	Wearing Course
37.5	100	100
20	84-100	95-100
10	50-74	60-83
6.3	38-64	48-72
3.35	28-52	35-58
1.70	21-42	26-44
425 microns	10-26	13-27
150 microns	6-14	7-18
75 microns	3-8	3-8

Source : The Asphalt Institute (January 1992)

c. Durability or resistance to weathering. The soundness of the stone is the measure of durability under weathering. Therefore aggregates used should be capable of withstading such weathering actions.

d. Specific gravity and absorption. Sp.gr is considered as an indicative to its strength and quality.Stones having higher sp. grs. are generally considered strong.

e. Chemical stability. Aggregate should be capable of withstanding chemical reactions with the surrounding environment.

f. Particle shape and surface texture. Aggregate particles may have rounded, cubical, angular,flaky or elongated shapes. Flaky and elongated shaped particles are less strong and durable than other shaped particles of the same stone.

g. Freedom from deleterious particles or substances. To achieve a compact mix, particles should be free from all sorts of foreign materials detrimental to design mix. Schists, slates and shales commonly produce flaky forms whereas granite, bassalt and quartzite usually yield more or less equidimensional particles. Flat particles will have objectionable influence on the workability, bitumen content, strength and durability. In general excessively flaky aggregate makes very poor asphaltic concrete.

2.2.1 Coarse Aggregates

a. Coarse aggregates (aggregates retained on 2.36mm sieve) for asphalt concrete should be clean, hard, durable and angular (BS 12 "Possessing well defined edges formed at the intersection of roughly planar faces") crushed rock or crushed gravel. At least 60% by weight of aggregate shall consist of crushed pieces having two or more faces produced by fracture.

b. Aggregates shall conform to the quality requirements of BS 882 and the test requirements of Table 2.3. When the stone is increased to the order of 40 to 50 percent, the particles of coarse aggregates begin to interfere with one another i.e. they begin to form some sort of mechanical structure, and then the resistance offered to permanent flow may increase markedly. The proportion of stone required to establish this structure and the strength of the structure when established will depend on the shape and texture of the coarse aggregates. In case of bituminous pavements stone aggregates constitute about 90% or even more of total construction materials. Aggregates should be clean, hard, tough, strong and durable and most important they must be properly graded.

Table-2.3

List of Tests for Aggregates in Asphaltic Concrete

Test	Test Designation	Limits
(1) Description and classification	BS 812: part 1:1975 Para.6	
(2) Particle size distribution	BS 1377:part 1:1975 Test by sieve analysis test 7A	
(3) Clay, fine silt and fine dust	BS 812:part 1:1975 Para. 7.2.4	method 7.2.4 3% max for natural or crushed gravel sands. 5% max for crushed stone sands. 1% max for natural or crushed gravel coarse aggregates. 3% max for crushed rock coarse aggregate.
(4) Clay lumps	ASTM C-142:1978	3% max for fine aggregate, 2% max for coarse aggregate
(5) Flakiness index	BS 812:part 1:1975 Para 7.3	25% max for all coarse aggregate test fractions
(6) Elongation Index	BS 812:part 1:1975 Para 7.4	25% max for all coarse aggregate test fractions
(7) Determination of relative densities and water absorption	BS 812: part 2:1975 Para 5	Water absorption 2% max for all aggregates
(8) 10% fines value	BS 812: Part 3:1975 Para 8	100 kN min
(9) Soundness of aggregate by use of 5 cycles of magnesium sulphate tests	ASTM C88-76:Magnesium sulphate	12% max wearing course, 12% max base course
(10) Aggregate impact value	BS 812:Part 3:1975 Para 6	30% max wearing course, 30% max base course
(11) Total acid soluble sulphate	Wet chemical analysis	0.4% max at each aggregate proposed
(12) Total acid soluble chloride content	BS 812: Part 4:1976	0.06% max of fine aggregate, 0.03% max of coarse aggregate.
(13) Abrasion resistance	Los Angeles ASTM C131 and C535	25% max wearing course
(14) Polished stone value	BS 812:Part 3:1975 Para 10	50% max wearing course

Source : The Asphalt Institute (January 1992)

2.2.2 Fine Aggregates

Fine aggregates (aggregates passing 2.36mm sieve) for asphalt concrete shall be clean naturally occurring sand or quarry fines free from clay, loam, loosely bonded aggregates and other foreign matter. Fine aggregate shall consist of clean, sound, durable, angular particles produced by crushing stone or gravel that meets the requirements determined by tests. Any combination of crushed fine aggregate and natural sand will be permitted provided that the percentage of natural sand does not exceed 15 percent of the total blend of aggregates. Fine aggregate particles shall be free from coatings of clay, silt or other objectionable matter and shall contain no clay ball. The fine aggregate including any blended filler, shall be tested for plasticity index in accordance with ASTM D4318. The amount of fine aggregate to be added will be adjusted to produce mixtures conforming to requirements of this specification.

2.2.3 **Filler Materials :** The bulk specific gravity of mineral filler is difficult to determine accurately at the present time. However, if the apparent specific gravity of the filler is used instead, the error is usually negligible. The voids in the mineral aggregate, VMA, are defined as the intergranular void space between aggregate particles in a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume. The mineral filler shall consist of finely divided mineral matter such as rock dust, hydrated lime, hydraulic cement, or other suitable mineral matter. At the time of use it shall be sufficiently dry to flow freely and essentially free from agglomerations. The mineral filler shall conform to the specification ASTM D242.

a. Filler materials (passing through 0.075mm sieve) shall conform to the requirements of AASHTO M17-70 mineral filler for bituminous paving mixtures.

b. Shall have a bulk density in toluene of between 0.5 and 0.95 grams per millilitre, when tested in accordance with BS 812 part 2 paragraph 6.4.

c. Shall be dry and free from aggregates of fine particles.

2.2.4 **Properties of Mix**

Bituminous mixes have to fulfil a wide range of requirments for today's traffic, in particular the ability to:

* Resist permanent deformation ;

* Resist fatigue cracking ;

* Be workable during laying, enabling the material to be satisfactorily compacted with the available equipment ;

* Be impermeable, to protect the lower layers of the road from water ;

* Be durable, resisting abrasion by traffic and the effects of air and water ;

* Contribute to the strength of the pavement structure ;

* Be easily maintained and, most importantly, this must be cost - effective ;

In addition to the above, wearing course materials must also fulfil the following tyre pavement interaction requirements:

* Provide a skid - resistant surface under all weather conditions ;

* Have an acceptable level of rolling resistance ;

* Provide a surface which, under trafficking, produces an acceptable level of tyre road noise ;

* Provide a surface of acceptable riding quality ;

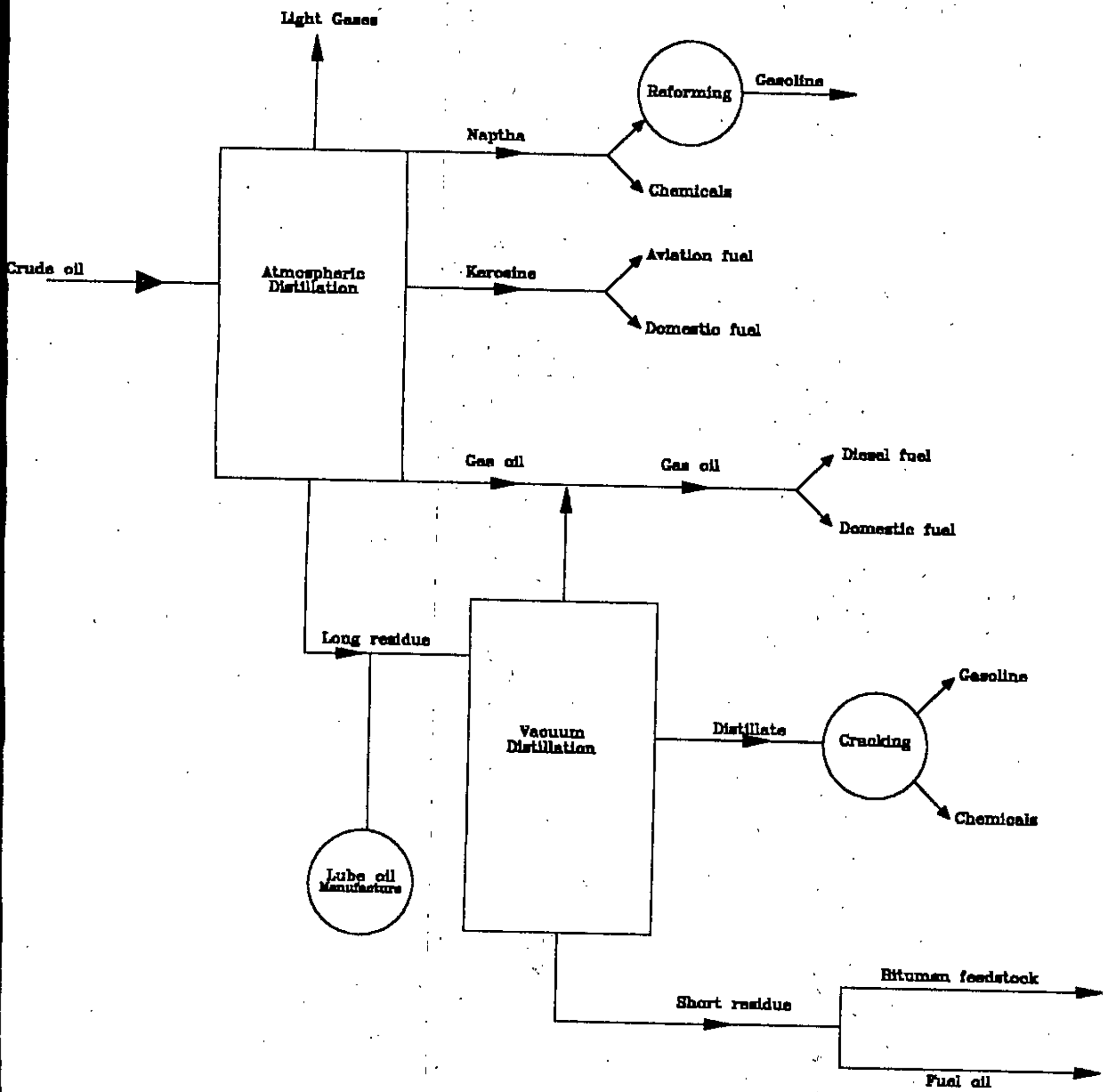
The formidable list as presented above demonstrates the need for the optimal design of a bituminous mix in order to ensure that the required performance is achieved without wasting valuable and limited resources. The objective of mix design is to produce an economical material, making full use of local material resources that meet the engineering requirements, that is, to design for optimal serviceability and economic performance.

2.3 Bitumen

Bitumen may be defined as a viscous liquid or solid material, black or dark brown in colour, having adhesive properties consisting essentially of hydrocarbons, derived from petroleum or occurring in natural asphalt, and soluble in carbon disulphide. The rheology of a bitumen at a given temperature is determined by the constitution and structure of the predominantly hydrocarbon molecular structures in the materials. Elementary analysis of bitumen manufactured from a variety of crude oils show that most of the bitumens contain:

Carbon	82-88%
Hydrogen	8-11%
Sulphur	0-6%
Oxygen	0-1.5%
Nitrogen	0-1%

A schematic diagram of the manufacture of bitumen is shown in Figure 2.3.



Source : The Shell Bitumen Hand book,1991,U.K

Figure 2.3 : Schematic diagram of the manufacture of bitumen.

2.3.1 Effects of Penetration Grade Bitumen

The penetration of a bituminous substance may be defined as the distance (in hundredths of a centimetre) to which a standard needle penetrates the material under known conditions of time, loading, and temperature. The classification of bituminous materials as to their grade can be on the basis of their consistency as in the Table 2.4.

Penetration grade bitumen 80/100, is normally used in Bangladesh for pavement construction. However, it is much debated by K.P. Nair and Dr. M Zakaria (Reference:6,7) as to its use throughout the country disregarding the climatic conditions. For certain zones, grade may be variable according to the suitability commensurate with that zone. However, we shall confine ourselves currently with the penetration grade of 80/100. Penetration grade bitumen for asphalt concrete shall conform to the requirements of :

a. AASHTO M20-70 penetration graded asphalt cement grade 60-70 or

b. BS 3690 part1 1982 Bitumen for building and civil engineering table 1 (preparation of penetration grade bitumen grade 70 penetration. Table 2.5 shows the specification for penetration grade bitumen)

Table 2.4

PENETRATIION LIMITS OF CONSISTENCY

Classification	Penetration	Load (g)	Time (Sec)	Temperature(c)
Liquid	351 or more	50	1	25
Semisolid	350 or less 11 or more	50 100	1 5	25 25
Solid	10 or less	100	5	25

Source : The Shell Bitumen Handbook 1991, UK.

Table 2.5

Specification for penetration grade bitumen.

Property		Test method	Grade of bitumen, 70 pen
Penetration at 25 °c dmm		BS 2000 part 49	70 + 10
Softening point,°c	min max	BS 2000 part 58	44 54
Loss on heating for 5 h at 163 °c a. Loss by mass % b. Drop in pen %	 max max	BS 2000 part 45	 0.2 20
Solubility in trichloroethylene % by mass	 min	BS 2000 part 47	99.5
Permittivity at 25 °c & 1592 Hz	min	BS 2000 part 357	2.630

Source : The Shell Bitumen Handbook 1991, UK.

2.3.2. Susceptibility to Temperature

All asphalts are thermoplastic; i.e. they become harder (more viscous) as their temperature decreases and softer (less viscous) as their temperature increases. This characteristic is known as temperature susceptibility, and is one of the asphalts' most valuable assets. Temperature susceptibility varies among asphalts from differing petroleum sources, even if the asphalts are of identical grade. Figure 2.4 and 2.5 show respectively the temperature susceptibilities of two asphalts (asphalt A and asphalt B) that are identical in penetration grade but originate from different crude sources. The handling temperature as recommended by Shell Bitumen Handbook (1991), UK. is presented in Table 2.6.

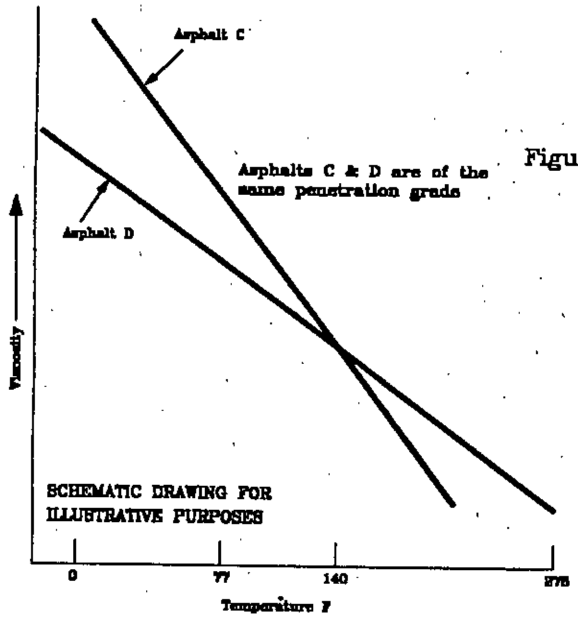


Figure 2.4: Variation in ViscosityTwo Viscosity Graded Asphalts at Different Temperatures.

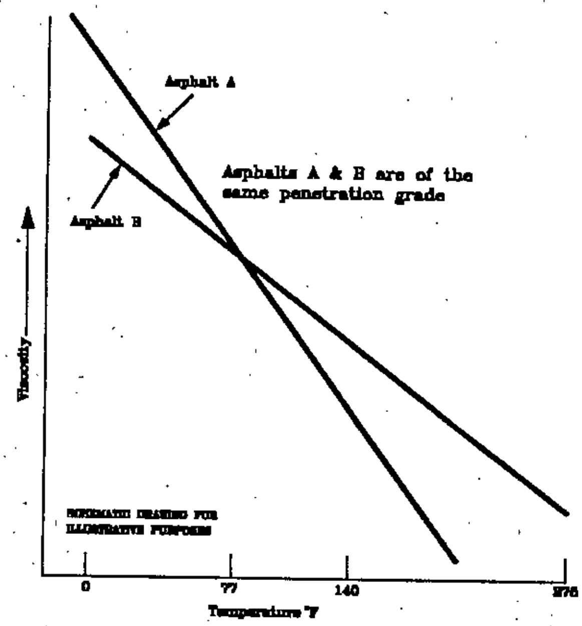


Figure 2.5 : Variation in Viscosity of Two Penetration Graded Asphalts at Different Temperatures.

Source : The Asphalt Institute,January 1983

Table 2.6

Handling Temperatures.

Grade	Min pumping temp (c)	Typical application temp (c)		Maximum safe handling temp(c)
		Mixing/coating	Spraying	
Penetration grades				
100	105	155	190	200
70	110	160	-	200
50	115	165	-	200
35	125	175	-	220
Oxidised grades				
75/30	150	195	-	230
85/25	165	210	-	230
85/40	165	210	-	230
95/25	175	220	-	230
Cutback grades				
50 secs	65	105	150	160
100 secs	70	110	160	170
200 secs	80	120	170	188

Source : The Shell Bitumen Handbook 1991, UK.

CHAPTER 3

MATERIALS AND LABORATORY INVESTIGATIONS.

3.1 Introduction :

The materials for this study consist of different shapes of coarse aggregates keeping fine aggregates, mineral filler and bitumen the same (in quality, proportion, grade etc) in all respect throughout. The locally available crushed stone is used as coarse aggregates for this study. The maximum size of coarse aggregates used is 20 mm.

3.2 Materials Used for the Study :

(1) Coarse aggregate collected from Sylhet

(2) Bitumen of penetration grade 80/100 @ 5.5% by weight

(3) 3% of filler material

3.3 Tests for Determining the Basic Properties of Mixes :

The correct design and physical testing of bituminous mixtures for roads and airfields is important if sound, durable pavements are to be constructed economically and to ensure minimum maintenance during the design life of the pavement. A good bituminous paving mix should exhibit stability, durability, workability and skid-resistance properties besides economy.

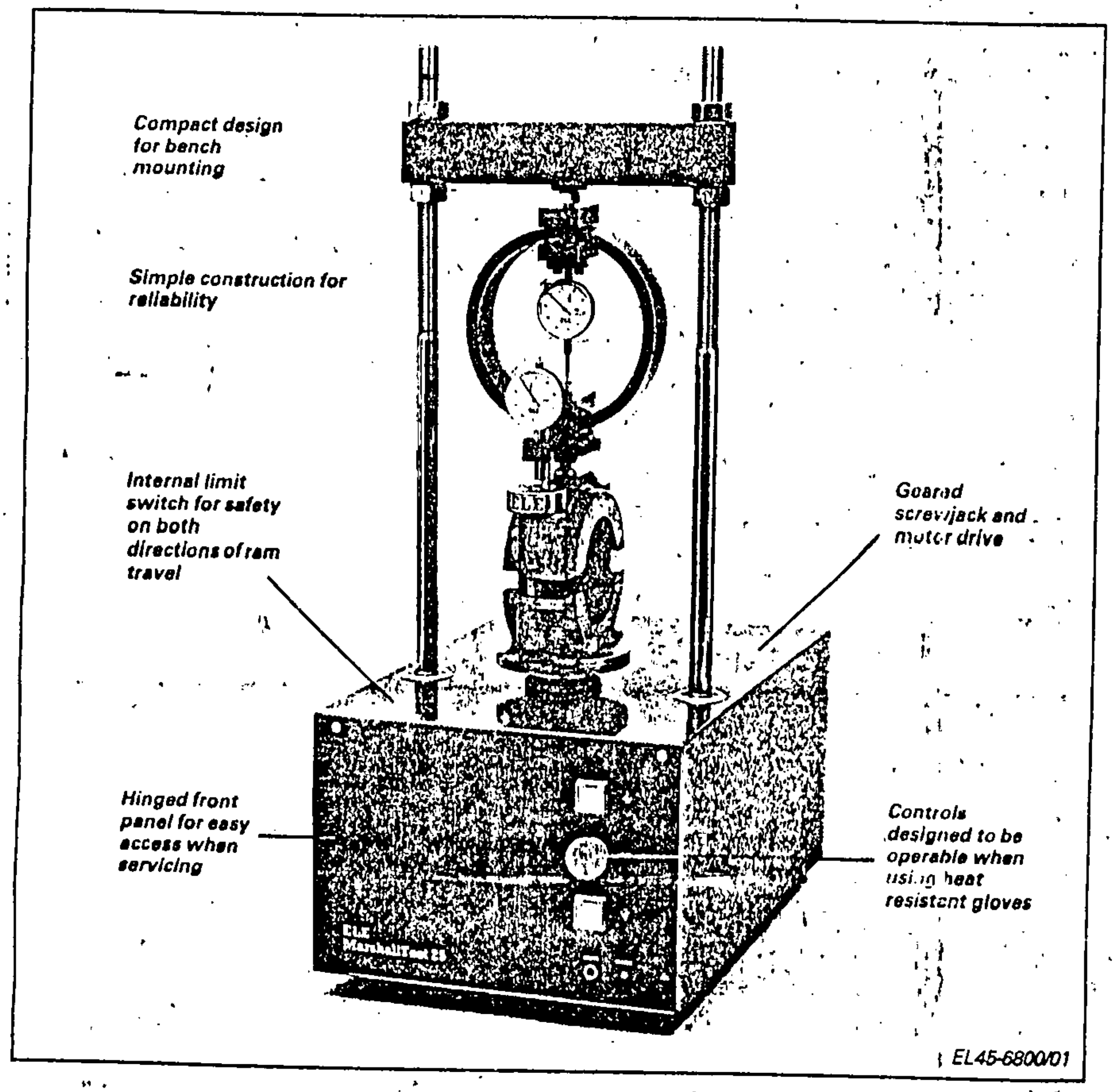
Temperature, mixing, compaction and physical testing all contribute towards the design of a suitable mixture. Procedures have evolved around the Marshall method of mix design developed by Bruce Marshall and subsequently improved by US corps of Engineers in 1948. The Marshall method uses standard test specimens of 64 mm (2.5 in) height x 102 mm (4 in) diameter. These are prepared using a specified procedure for heating, mixing and compacting the asphalt-aggregate mixtures . The two principal features of the Marshall method of mix design are a density-voids analysis and a stability-flow test of the compacted test specimens. We will use in our case the latter one. However, density - void analysis would have given more accurate results but due to laboratory constraints, the tests were confined to stability - flow tests only. The stability of the test is the maximum load resistance in Newtons(lb) that the standard test specimen will develop at 60^0 C (140^0 F) when tested. The flow is the total movement or strain, in units of 0.25 mm (0.01 in) occurring in the specimen between no load and maximum load during the stability test.

The load is applied to the specimen at constant rate of deformation until failure occurs. The point of failure is defined by the maximum load reading obtained. The total number of Newtons (lb) required to produce failure of the specimen at 60^0 C (140^0 F) shall be recorded as its Marshall stability value.

While stability is in progress, the flow meter is held firmly in position over guide rod and removed as the load begins to decrease ; reading is taken and recorded. This reading is the flow value for the specimen expressed in units of 0.25 mm (0.01 in).Two properties are determined: the maximum load the specimen will carry before failure- this is known as the Marshall stability and the amount of deformation of the specimen before failure occurred - this is known as the Marshall flow. The ratio stability to flow is known as the Marshall quotient which is a measure of the material's resistance to permanent deformation. The laboratory equipment (ELE) used for determining the stability and flow value is shown in Figure 3.6.

The results of the Marshall tests for stability and flow value are shown in the Table 3.7.(Using 50 blows to each end, being commonly practised in our country). It is estimated that elongated particles produce less stability i.e. less the elongated particles more is the stability. Flakiness index may not be made negligible to get a good mix rather a tolerated amount of both flakiness and elongation index can produce a desired stability. Curves showing effects of elongation and flakiness indices in respect of stability and flow values are shown in Figures 3.7 through 3.11.

Stability and flow



Source : Materials testing catalogue - (ELE) International, England.

Figure 3.6: Equipment used for Marshall Stability test

Table 3.7

Marshall Test Results

Indices	Stability and flow at 300° (F)	Stability & flow at 320° (F)
Flakiness index = 35% Elongation index = 29%	2737, 14	2468, 14.8
Flakiness index = 35% Elongation index = 19%	2757, 17.85	2909, 18.10
Flakiness index = 35% Elongation index = o%	3151, 18.20	3121, 17.20
Flakiness index = 15% Elongation index = 29%	2424, 18.25	2333, 16.75
Flakiness index = o% Elongation index = 29%	2394, 18.25	2272.5, 17.25
Flakiness index = o% Elongation index = o%	1805,19.25	2139,17.33

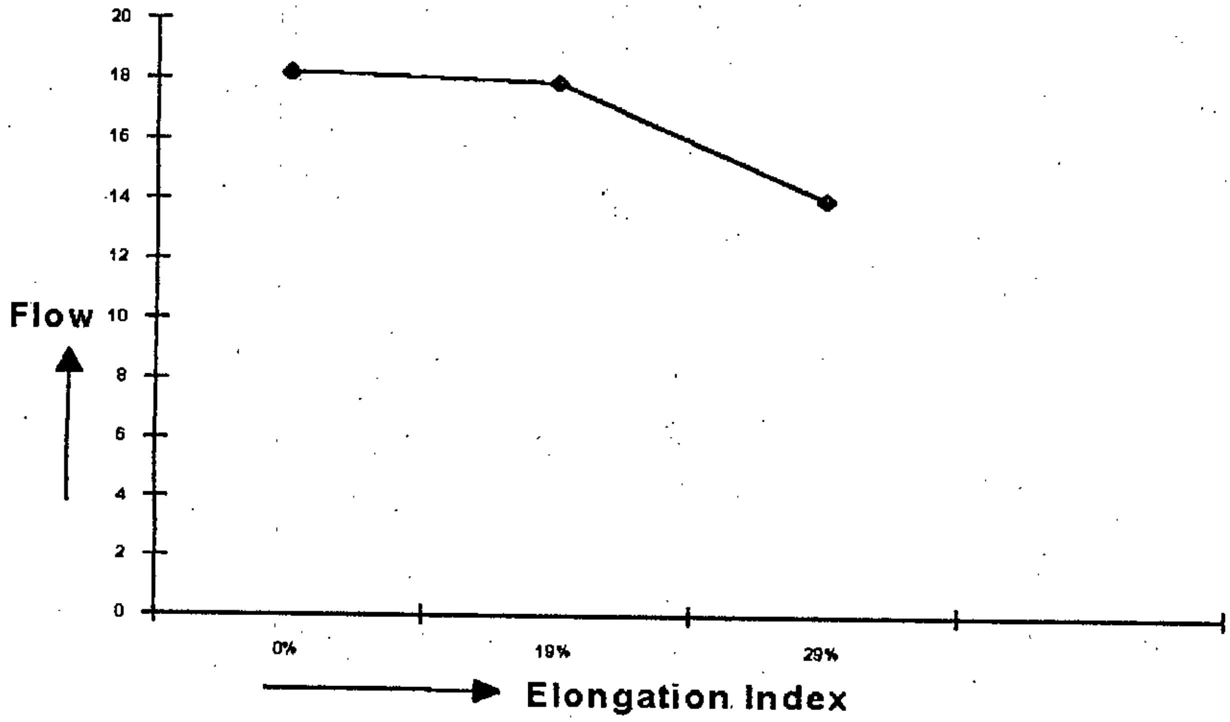


Figure 3.7 : Variation of flow with Elongation Index at constant Flakiness Index (35%)

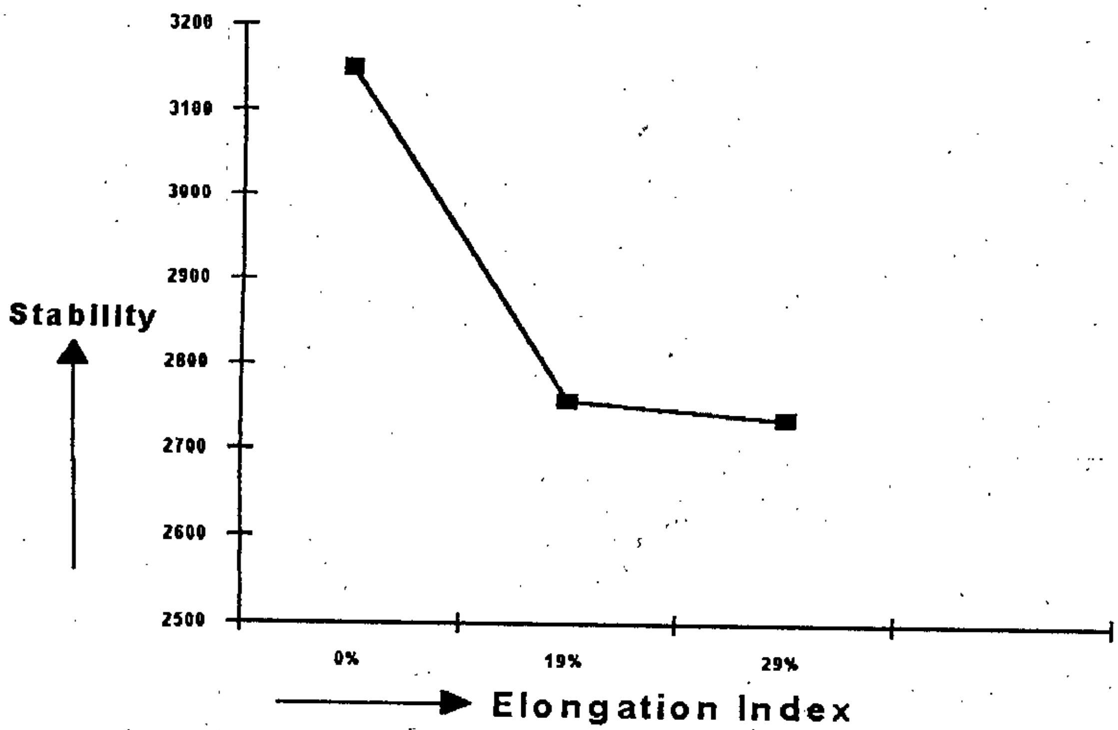


Figure 3.8 : Variation of stability with Elongation Index at constant Flakiness Index (35%)

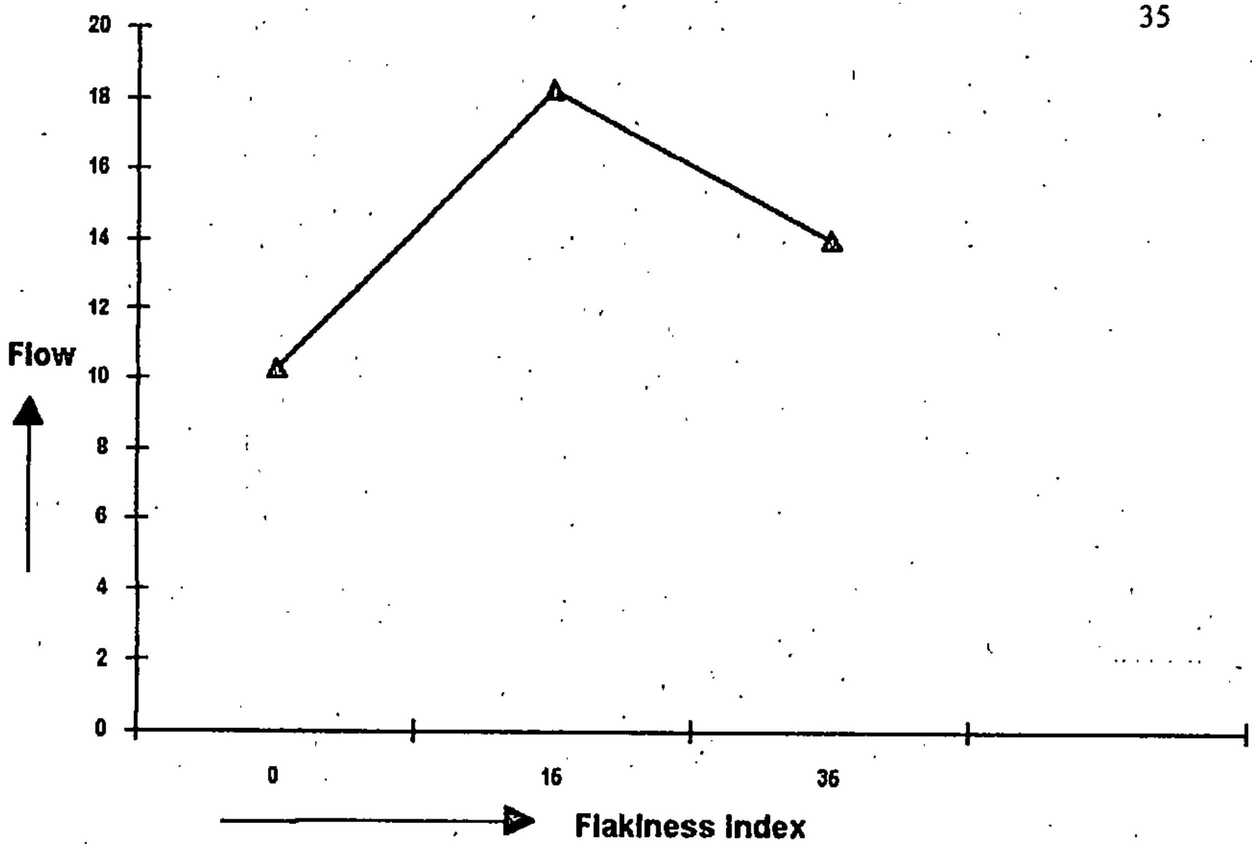


Figure 3.9 : Variation of flow with Flakiness Index at constant Elongation Index (29%)

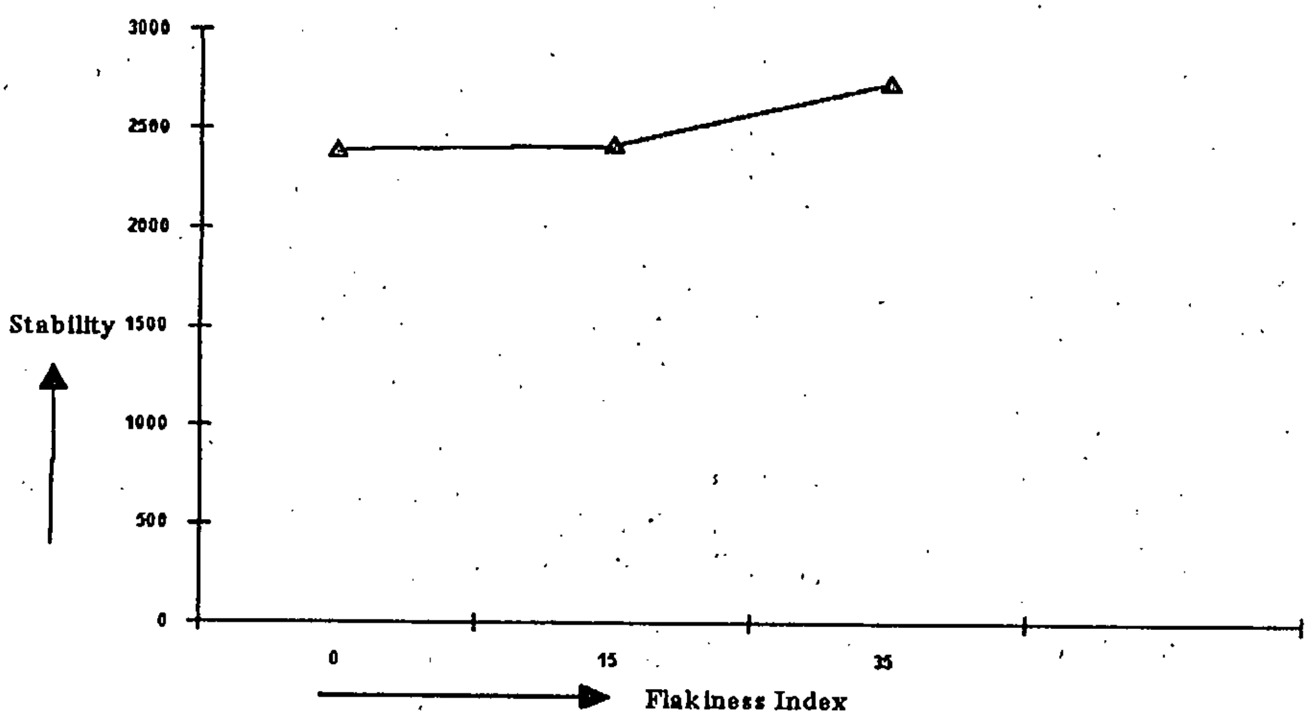


Figure 3.10 : Variation of Stability with Flakiness Index at constant Elongation Index (29%)

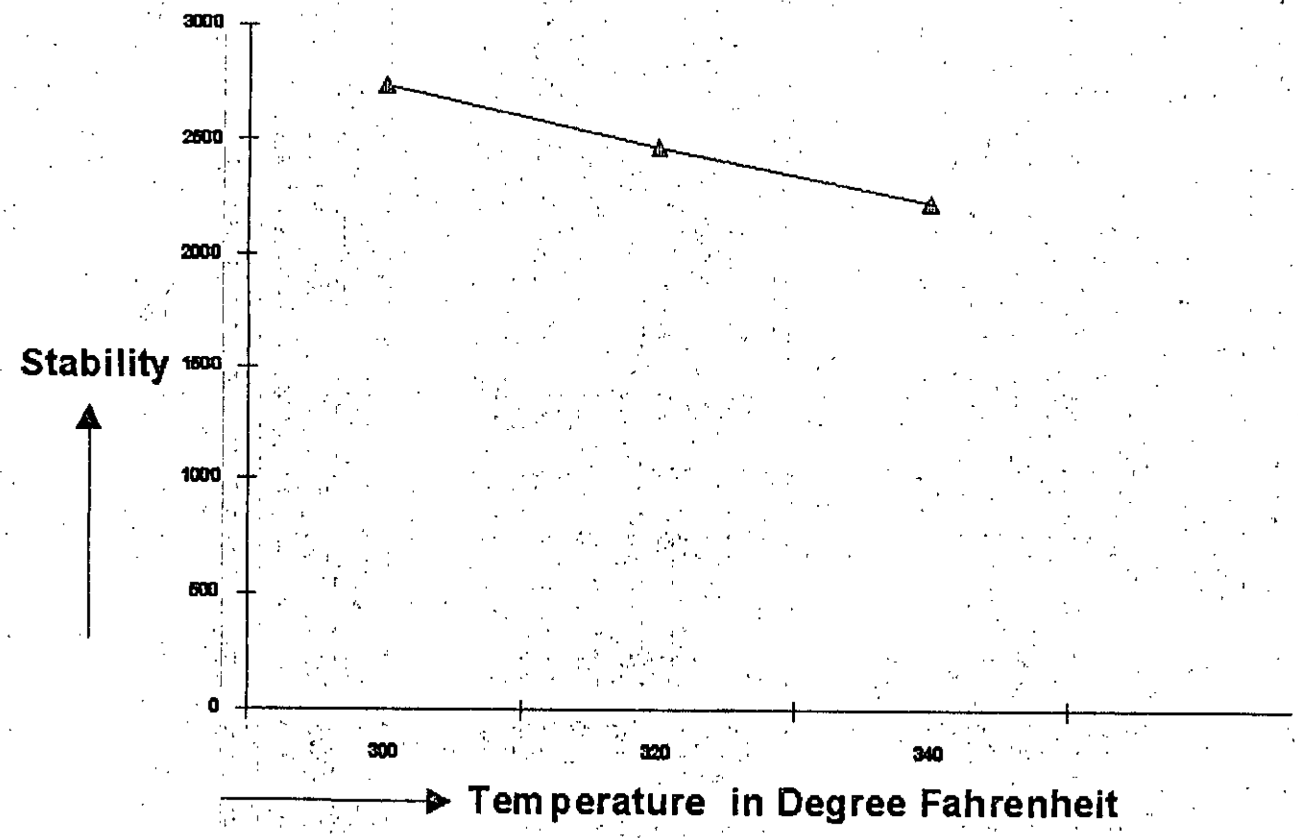


Figure 3.11: Variation of stability with Temperature (Flakiness Index and Elongation Index constant)

CHAPTER 4

DISCUSSION AND IMPLEMENTATION OF THE TEST RESULTS.

4.1 Strength of Mix

There are two categories of stiffness namely elastic stiffness under conditions of low temperatures or short times of loading and viscous stiffness at high temperatures or long times of loadings. The former is used to calculate strains in the structure and the latter is used to assess the resistance of the material to deformation. To determine the permanent deformation resistance of a bituminous mix, its response at high temperatures or long loading time is analysed. When the stiffness of bitumen is less than $5x10^6$ Pa, the mix behaviour is much more complex than it is in the elastic zone. Under such conditions the stiffness depends on that of bitumen and volume of aggregate and other factors such as aggregate grading, its shape, texture and degree of interlock. Under traffic loading the layers of a flexible pavement structure are subjected to continuous flexing. The magnitude of strains is dependent on the overall stiffness and nature of the pavement construction, but analysis confirmed by in-situ measurements has indicated that tensile strains of the order of 30 to 200 x 10^{-6} for a standard wheel load occur. Under these conditions the possibility of fatigue cracking exists. The Aggregate Impact Value (AIV), Ten Percent Fines value(TPF),Aggregate Abrasion Value(AAV)etc are determined and shown in Table 4.8.

4.2 Influence of Strength of Mixes on Pavement Design and Performance.

Correct forecasting of traffic growth rate is quite problematic and an overestimate can result finance invested prematurely and underestimate can call for frequent maintenance, so stage construction is generally followed in Bangladesh in accordance with Road Note 31. 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. The selected mix design is usually the most economical one which will satisfactorily meet all of the established criteria. 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

Table 4.8

Aggregate Test Results.

Sl No	Name of test	Result
1.	Flakiness index (%)	35 (Thirty five)
2.	Elongation index (%)	29(Twenty nine)
3.	Aggregate impact value (%)	13 (Thirteen)
4.	Ten percent fines value (kN)	250 (Two hundred fifty)
5.	Los Angeles abrasion (%)	16 (Sixteen)

Source : Transportation Laboratory, BUET.

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.

4.3 Influence of Elongation Index

Figure 3.7 shows that while flakiness index is increased, the flow value decreases. Figure 3.8 reveals that stability decreases with the increase in elongation index. It is concluded from this study that elongation index affects adversely the stability of mix.

4.4 Influence of Flakiness Index

Figure 3.9 shows that while flakiness index is increased, flow value also increases steadily upto 15% flakiness. As the flow value increases, the mix becomes unstable. But when the flakiness index further increases the flow value decreases indicating a stable mix. Figure 3.10 shows that increasing the flakiness index increases the stability value. It is concluded that certain amount of flakiness is necessary to have a good mix for the study under consideration.

4.5 Influence of Temperature

The specimens were prepared for stability testing on the basis of two level of temperatures i.e. at 300 ° F and at 320 ° F. Although more number of samples in each one would have given more closer average value but a general trend is discerned that bitumen spread at temperature between 300 - 350 ° F do not differ substantially in quality (Figure 3.11). However, it can be seen from Table 3.7 that at lower mixing temperature (300 ° F), the stability value slightly increases and thereby provides more strength to the design life of a pavement as compared to a mixing temperature of 320 ° F.

4.6 Approximate Cost Analysis

The cost analysed on the basis of field study and prevalent schedule of rates indicates very little difference between the cost of different shapes of samples under study. However, gradation, careful selection and quality control demand extra supervision which of course, entails more time and consequently more wage. On the other hand, considering the long term effects on the riding quality and routine maintenance , the added value is much more justified. Double rate is assumed to pay for extra labour to sort out flaky and elongated particles and it can be seen that approximately one taka per sqm is added more for each sqm to sort out the flakiness and elongation by manual labour.

A comparative cost analysis is given in appendix A.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The present study focusses on the variation of strength properties of coarse aggregates in respect of stability and flow value (Marshall tests) for different shapes of coarse aggregates in respect of flakiness and elongation keeping the binder content same and also when no other variation is made in any other constituents. The aim is to find the effects of aggregate shape on the overall properties of bituminous mixes. No field test was carried out and keeping the constraints of the materials and conditions of testing the following conclusion are made from the study :

i. When flakiness and elongation indices exceed more than 20%, the stability of the mix decreases.

ii. When flakiness and elongation indices are made negligible, the stability does still decrease.

iii. Elongated particles cause more destability than that of flaky particles.

iv. Very little difference is observed in respect of stability value as to the variation in the mixing temperature, differing between 300 and 320 ° F.

5.2 Recommendations for Future Investigation.

This study provides enormous scope for future investigations in the following areas :

i. Performance of both laboratory and field tests to evaluate the strength characteristics of bituminous mixes.

ii. Density - void analysis investigations to facilitate laboratory results with specified properties of mixes.

iii. Use of filler material in amounts between 5 - 6% to provide dense mixes.

iv. Detailed tests on different sources of aggregates to verify their acceptability in bituminous mixes.

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Appendix 'A'

An example is given below to show the difference between the cost of premix carpet with normally available gravels and that of sorted gravels in respect of flakiness and elongation.

1. Premix carpet, 50mm thick consolidated on bituminous surface as specified including tack coat (MES Schedule of Rates - 1995)

Analysis per sqm

(1) Cost of Materials :

a. Shingle/gravel = 0.061 cum @ Tk.1130/cum - Tk. 68.93

b. Bitumen including tack coat= 4.588 kg @Tk.16,000/ton - Tk.73.40

c. Firewood = 16 kg @ Tk. 3/kg = Tk. 48.00

(2) Cost of Labour

a. For heating and mixing of gravel and bitumen = 0.013 Nos @ Tk. 70/each - Tk. 0.91

b. For brooming and cleaning = 0.036 Nos @ Tk. 60/each - Tk.2.16

c. For spreading = 0.036 Nos @ Tk. 60/each - Tk. 2.16

d. For levelling and packing = 0.036 Nos @ 70/each - Tk.2.52

e. Tools & Plants and sundries = L.S - Tk. 2.00

f. Hire charge of Roller = L.S - Tk.2.00

	Tk. 202.08
Add 10% contractor's profit	Tk. 20.20
Add 4.5% VAT	Tk. 10.00
	Tk. 232.28

Therefore cost per sqm = Tk. 232.28

Analysis per sqm after sorting out of flakiness and elongation

(1) Cost of Materials :

a. Shingle/gravel = 0.061 cum @ Tk.1130/cum - Tk. 68.93

b. Bitumen including tack coat= 4.588 kg @Tk.16,000/ton - Tk.73.40

c. Firewood = 16 kg @ Tk. 3/kg = Tk. 48.00

(2) Cost of Labour

a. For heating and mixing of gravel & bitumen with sorting out for flakiness and elongation = 0.013 Nos @ Tk. 140/each - Tk. 1.82

b. For brooming and cleaning = 0.036 Nos @ Tk. 60/each - Tk.2.16

c. For spreading = 0.036 Nos @ Tk. 60/each - Tk. 2.16

d. For levelling and packing = 0.036 Nos @ 70/each - Tk.2.52

e. Tools and Plants and sundries = L.S - Tk. 2.00

f. Hire charge of Roller = L.S - Tk.2.00

	Tk. 202.99
Add 10% contractor's profit	Tk. 20.30
Add 4.5% VAT	Tk. 10.05
	Tk. 233.34

Therefore cost per sqm = Tk. 233.34