EFFECT OF FLAKINESS AND ELONGATION AGGREGATES ON THE BITUMINOUS MIXES

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ABSTRACT: Flakiness &Elongation indexis one of the most prominent criteria that governbehavior and performance of aggregate in the bituminous mixes. The strength and serviceability requirements of bituminous mixture such as Stability, Flow, Voids in Total mix(VTM), Voids Filled with Bitumen (VFB) highly depends on the physical properties of aggregates. This study conducted by observing the effect of flakiness& elongated index by adding different percentages of flaky& elongated aggregates from(0-50)% of flaky& elongated aggregates of different sieve with required quantity to the bituminous mixes. The method of Marshall Mix design is adopted for this purpose. The change in rotation angle of coarse aggregate was found to correlate well with the internal resistance of a HMA mix. The particle shape determined how aggregate was packed into a dense configuration and also determined the internal resistance of a mix. Cubical particle swere desirable for increased aggregate internal friction and improved rutting resistance. Also, the Particle Index(PI) value correlated well to aggregate geometric characteristics. The more cubical the aggregate, the higher the PI value is obtained.
Keywords: Bituminous Concrete(B.C), Flakiness Index(F.I, Flow, Hot Mix Asphalt (HMA), ,Stability ,Voids Filled with Bitumen (VFB),Voids in Total Mix (VTM).

I. INTRODUCTION

Road transport provides greater utility in transport over short and long hauls of lighter weight commodities and of lesser volumes as also for passenger transport for short and medium hauls. Road transport has shown immense potential in highly advanced countries, especially for passenger transport due to flexibility in operation and door to door service. Development in road network is regarded as a social, commercial and economic progress of a country. No region or country can flourish, if it lacks adequate transport facilities and mainly in road network. Road as one of land transportation infrastructure is very important in supporting the economic for both regional and national development.

Pavement consists of more than one layer of different material supported by a layer called sub-grade. Generally pavements are of two types. Flexible pavement and rigid pavement. Flexible pavements are so named because the total pavement structure deflects, or flexes, under loading. A flexible pavement structure is typically composed of several layers of material. Each layer receives the loads from the above layer, distributes the load then transfers on these loads to the next layer below. Typical flexible pavement structure consisting of:

* Surface course. This is the top layer and the layer that comes in contact with traffic. It may be composed of one or several HMA sub layers. HMA is a mixture of coarse and fine aggregates and asphalt binder
* Base course. This is the layer directly below the HMA layer and generally consists of aggregate (either stabilized or un-stabilized).
* Sub-base course. This is the layer (or layers) under the base layer. A sub-base is not always needed.

II. EXPERIMENTAL INVESTIGATIONS

3.2.1 Aggregate

Aggregate is the major component of all materials used in road construction. It is used in granular bases and sub base and in bituminous courses. The aggregate component which is used in this thesis is from Tirupati, India. They should conform to bituminous concrete (B.C) gradation of grade (1) of 19 mm nominal size aggregate. The aggregate and the bitumen which are used in the study should have passed in the following tests. For aggregate such as Los angles abrasion test, impact value and crushing and water absorption. The aggregate should be sufficiently strong to withstand the stresses due to traffic intensity and wheel load; aggregate should have hard enough to resist the wear due to abrasive action of traffic and aggregate should have resistance to impact or toughness.

3.2.2 Bitumen

The bitumen which is used in this study is base bitumen of paving grade Crumb rubber modified bitumen. For bitumen these tests should be done like penetration, softening point, ductility and Viscosity. The binder content for this study is chosen as 5.2%[IS: 2386 part 2,4 and 7 and IS: 6241.1997].It should be fluid enough at the time of mixing to coat the aggregate evenly by a thin film, It should have low temperature susceptibility, It should show uniform viscosity characteristics, bitumen should have good amount of volatiles in it, and it should not lose them excessively when subjected to higher temperature. The bitumen should be ductile and not brittle, the bitumen should be capable of being heated to the temperature at which it can be easily mixed without anyfire hazards, the bitumen should have good affinity to the aggregate and should not be stripped off.

1 Impact Test

Impact is application of load on aggregate for a short instant of time then unloading of that load. Toughness is the property of a material to resist impact. During the construction process of pavement layers, particularly compaction by heavy rollers and also due to movement of heavy wheel loads of traffic, the road aggregates subjected to impact or pounding action and there is possibility of some stones breaking into smaller pieces.

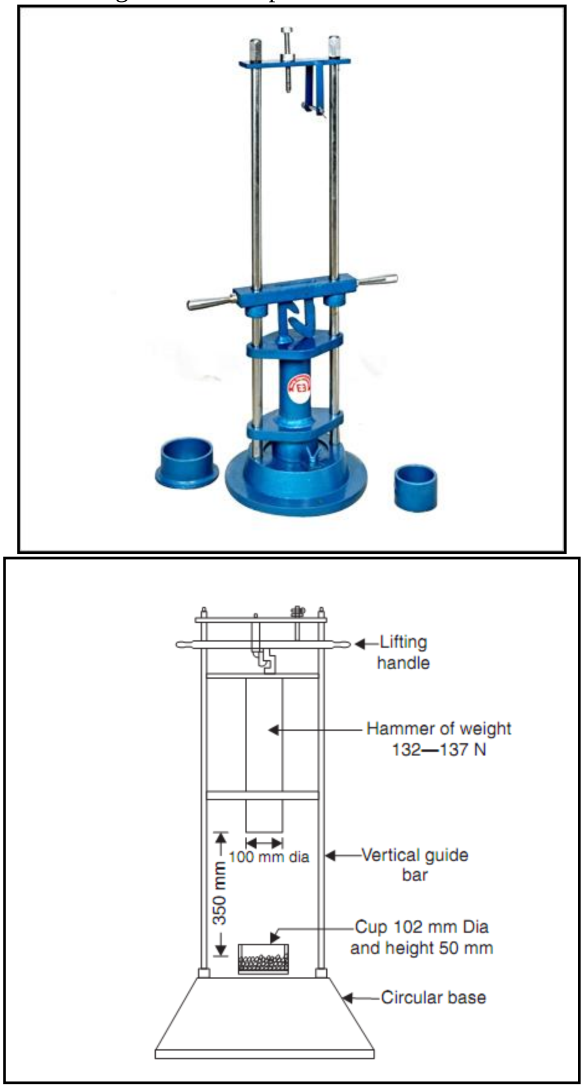


Fig 3.1 Aggregate impact testing machine

Aggregate impact value (AVI) % = $\left(\frac{W2}{W1}\right) * 100$ ……………………… Eq.3.1

W2 = Weight of fines passing 2.36 mm

W1 = Weight of sample

Table (3.1) Aggregate Impact Test specifications

Specifications

Type of Pavement Material/Layer	Aggregate Impact Value, Max, %
WBM Sub-base course	50
Cement Concrete Base course	45
Bituminous Macadam, Base course	35
WBM Surface course	30
Bituminous Wearing Surfaces	30

Los Angeles abrasion Test

The principle of Los Angeles abrasion test is to find the percentage wear due to the relative rubbing action between the aggregates and steel balls used as abrasive charge. During Los Angeles abrasion test, both abrasion or rubbing action between the aggregates and the steel balls and pounding action of these balls on the aggregates take place. Some investigators are of the opinion that Los Angeles abrasion test is more reliable for evaluating the suitability of coarse aggregates in pavements as both abrasion and impact occur during the test similar to the field conditions.

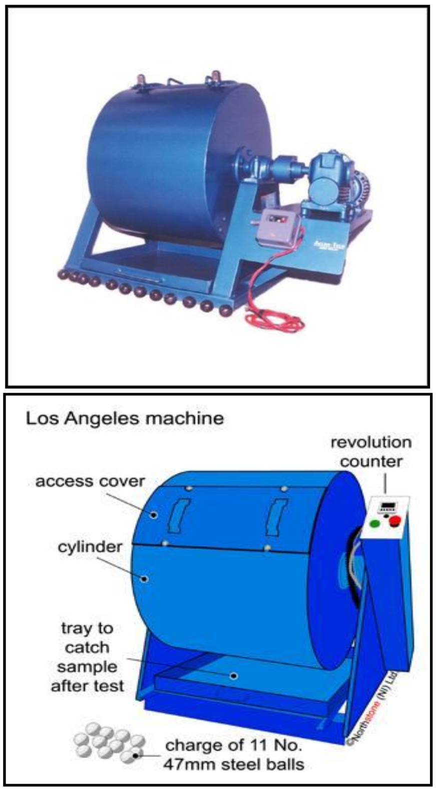


Fig 3.2 Los Angeles abrasion testing machine

Aggregate abrasion value is determined by

Los Angeles abrasion value (LAAV) %= $\left(\frac{W2}{W1}\right) * 100$ ……………Eq. 3.2

W2 = Weight of fines passing 1.7 mm

W1 = Weight of the sample.

Table 3.2 Los Angeles abrasion test specification

Specifications

Type of Pavement Layer	L. A. Abrasion Value, Max, %
WBM Sub-base course	60
WBM Base course with bit. Surfacing, BM Base course	50
WBM Surface course, BM binder course	40
Bituminous Carpet, SD, Cement Concrete surface course	35
Bituminous/Cement concrete Wearing course	30

3.3.1.3 Aggregate crushing value Test

The resistance to crushing of coarse aggregates under gradually applied compressive load is expressed in terms of Aggregate Crushing Value. Coarse aggregates used in construction should be strong enough to resist crushing under rollers during compaction as well as due to the heavy traffic wheel loads. If the aggregates are week, the stability and performance of the pavement structure is likely to be adversely effected. The strength of coarse aggregates or the resistance to crushing of the coarse aggregates under the applied load is generally assessed by conducting aggregate test. A low aggregate crushing value indicates higher resistance to getting crushed under the application of the specified or higher crushing strength.

Fig. 3.3a Aggregate Crushing value

Fig. 3.3b Mould and plunger Testing Machine

Fig.3.3 Aggregate Crushing value Testing Machine

$$\textbf{Aggregate crushing value } \% = \left(\frac{\mathbf{W2}}{\mathbf{W1}}\right) \times \mathbf{100} \quad \text{....Eq. 3.3}$$

W_1= Total weight of the sample

W_2= weight of crushed aggregate

Table 3.3 Aggregate Crushing value test specification

Specifications

Specified By	Aggregate Crushing Value for Cement Concrete Pavements	
As per IRC:15 1970 And IS: 2386:Part IV	30 % Max for Surface Course	45 % Max for Other Surfaces

3.3.1.4 Stripping Test of aggregate

The stripping value of aggregates is determined as the ratio of the uncovered area observed visually to the total area of aggregates, expressed as a percentage. Stripping value should not be less than 95% (IS: 6241, 1998).

Fig.3.4Stripping test of aggregate

3.3.1.5 Flakiness & Elongation index Test of aggregate

The flakiness index of aggregates is the percentage by weight of particles whose least dimension is less than (0.6) of their mean dimension. Applicable to sizes (≥) 6.3mm.The sample is sieved through IS sieve sizes (63, 50, 40, 31.5, 25, 20, 16, 12.5, 10 and 6.3 mm). Minimum 200 pieces of each fraction to be tested are taken and weighed (W1 gm). Separate the flaky material by using the standard thickness gauge (IS: 2386, 1997).

$$\text{Flakiness index } \% = \left(\frac{\sum W1}{\sum W2}\right) * \mathbf{100} \ldots\ldots\ldots\ldots \text{Eq. 3.4}$$

W1=Retained weight from each sieve

W2= Retained weight passed flakiness gauge

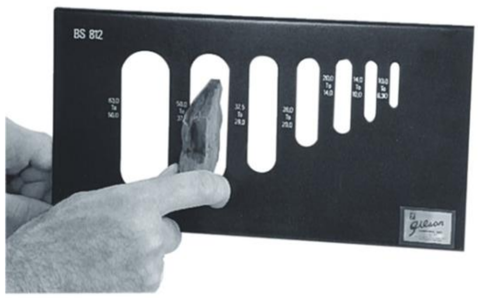


Fig. 3.5a Test of flakiness index

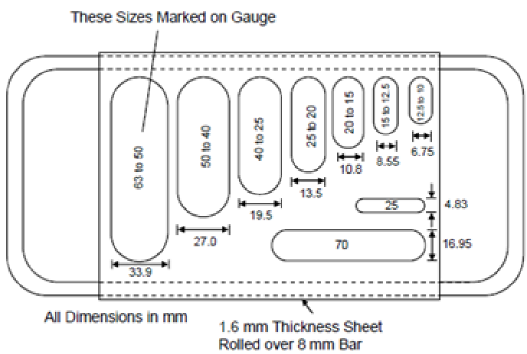


Fig. 3.5b Thickness gauge

Elongation index of an aggregate can be defined as a percentage by weight of particles whose greatest dimension (Length) is greater than one and four fifth times or 1.8 times of their mean dimension. The elongations test is not applicable to sizes of aggregate particles smaller than 6.3 mm. The weights of the separated aggregates of different size ranges are weighed =W1, W2, etc. The total weight of aggregate samples is =(W1+W2+....)=W gm

The weights of elongated portion if aggregates retained on the different specified slots of the length gauge are = E1, E2, etc.
Elongation index is the total weight of elongated particles retained on the various slots of the length gauge expressed as a percentage of the total weight of aggregate sample, i.e.

$$EI = \frac{100(E1+E2+....)}{(W1+W2+...)} \quad ....Eq.3.5$$

Fig. 3.5 c Length gauge

3.3.1.6 Specific gravity of aggregate

Specific gravity of aggregate is considered as measures of strength .Aggregates having low specific gravity are generally weaker than those with high specific gravity values. The accepted specific gravity of aggregate is between 2.5-3.2 and average value is 2.7 (IS: 2386, 1997).

W_1g = weight of saturated aggregate suspended in water with basket.
W_2g = weight of basket suspended in water
W_3g = weight of saturated surface dry aggregate in air.
W_4g = weight of oven dried aggregate.
W_Sg = weight of saturated aggregate in water (W_1-W_2)

$$\text{Specific gravity} = \frac{\text{Dry weight of aggregate}}{\text{Weight of equal volume of water}}$$

$$\text{Specific gravity} = \frac{W_4}{W_3 - W_s} \quad .... \text{Eq.3.6}$$

3.3.2. Bitumen tests

3.3.2.1. Penetration Test

Penetration test determines the consistency of the bitumen for the purpose of grading. Penetration of a bituminous material is the distance in tenths of millimeter that standard needle will penetrate vertically into a sample under standard conditions of temperature, load and time see fig3.6b. The penetration value is obtained at 3 places (IS: 1203, 1978).

Fig.3.6 Penetration Test

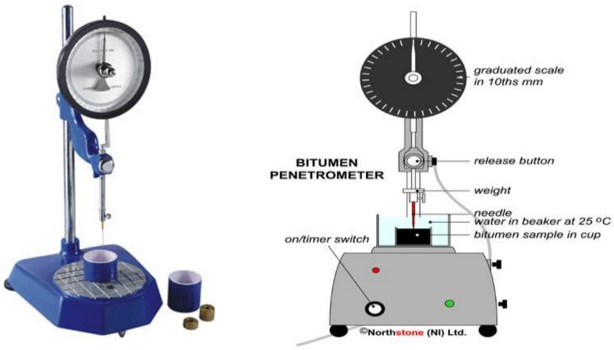


Fig. 3.6a Penetration Test device

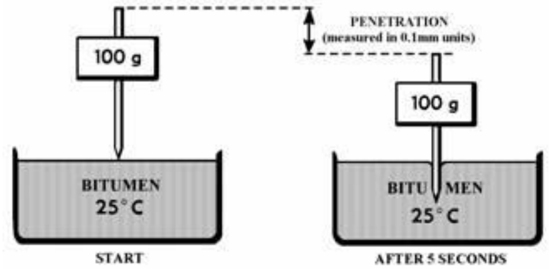


Fig. 3.6b Penetration Test

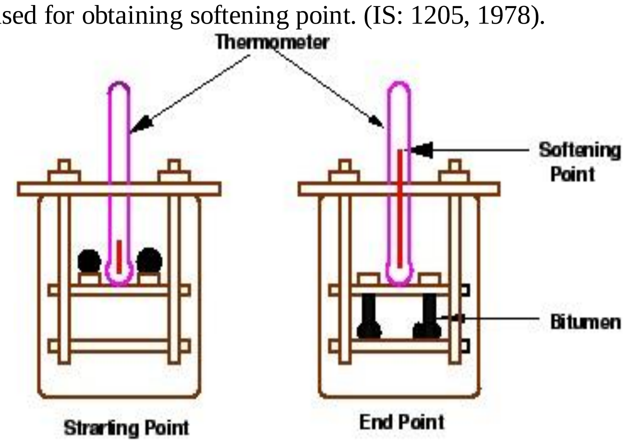
IS Specifications

Penetration Grade	Repeatability
0-80	4%
80-225	5%
Above 225	7%

Bitumen Grade	A25	A35 & S35	A45 & S45	A65 & S65	A90 & S90	A200 & S200
Penetration Value	20-30	30-40	40-50	60-70	80-100	175-225

3.3.2.2. Softening point Test

Bitumen changes gradually from solid to liquid state as the temperature increases. Softening point is the temperature at which the bitumen attains particular degree of softening under specified test conditions .Ring and ball apparatus is used for obtaining softening point. (IS: 1205, 1978).



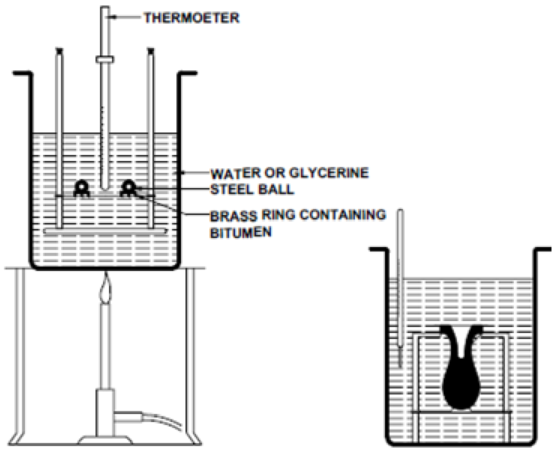


Fig. 3.7a Ring and Ball softening point

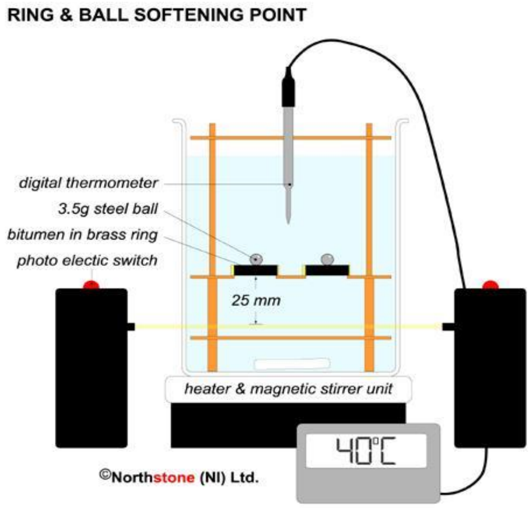


Fig. 3.7b Ring and Ball softening point

Table 3.5 Softening point specification

IS Specifications

Softening Point	Repeatability (°C)	Reproducibility (°C)
<30°C	2	4
30°C- 80°C	1	2
>80°C	2	4

Bitumen Grades	Softening Point (°c)
S 35	55-65
A 45, S 45 & A 65	45-60
S 65	40-55
A 90 & S 90	35-50
A 200 & S 200	30-45

3.3.2.3. Ductility Test
Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be stretched without breaking. Dimension of the briquette thus formed is exactly 1 cm square. A minimum ductility value of 50-75 cm has been specified by the IS: 73-2006 (IS: 1208, 1978).

Viscosity Test
This test method is useful in characterizing certain petroleum products, such as bitumen and determining their flow ability. This test method covers the empirical procedures for determining the Saybolt Universal or SayboltFurol viscosities of petroleum products at specified temperatures between 21 and 99°C.Certified calibration factor of the tube may be made use of, if available. Otherwise, the oil tube may be calibrated using oil of known furol viscosity in seconds.
Specific gravity of bitumen

The specific gravity is defined by BIS as the ratio of the mass of a given volume of the bituminous material to the mass of an equal volume of water, the temperature of oth being specified as is heated to a pouring temperature and is poured in 27°C ± 0.1 °C.(IS: 1202-1978).

Specific gravity = $\frac{weig\ ht\ of\ bitumen}{weig\ ht\ of\ equal\ volume\ of\ water}$

Specific gravity =$\frac{(c-a}{(b-a)-(d-c)}$.............................Eq.3.7

a= weight of specific gravity bottle, (g)
b= weight of bottle filled with distilled water, (g)
c=weight of specific gravity bottle with half-filled bitumen, (g)
d= weight of bottle +bitumen+ distilled water, (g)

3.3.3. Mix Design
Mix design is a process of obtaining optimum binder content for the mix and determining mix constituents proportions such as coarse aggregate, fine aggregate and dust. In this thesis Marshall mix design method is adopted. The Marshall Stability and flow test provides the performance prediction measure for the Marshall mix design method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. Load is applied to the specimen till failure, and the maximum load is designated as stability. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) as a result of the loading. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded
Theoretical specific gravity of the mix Gt
Theoretical specific gravity Gt is the specific gravity without considering air voids, and is given by:

$$G_t = \frac{W_1 + W_2 + W_3 + W_4}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_4}{G_4}}$$ Eq.3.8

where, W1 is the weight of coarse aggregate in the total mix, W2 is the weight of fine aggregate in the total mix, W3 is the weight of filler in the total mix, W_b is the weight of bitumen in the total mix, G1 is the apparent specific gravity of coarse aggregate, G2 is the apparent specific gravity of fine aggregate, G3 is the apparent specific gravity of filler and Gb is the apparent specific gravity of bitumen.

3.3.3.4 Bulk specific gravity of mix Gmb
The bulk specific gravity or the actual specific gravity of the mix Gm is the specific gravity considering air voids and is found out by:

$$G_m b = \frac{W_m}{W_m - W_\omega} \text{ ....Eq.3.9}$$

Where, Wm is the weight of mix in air,
Ww is the weight of mix in water.

3.3.3.5 Air voids percent VvOr VTM
Air voids Vv is the percent of air voids by volume in the specimen and is given by:

$$V_\upsilon = \frac{(G_t - G_m)100}{G_t} \text{ ....Eq.3.10}$$

WhereGt is the theoretical specific gravity of the mix.
Gmb is the bulk or actual specific gravity of the mix.
Or below formula can be adopted.

VTM = {1- (Gmb/Gt)} $\times$100............................Eq.3.11

3.3.3.6 Percent volume of bitumen Vb
The volume of bitumen Vb is the percent of volume of bitumen to the total volume and given by:
Vb =Gmb$\times \frac{wb}{Gb}$.......................................Eq.3.12

Wb= the weight of bitumen in the total mix,
Gb = the apparent specific gravity of bitumen
Gmb = the bulk or actual specific gravity of the mix.

3.3.3.7 Voids in mineral aggregate VMA
Voids in mineral aggregate (VMA) is the volume of voids in the aggregates, and is the sum of air voids and volume of bitumen, and is calculated from:
VMA (%) = $V_v + V_b$........................Eq.3.13
Where, Vv is the percent air voids in the mix, given by equation 3.10. AndV_b is percent bitumen content in the mix, given by equation 3.12.
VMA can be also calculated by this equation:

VMA % = {1- Gmb (1-Pb) / Gse} $\times$ 100…........Eq.3.14
P_b= percentage of bitumen,
Gse = combined specific gravity of aggregate.

3.3.3.8 Voids filled with bitumen VFB
Voids filled with bitumen VFB is the voids percentage in the mineral aggregate frame work filled with the bitumen, and is calculated as:

VFG (%) =$\frac{vb \times 100}{VMA}$……...........................Eq.3.15

This equation also can be adopted to find VFB:

VFB % = {(VMA – VTM) / VMZ} $\times$100…….........Eq.3.16

3.3.3.9 Marshall Testing
Marshall stability is the maximum load required to produce failure of marshal specimen. When all the samples which contain required flakiness& elongation index is prepared, then the samples are kept in a water bath of 60°C temperature for 30-40 minutes. After that the sample is tested in Marshall Stability testing machine to obtain stability and flow of the mix.(S.K khanna and C.E.G. Justo - A.Veeraragavan, 2009)(Asphalt institute, 1995).

Fig. 3.13 Marshall Testing Device

Table 3.6 Marshall Volume correction

Correction factors for Marshall stability values Volume of Thickness Correction		
specimen (cm3)	of specimen (mm)	Factor
457 -470	57.1	1.19
471 -482	68.7	1.14
483 -495	60.3	1.09
496 -508	61.9	1.04
509 -522	63.5	1
523 -535	65.1	0.96
536 -546	66.7	0.93
547 -559	68.3	0.89
560 -573	69.9	0.86

Note: The stability value will be multiplied by correction factor.

Table 3.7 Marshall Specifications

Bitumen content 3	Stability (kg)	Flow (units)	Vv (%)	V F B (%)	Gm
3	499.4	9	12.5	34	2.17
4	717.3	9.6	7.2	65	2.21

5	812.7	12	3.9	84	2.26
6	767.3	14.8	2.4	91	2.23
7	662.8	19.5	1.9	93	2.18

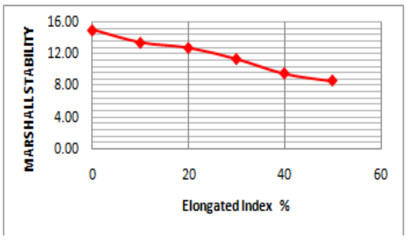
Test property	Specified Value
Marshall stability, kg	900 (minimum)
Flow value, mm	2 - 4
Percent air voids in the mix VTM %	3 - 6
Voids filled with bitumen VFB%	65 - 75
Void In mineral aggregate VMA %	12 - 14

DISCUSSION OF RESULTS
Average values of Marshall Test

%ofFlaky &Elongated Particles	Airvoids(Va)%	VoidsinMin.Agg.(VMA)%	Voidsfilled withBit.(VFB)%	MARSHALL STABILITY	Flow(mm)
	100-(100*Gmb/Gmm)	100-Gmb(100-pb)/Gsb	100x(VMA-Va)/VMA	Corr.Load (kn)Stability	
0	4.56	15.43	70.45	15.03	7.37
10	4.25	15.30	72.24	13.44	6.23
20	3.86	15.05	74.35	12.78	5.17
30	3.29	14.63	77.52	11.38	4.03
40	3.06	14.52	78.94	9.55	2.87
50	2.64	14.27	81.51	8.63	1.40

Marshall Stability

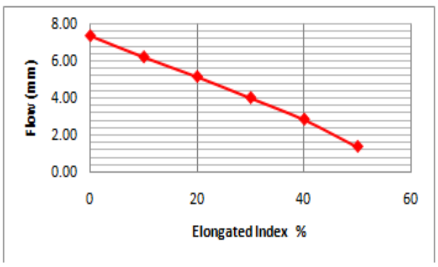
Flaky & Elongated %	MARSHALL STABILITY(KN)
0	15.03
10	13.44
20	12.78
30	11.38
40	9.55
50	8.63



From the above table and graph, it can be observed that with the increasing flakiness & elongation index, stability decreasedby42.58%.The maximum stability is 15.03 KN and sharply decreased to 8.63 KN at 50% flakiness & elongation index.

Marshall Flow

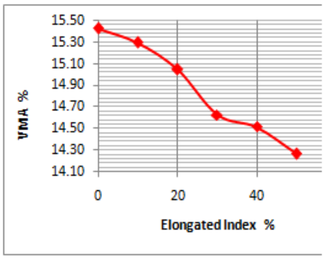
Flaky & Elongated %	Flow (mm)
0	7.37
10	6.23
20	5.17
30	4.03
40	2.87
50	1.40



From the above table and graph, it can be observed that with the increasing flakiness & elongation index, flow valued ecreased by 81%. The maximum value off low is 7.37 mm at non -flakymix. Andits 1.40 mm at 50% elongation index.

Voids in Mineral Aggregates

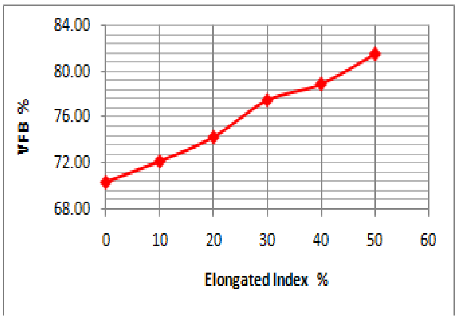
Elongated Index %	VMA %
0	15.43
10	15.30
20	15.05
30	14.63
40	14.52
50	14.27



From the above table and graph, the value of VMA is decreasing with increasing of flakiness & elongation index by 7.51%. VMA value is 15.43% at 0% flakinesss & elongation index and 14.27 % at 50 % flakiness & elongation index.

Voids Filled by Bitumen

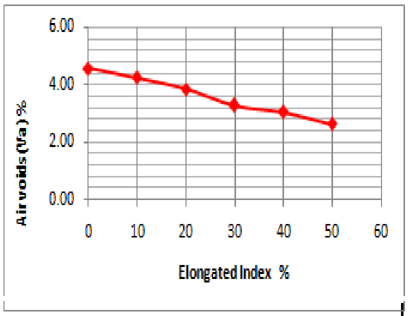
Flaky & Elongated %	VFB %
0	70.45
10	72.24
20	74.35
30	77.52
40	78.94
50	81.51



From the above table and graph, its observed that the value of VFB is increased by 13.57 % from 70.45% at 0% flaky & elongation index to 81.51% at 50% flakiness & elongation index. The standard limit for VFB is between 65-75%.

Voids in Total Mix

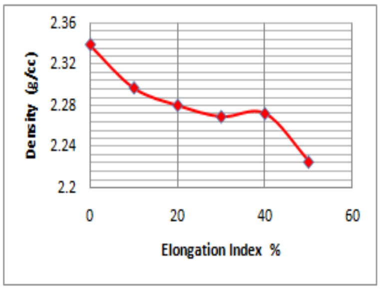
Flaky & Elongated %	Air voids(Va) %
0	4.56
10	4.25
20	3.86
30	3.29
40	3.06
50	2.64



From the above table and graph, it can observed that VTM is decreasing with increasing of elongation index by 34.19%. The value of VTM is decreased from 4.56% at 0% flakiness & elongation index to 2.64% at 50% flakiness & elongation index, while its limit is between 3-6 %.

Density

% of Elongated particles	Density (g/cc) Gmb=W1/V
0	2.34
10	2.298
20	2.281
30	2.27
40	2.273
50	2.226



From the above table and graph, it can observed that the value of density is decreasing with increasing of flakiness & elongation index by 4.871%. At 0% the value of density is 2.34g/cc, but at 50% flakiness & elongation index is 2.226%.

III. CONCLUSIONS

● From the results that are obtained from this study it has been concluded that flakiness & elongation index should be kept below 30 % for a better strength and durability.

● Increase of flaky & elongation index decreases the stability due to negative performance of flaky & elongated aggregates in the mix, since it's evident that flaky & elongated aggregates are weak and don't have a good interlocking ability and strength to form a good bond with surrounding aggregates.

● Flow is decreasing with increase in flakiness & elongation index in the mix, because due to lack of degree of interlocking the sample disintegrates earlier the lesser flow value will be obtained. Flow is a characteristic that varies by property and quantity of the bitumen depending on the elastic and viscous property of the bitumen.

● Voids in total mix (VTM) is decreased with increasing of flaky & elongation index , because in case of flaky & elongated aggregates with lacks an angular and cubical form the aggregate particles will be drawn nearer to each other but lacking stability and good compaction and interlocking, then voids between them are filled more and more by bitumen and dust particles, then voids in the mix will be reduced. This is a negative phenomenon, because presence of voids in the mix within acceptable range is very mandatory. In high temperature condition the bitumen inside the mix flows into those voids, so nonexistence of those voids will cause bleeding of the pavement. But in case of angular and cubical aggregates those void can be formed in a better form.

● Void filled with bitumen (VFB) is a property that is highly related to VTM. The more void percentage in the mix, decreases the strength and the more voids are filled by bitumen. So they are inversely proportional.

● Though VMA is an attribute which is related with filler ratio and viscosity of the bitumen but also it can be influenced by elongation index as well. Since we can see that VMA is related with VTM and both of them are influenced by particle shape and geometry.

● It can be observed that density is also related with VTM and flaky & elongation index. When the void in the mix decreases it implies that the mix is getting denser. Density increases with increase of flaky & elongation index.

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