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# Upgrading Properties of Aggregates in Flexible Pavements with e-Control

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**Abstract---** This paper involves a case study which has been carried out to upgrade the properties of aggregates with the use of e-quality control system in Highway construction. Flaky aggregates have larger surface area which results in higher demand of bitumen content in bituminous mix. Flaky aggregates also break during rolling and decrease the strength of the pavement layer. During the actual execution of work, the grading and size of the aggregates change from the designed one in the job mix formula due to practical reasons. These changes, even when within tolerance limits of the specifications, can upset the properties like workability and cohesiveness of bituminous mixes resulting in substandard quality of work. More compacting effort is required as the percentage of flakiness and elongation indices increases. The different percentage of flaky particles largely effect the properties of aggregates, such as, bulk density, impact value, crushing value, water absorption and angularity number etc. This study involves the solution of a real life problem faced by an engineer during the construction of a highway. In this paper, we present a methodology using e-quality control system how to upgrade the properties of aggregates in flexible pavements so as to get the best workability & strength with optimum use of bitumen content in the mix.

**Index Terms—** Angularity, Density, Elongation, e-control, Flakiness, Tolerance etc.

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## 1 Introduction

The quality of highway construction largely depends on the quality of aggregates used in the construction work. The properties of aggregates largely depend on the type of rock, strata of rock bed and the method used for its crushing etc. The property 'shape of aggregates' is measured in terms of Flakiness Index (FI), Elongation Index (EI) and Angularity Number (AN) [1]. Flaky and elongated aggregates are poor in physical strength, less workable due to high particle to particle contact area and need more bitumen content for same degree of workability compared to cubical aggregate of the same size and source due to higher surface area per unit weight. Such aggregate are not desired in the construction of highways [2]. However, it is very difficult to crush the aggregates totally free from flakiness. FI and EI are the measures of the extent of presence of flaky and elongated pieces in an aggregate mass. The lesser is the value of these measures in the aggregates, the better are the aggregates for construction purpose. Maximum values of these measures are prescribed in Ministry of Road Transport & Highways (MoRTH) Specification [3]. Neglecting the flakiness and elongation indices not only increases the immediate cost of the road but also affects the strength and durability of the pavement in the long run.



There are defined ranges of sizes of aggregates in specifications for use in different layers of highway construction. Even for the same layer, there are different grading sets with defined ranges i.e. tolerance limits. The sizes of aggregates, as per specifications, can be used within these tolerance limits. This high variation in proportions of materials within permissible tolerance limits in the specifications can also upset a well-designed mix resulting into poor quality of work. It is also affecting the degree of workability and other properties of the finished work including bitumen content as designed in the job mix formula. These tolerance limits in the sizes of aggregates are too wide that even the use of aggregates within the prescribed limits can also change the properties of the designed mix. The properties of the aggregates can be upgraded through use of e-quality control system [4] which can also control the shape and size of aggregates to make those as close as possible to grading in job mix formula. Tolerance limits [5] also needs to be reduced so that any use of aggregates within the prescribed limits may not affect the properties of designed mix. It will also improve the riding quality of the highways [6] with the use of updated sophisticated machinery [7].

## 2. Effects of Surface Area of Aggregates

In the codal provisions/specifications, the tolerance limits have been given for the range of aggregates to be used in various type of mixes. While designing the job mix formula, it is designed on particular size of grading of aggregates and not for range of aggregates. When some other grading of aggregates which are different from the designed one are used, the surface area of the aggregates changes which largely affects the properties of aggregates. There can be increase in the flaky particles which will require more bitumen content for more surface area of aggregates. It also reduces the strength & workability of bituminous mix [8].

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The design of a bituminous mix for the construction of a highway also depends on shape and size of the aggregates. As there is wide range of tolerance limits for size of aggregates in the specifications, whenever the material used is of lesser size or more flaky then the designed size of aggregates in job mix formula, then there is increase in surface area per unit weight of aggregates requiring more quantity of bitumen content in bituminous mix for same weight of aggregates. The shape & size of the aggregates largely affect the surface area of aggregates as given below in para 2.1 and 2.2.

## 2.1 Shape of Aggregates

The cubical shape of the aggregates is the most desirable shape. Flaky aggregates have more surface area per unit weight as compared to cubical aggregates for the same condition of size based on sieve analysis. This is explained analytically in Table No. 1 by taking imaginary shapes of aggregates:

**Table No. 1**
**(Effect of shape on Surface Area per unit weight of Aggregates)**

| Aggregate Size (mm) | Aggregates | | Vol. of single piece (mm3) | Wt. of single piece (g)=col 4 x 2.78/1000 | Surface area of single piece(mm2) | Surface area per unit wt (mm2/g) = col 6/ col 5 | Remarks |
|---|---|---|---|---|---|---|---|
| | Cate-gory | Shape | | | | | |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 26.5 | A | Cubical (26.5 x 26.5 x 26.5) | 18609.6 | 51.73 | 4229.40 | 81.76 | With change in shape from type A to type B, the surface area increases 1.08 times and to type C, the surface area increases 1.22 times |
| | B | One dimension of cube is 80% (26.5 x 26.5 x 21.2) | 14887.7 | 41.39 | 3651.7 | 88.23 | |
| | C | One dimension of cube is 60% (26.5 x 26.5 x 15.9) | 11165.8 | 31.04 | 3089.9 | 99.55 | |



From the above table it is clear that surface area per unit weight increases 1.22 times as the shape of aggregates changes from shape type A to type C which is flaky.

## 2.2 Size of Aggregates

Smaller the size of aggregate-piece, large is the surface area per unit weight. This fact is made clear in Table No.2 below:

**Table no. 2**
**(Effect of variation in Size of aggregates on Surface Area of Aggregates)**

| Aggregate Shape | Size of Aggregates | Vol. of single piece (mm3) | Wt. of single piece (g) = col 4 x 2.73/1000 | Number of pieces per kg | Surface area of single piece (cm2) | Surface area per unit wt (mm2/g) = col 6/ col 5 | Remarks |
|---|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| Cubical | 26.5 | 18610 | 50.78 | 19.69 | 42.14 | 829.74 | With change in size from 26.5 mm to 22.4 mm, the surface area increases by 1.19 times and to size 13.2 mm, the surface area increases by 2.01 times |
| | 22.4 | 11139 | 30.41 | 32.88 | 30.11 | 990.01 | |
| | 13.2 | 2300 | 6.28 | 159.24 | 10.45 | 1664.06 | |

From the above table it is clear that surface area per kg of aggregates increases to 1.19 times as the change in size of aggregates from 26.5 mm to 22.4 mm & 2.01 times in case of change to 13.2 mm size.

## 3. Experimental Work

For an experimental work, we select a sanctioned project "Construction of NH-4 (Belgaum-Dharwad section from km.433 to km.515) executed in the State of Karnataka, India" at an estimated cost of Rs.480.00 crores on DBFO (Design, Built, Finance & Operation) pattern. The execution of work is being carried out by National Highways Authority of India according to technical specifications laid down by Ministry of Road Transport & Highways (MoRT&H). For the sake of simplicity in presenting our methodology the data is collected at site and evaluated as under:

### 3.1 Properties of Aggregates

The laboratory tests were carried out on the aggregates to ascertain their various properties such as, sieve analysis, specific gravity, impact value, crushing value, flakiness index, elongation index, water absorption, angularity number and bulk density etc. The results are shown below in Table No. 3:

**Table No. 3**
**(Properties of Aggregates)**

| Sr. No. | Properties | Test Value | Method of Test |
|---|---|---|---|
| 1 | Specific gravity | 2.78 | IS:2386 Part (IV) – 1963 |
| 2 | Impact value, % | 14 | IS: 2386 Part (IV) - 1963 |
| 3 | Crushing value, % | 22 | IS: 2386 Part (I) - 1963 |
| 4 | Flakiness index, % | 12.1 | IS: 2386 Part (I) - 1963 |
| 5 | Elongation index, % | 11.2 | IS: 2386 Part (I) - 1963 |
| 6 | Water absorption, % | 1.25 | IS: 2386 Part (III) - 1963 |
| 7 | Angularity number | 5.6 | IS: 383 – 1970 |
| 8 | Bulk density, kg/m3 | 1.677x103 | IS: 383 – 1970 |

The flakiness index of aggregates as tested is 12.1% and elongation index is 11.2%. The combined flakiness and elongation index was 23.3%.



### 3.2 Change in Properties of Aggregates with increase in Flaky Particles

All the flaky particles are separated from the aggregates collected. Six different aggregate mixtures are prepared by changing the percentage of flaky aggregates as 0, 30, 40, 60, 70 and 100 in the total aggregates. The properties of the aggregates such as bulk density, impact value, crushing value, water absorption and angularity number with different percentages of flaky particles are determined. The results are shown below in Table 4:

**Table No. 4**
**(Properties of Aggregate with Different Percentages of Flaky Particles)**

| Flaky Particle (%) | Impact value (%) | Bulk density (kg/m3) | Crushing value (%) | Angularity number | Water absorption (%) |
|---|---|---|---|---|---|
| 0 | 13 | 1.69 x 103 | 21 | 3.5 | 1.22 |
| 30 | 15 | 1.66 x 103 | 23 | 6.0 | 1.28 |
| 40 | 16 | 1.65 x 103 | 23 | 8.8 | 1.36 |
| 60 | 18 | 1.61 x 103 | 24 | 10 | 1.42 |
| 70 | 18 | 1.58 x 103 | 25 | 11 | 1.48 |
| 100 | 22 | 1.57 x 103 | 28 | 12 | 1.56 |

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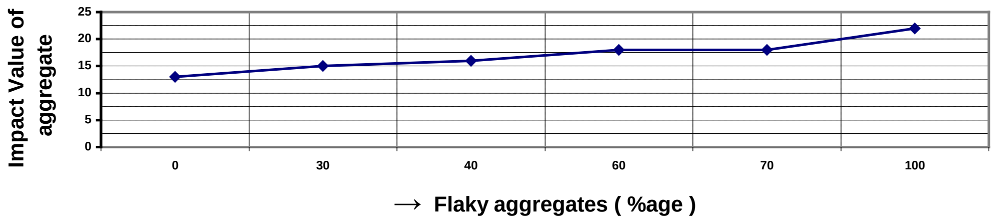
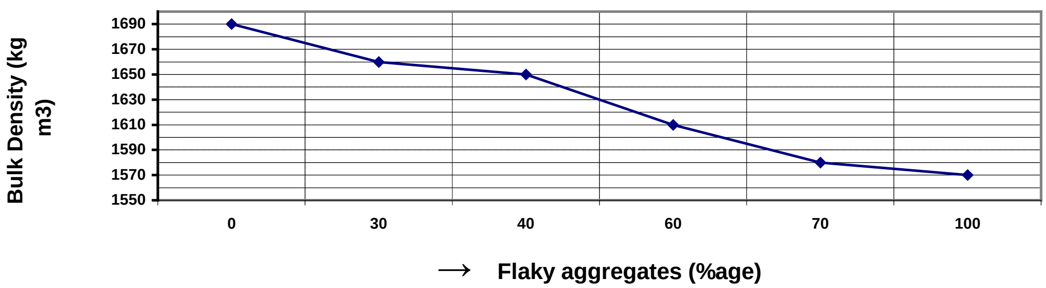
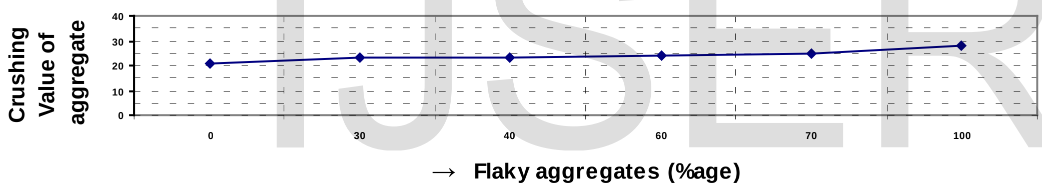
**Graph No.1 : % age Flaky Aggregate Vs Impact Value**




**Graph No.2 : % age Flaky Aggregate Vs Bulk Density**

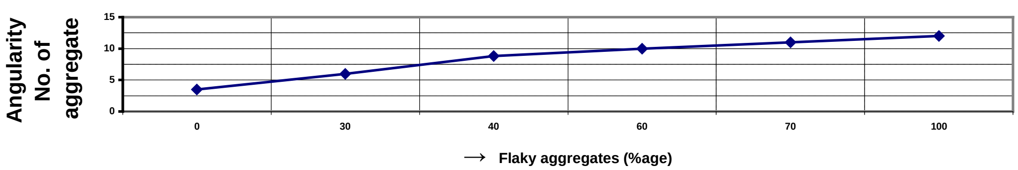



**Graph No.3 : % Flaky Aggregate Vs Crushing Value**

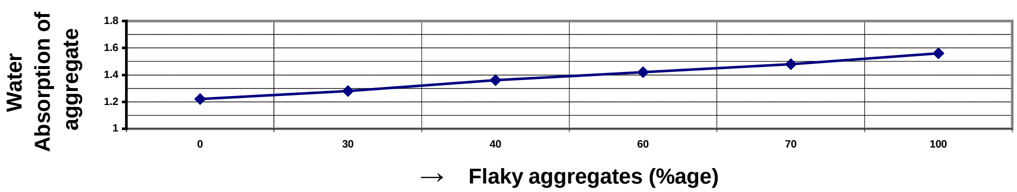





**Graph No.4 : % Flaky Aggregates Vs Angularity Number**




**Graph No.5 : % Flaky Aggregate Vs Water Absorption**



### 3.3 Effect of Size & Shape of Aggregates on Bitumen Content in DBM

For ascertaining the effect of shape and size of aggregates within the tolerance limits prescribed in the specifications, the different moulds were prepared using the gradation close to the higher & lower limits permissible in the specifications in DBM (Grade-1) as under:

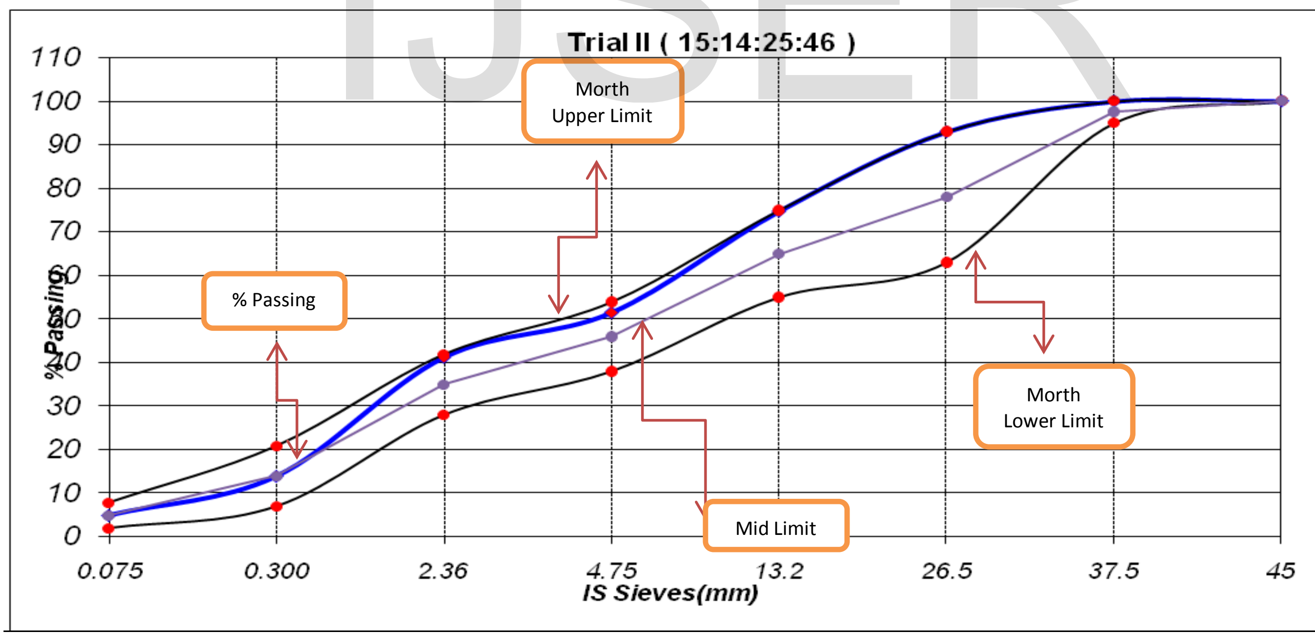
**Table No. 5**
**(Grading of Aggregate in DBM Gradre-1)**

| Sr. No. | Sieve Size (mm) | Limits as per Specifications | | | Grading as per Trail | |
|---|---|---|---|---|---|---|
| | | Limits | Higher Limits | Lower Limits | Higher Limits | Lower Limits |
| 1 | 45 | 100 | 100 | 100 | 100 | 100 |
| 2 | 37.5 | 95-100 | 100 | 95 | 99.96 | 99.89 |
| 3 | 26.5 | 63-93 | 93 | 63 | 92.96 | 80.33 |
| 5 | 13.2 | 55-75 | 75 | 55 | 74.73 | 55.15 |
| 6 | 4.75 | 38-54 | 54 | 38 | 51.49 | 38.42 |
| 7 | 2.36 | 28-42 | 42 | 28 | 41.25 | 30.51 |
| 8 | 0.300 | 7-21 | 21 | 7 | 13.97 | 10.34 |
| 9 | 0.075 | 2-8 | 8 | 2 | 5.00 | 3.71 |

### (a) Using Higher Limits

The higher limits of size of aggregates as given in Table No. 5 are taken for the trail and their variation from the limits in the specifications is shown below in Graph No. 6:

**Graph No. 6**
**(Gradation of Aggregates with Upper Limit in DBM)**




The Marshall tests are conducted as shown in Table No. 6 & the results are graphically presented in Graph No.7:

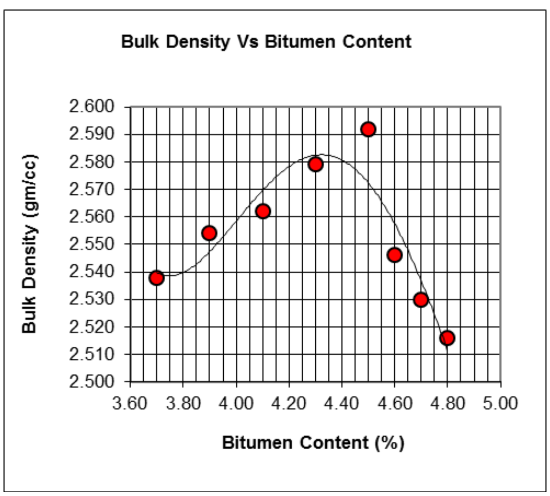
**Table No. 6**
**(Marshall Test with Upper Limits in DBM)**

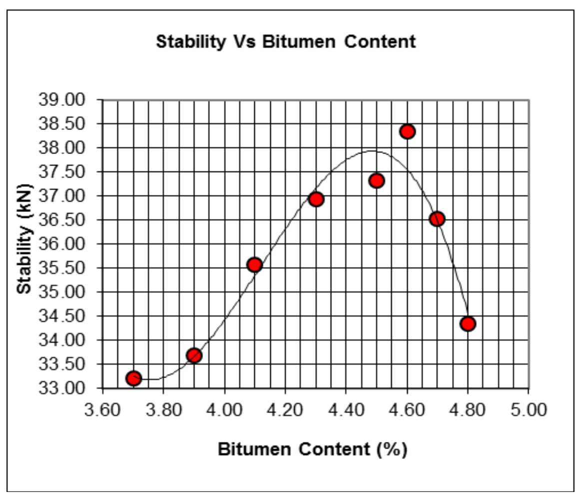
| Test | Bitumen | Bulk | Average | Air void's | Void's in | Void's filled | Marshall Stability | Flow | Average |
|---|---|---|---|---|---|---|---|---|---|

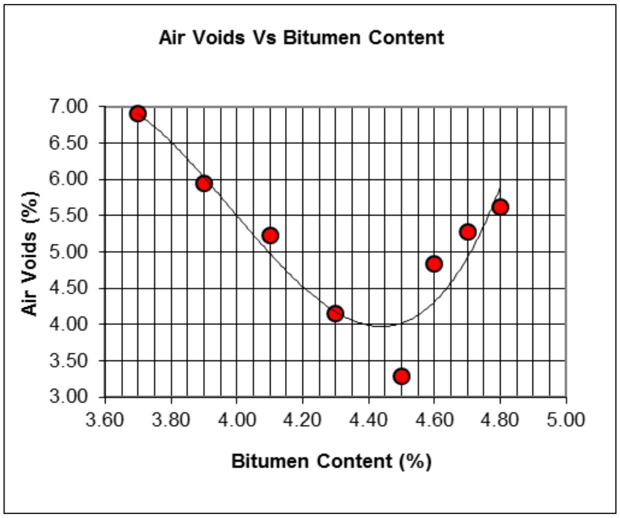
| No. | Content (%) | Density (g/cc) | bulk density (g/cc) | (Va) (%) | Mineral Aggregate (VMA) (%) | by Bitumen (VFB) (%) | Corrected Load (KN) | Average Load (KN) | (mm) | flow (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| A1 | | 2.545 | | | | | 33.15 | | 2.10 | |
| A2 | 3.70 | 2.531 | 2.538 | 6.91 | 14.92 | 53.65 | 33.45 | 33.22 | 2.40 | 2.37 |
| A3 | | 2.537 | | | | | 33.05 | | 2.60 | |
| B1 | | 2.559 | | | | | 38.01 | | 2.10 | |
| B2 | 3.90 | 2.548 | 2.554 | 5.94 | 14.55 | 59.18 | 29.13 | 33.70 | 4.00 | 2.83 |
| B3 | | 2.554 | | | | | 33.96 | | 2.40 | |
| C1 | | 2.561 | | | | | 36.39 | | 2.80 | |
| C2 | 4.10 | 2.564 | 2.562 | 5.23 | 14.46 | 63.83 | 36.79 | 35.58 | 2.90 | 2.93 |
| C3 | | 2.560 | | | | | 33.56 | | 3.10 | |
| D1 | | 2.590 | | | | | 37.60 | | 1.90 | |
| D2 | 4.30 | 2.569 | 2.579 | 4.15 | 14.05 | 70.47 | 36.39 | 36.93 | 3.70 | 2.97 |
| D3 | | 2.579 | | | | | 36.79 | | 3.30 | |
| E1 | | 2.591 | | | | | 38.01 | | 2.80 | |
| E2 | 4.50 | 2.589 | 2.592 | 3.29 | 13.81 | 76.20 | 36.79 | 37.33 | 3.70 | 3.23 |
| E3 | | 2.595 | | | | | 37.20 | | 3.20 | |
| F1 | | 2.545 | | | | | 38.19 | | 4.50 | |
| F2 | 4.60 | 2.548 | 2.546 | 4.84 | 15.44 | 68.66 | 38.01 | 38.34 | 4.00 | 4.20 |
| F3 | | 2.543 | | | | | 38.81 | | 4.10 | |
| G1 | | 2.530 | | | | | 36.39 | | 4.40 | |
| G2 | 4.70 | 2.528 | 2.530 | 5.27 | 16.04 | 67.13 | 36.20 | 36.53 | 4.60 | 4.40 |
| G3 | | 2.532 | | | | | 36.99 | | 4.20 | |
| H1 | | 2.516 | | | | | 34.63 | | 3.20 | |
| H2 | 4.80 | 2.511 | 2.516 | 5.62 | 16.59 | 66.14 | 35.41 | 34.36 | 3.10 | 3.23 |
| H3 | | 2.521 | | | | | 33.05 | | 3.40 | |

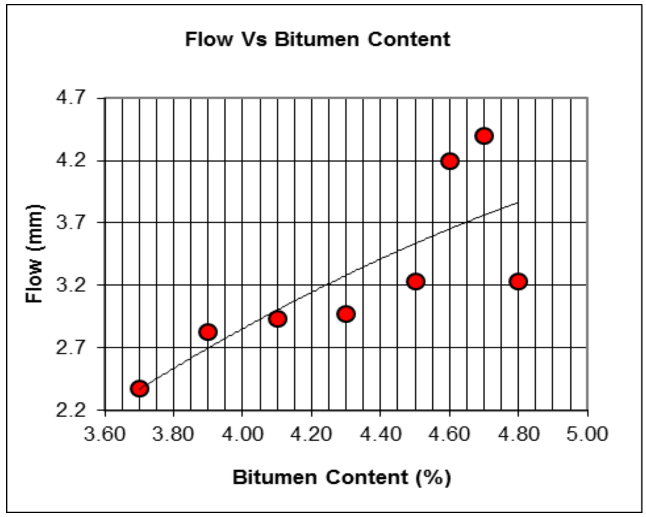


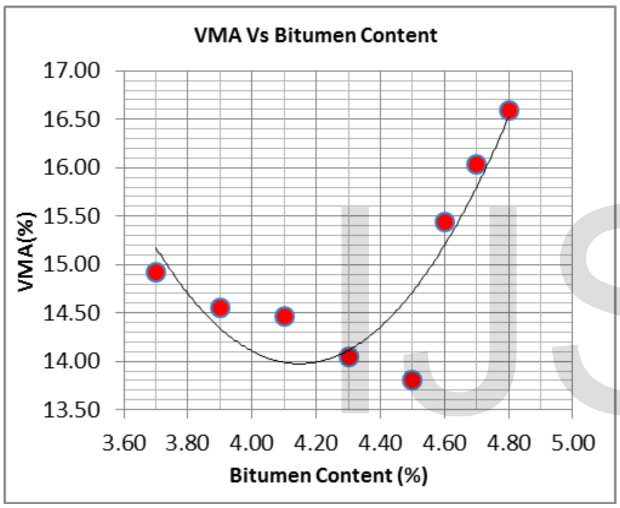
**GRAPH NO. 7**
**(MARSHALL TRAIL IN DBM WITH UPPER LIMIT)**

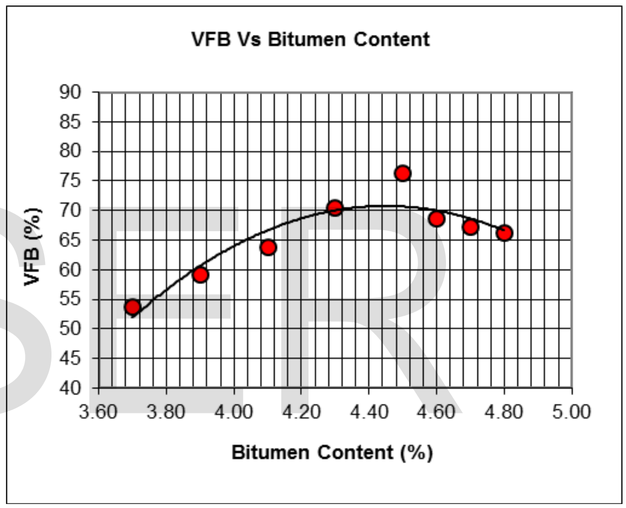




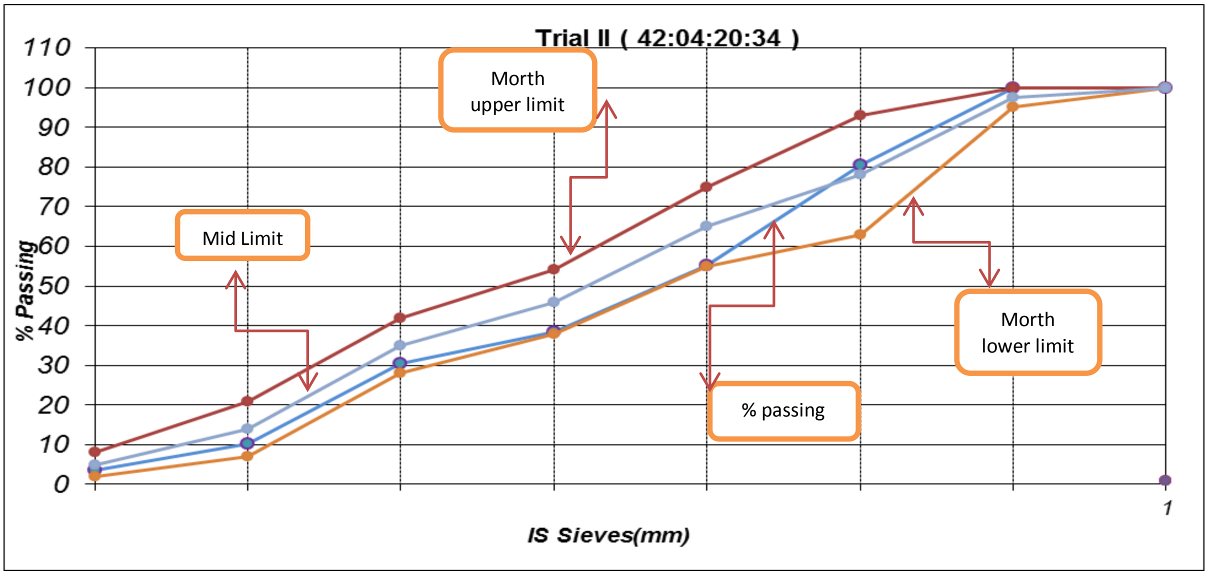




## (b) Using Lower Limits

The lower limits of size of aggregates as given in Table No. 5 are taken in the trail and their variation from the limits in the specifications is shown below in Graph No. 8:

**GRAPH NO. 8**
**(GRADATION OF AGGREGATES WITH LOWER LIMIT IN DBM)**



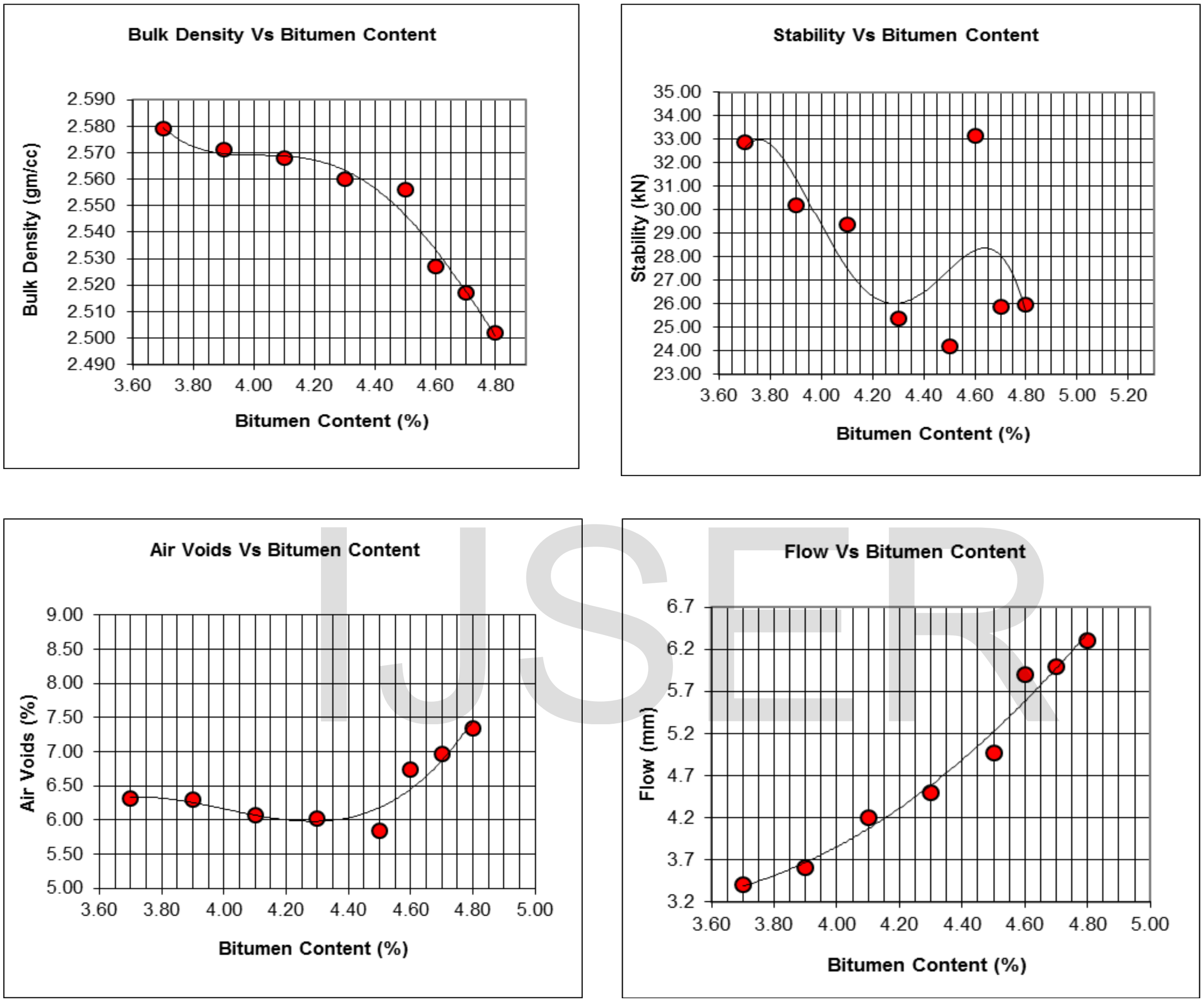

The Marshall tests are conducted as shown in Table No.7 & the results are graphically presented in Graph No.9:

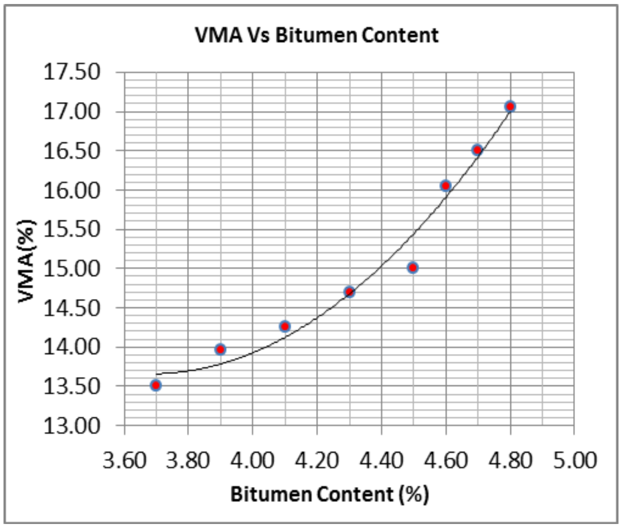
**TABLE NO.7**
**(MARSHALL TEST WITH LOWER LIMITS IN DBM)**

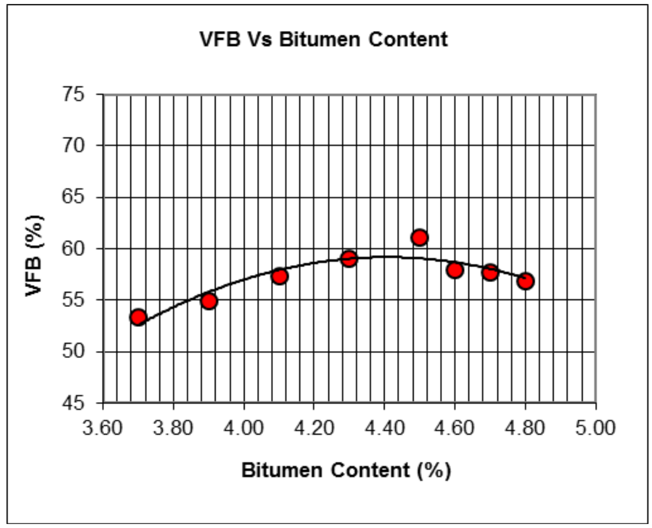
| Test No. | Bitumen Content (%) | Bulk Density (g/cc) | Average bulk density (g/cc) | Air void's (Va) (%) | Void's in Mineral Aggregate (VMA) (%) | Void's filled by Bitumen (VFB) (%) | Marshall Stability | | Flow (mm) | Average flow (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Corrected Load (KN) | Average Load (KN) | | |
| A1 | 3.70 | 2.575 | 2.579 | 6.31 | 13.51 | 53.32 | 38.41 | 32.88 | 2.50 | 3.40 |
| A2 | | 2.586 | | | | | 27.49 | | 4.30 | |
| A3 | | 2.577 | | | | | 32.75 | | 3.40 | |
| B1 | 3.90 | 2.577 | 2.571 | 6.30 | 13.97 | 24.87 | 33.15 | 30.19 | 3.40 | 3.60 |
| B2 | | 2.564 | | | | | 27.09 | | 3.80 | |
| B3 | | 2.572 | | | | | 30.32 | | 3.60 | |
| C1 | 4.10 | 2.570 | 2.568 | 6.07 | 14.25 | 57.39 | 33.56 | 29.38 | 3.40 | 4.20 |
| C2 | | 2.566 | | | | | 25.07 | | 5.00 | |
| C3 | | 2.568 | | | | | 29.52 | | 4.20 | |
| D1 | 4.30 | 2.562 | 2.560 | 6.02 | 14.70 | 59.03 | 24.40 | 25.38 | 6.00 | 4.50 |
| D2 | | 2.559 | | | | | 26.28 | | 3.00 | |
| D3 | | 2.559 | | | | | 25.47 | | 4.50 | |
| E1 | 4.50 | 2.556 | 2.556 | 5.84 | 15.00 | 61.03 | 25.18 | 24.22 | 3.90 | 4.97 |
| E2 | | 2.560 | | | | | 23.85 | | 5.90 | |
| E3 | | 2.553 | | | | | 23.61 | | 5.10 | |
| F1 | 4.60 | 2.527 | 2.527 | 6.74 | 16.05 | 58.00 | 33.15 | 33.15 | 5.90 | 5.90 |
| F2 | | 2.528 | | | | | 32.35 | | 6.20 | |
| F3 | | 2.526 | | | | | 33.96 | | 5.60 | |
| G1 | 4.70 | 2.517 | 2.517 | 6.97 | 16.50 | 57.76 | 25.88 | 25.88 | 6.00 | 6.00 |
| G2 | | 2.514 | | | | | 24.26 | | 6.20 | |
| G3 | | 2.519 | | | | | 27.49 | | 5.80 | |
| H1 | 4.80 | 2.502 | 2.502 | 7.35 | 17.05 | 56.89 | 25.97 | 25.97 | 6.30 | 6.30 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| H2 | | 2.509 | | | | | 23.61 | | 6.20 | |
| H3 | | 2.496 | | | | | 28.33 | | 6.40 | |

**GRAPH NO. 9**
**(MARSHALL TRAIL IN DBM WITH LOWER LIMIT)**






### 3.3.1 Effect of Size & Shape of Aggregates on Bitumen Content in Case of BC

Similarly, for ascertaining the effect of shape and size of aggregates within the tolerance limits prescribed in the specifications, the different moulds were prepared using the gradation close to the higher & lower limits permissible in the specifications in BC (Grade-2) as under:

**Table No. 8**
**(Grading of Aggregate in BC Gradre-2)**

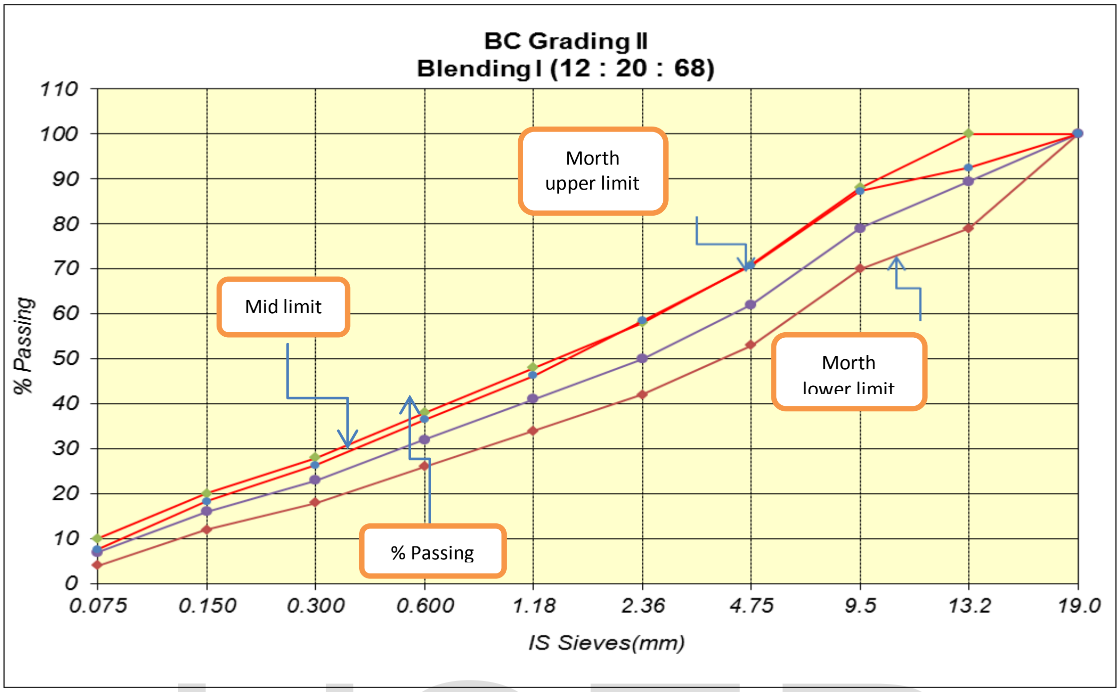


| Sr. No. | Sieve Size (mm) | Limits as per Specifications | | | Grading as per Trail | |
|---|---|---|---|---|---|---|
| | | Limits | Higher Limits | Lower Limits | Higher Limits | Lower Limits |
| 1 | 19 | 100 | 100 | 100 | 100 | 100 |
| 2 | 13.2 | 79-100 | 100 | 79 | 92.53 | 81.33 |
| 3 | 9.5 | 70-88 | 88 | 70 | 87.27 | 70.41 |
| 4 | 4.75 | 53-71 | 71 | 53 | 70.75 | 53.52 |
| 5 | 2.36 | 42-58 | 58 | 42 | 58.40 | 43.55 |
| 6 | 1.18 | 34-48 | 48 | 34 | 46.28 | 34.23 |
| 7 | 0.600 | 26-38 | 38 | 26 | 36.47 | 26.98 |
| 8 | 0.300 | 18-28 | 28 | 18 | 26.37 | 19.39 |
| 9 | 0.150 | 12-20 | 20 | 12 | 18.25 | 13.42 |
| 10 | 0.075 | 4-10 | 10 | 4 | 7.56 | 5.56 |

### (a) Using Higher Limits

The higher limits of size of aggregates as given in Table No.8 are taken in the trail and their variation from the limits in the specifications is shown below in Graph No. 10:

**GRAPH NO. 10**
**(GRADATION OF AGGREGATES WITH HIGHER LIMIT IN BC)**




The Marshall tests are conducted as shown in Table No. 9 & the results are graphically presented in Graph No.7:

| Test No. | Bitumen Content (%) | Bulk Density (g/cc) | Average bulk density (g/cc) | Air void's (Va) (%) | Void's in Mineral Aggregate (VMA)(%) | Void's filled by Bitumen (VFB)(%) | Marshall Stability | | Flow (mm) | Average flow (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Corrected Load (KN) | Average Load (KN) | | |
| A1 | 4.00 | 2.491 | 2.494 | 7.36 | 15.76 | 53.30 | 11.29 | 12.10 | 2.20 | 1.90 |
| A2 | | 2.499 | | | | | 13.71 | | 1.50 | |
| A3 | | 2.492 | | | | | 11.29 | | 2.00 | |
| B1 | 4.20 | 2.507 | 2.506 | 6.59 | 15.52 | 57.53 | 14.52 | 15.33 | 2.40 | 2.00 |
| B2 | | 2.511 | | | | | 16.94 | | 1.40 | |
| B3 | | 2.500 | | | | | 14.52 | | 2.20 | |
| C1 | 4.40 | 2.544 | 2.543 | 4.88 | 14.47 | 66.27 | 17.72 | 16.93 | 2.20 | 2.23 |
| C2 | | 2.539 | | | | | 16.13 | | 2.40 | |
| C3 | | 2.545 | | | | | 16.94 | | 2.10 | |
| D1 | 4.60 | 2.572 | 2.573 | 3.42 | 13.63 | 74.94 | 18.56 | 19.40 | 2.60 | 2.30 |
| D2 | | 2.573 | | | | | 20.25 | | 1.50 | |
| D3 | | 2.574 | | | | | 19.40 | | 2.80 | |
| E1 | 4.80 | 2.577 | 2.561 | 3.53 | 14.20 | 75.14 | 19.40 | 17.89 | 2.00 | 2.43 |
| E2 | | 2.551 | | | | | 16.94 | | 2.80 | |
| E3 | | 2.556 | | | | | 17.34 | | 2.50 | |
| F1 | 5.00 | 2.545 | 2.551 | 3.60 | 14.73 | 75.58 | 16.03 | 16.77 | 2.90 | 2.77 |
| F2 | | 2.551 | | | | | 17.34 | | 2.40 | |
| F3 | | 2.557 | | | | | 16.94 | | 3.00 | |
| G1 | 5.20 | 2.548 | 2.540 | 3.67 | 15.27 | 75.95 | 15.39 | 16.15 | 3.00 | 3.03 |
| G2 | | 2.535 | | | | | 18.55 | | 2.90 | |
| G3 | | 2.538 | | | | | 14.52 | | 3.20 | |
| H1 | 5.40 | 2.532 | 2.530 | 3.76 | 15.78 | 76.17 | 14.52 | 14.65 | 3.90 | 3.67 |
| H2 | | 2.537 | | | | | 16.54 | | 3.20 | |
| H3 | | 2.522 | | | | | 12.91 | | 3.90 | |

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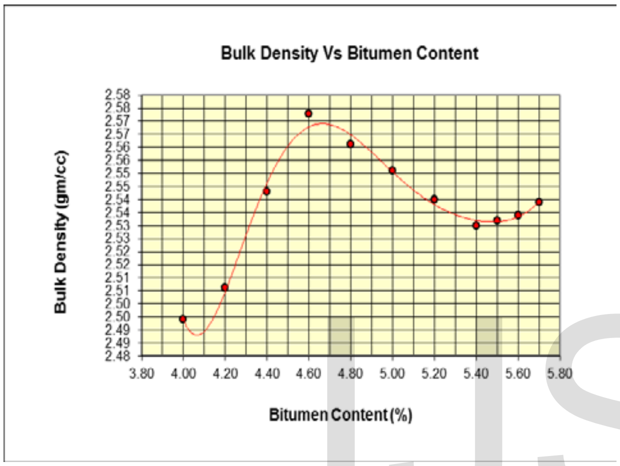
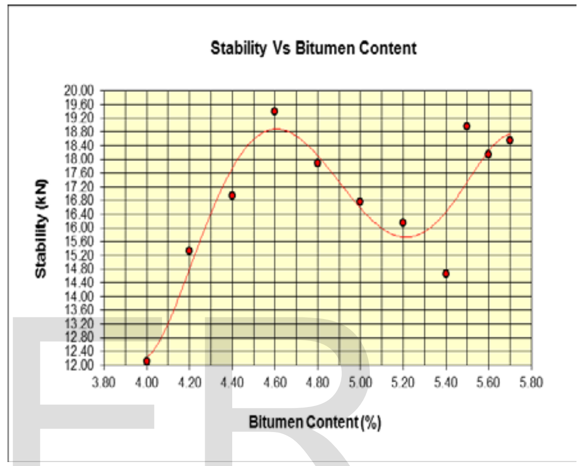
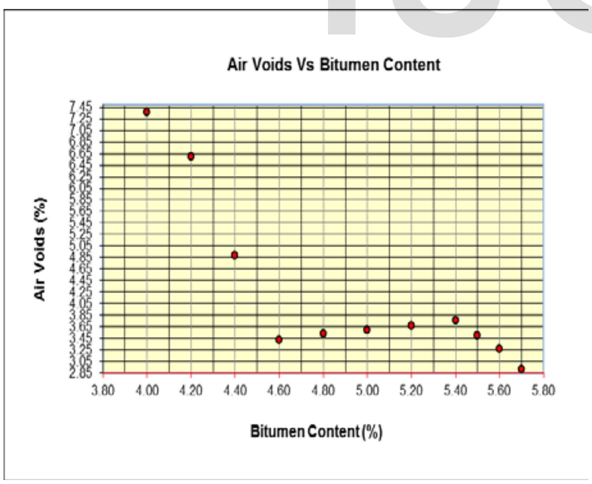
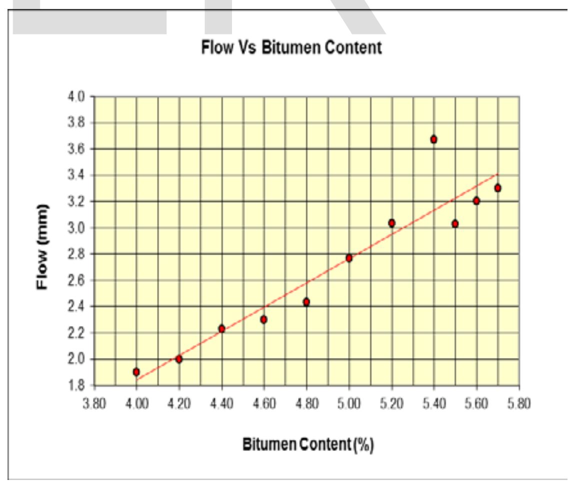
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| I1 | 5.50 | 2.539 | 2.532 | 3.50 | 15.80 | 77.85 | 18.96 | 18.96 | 3.00 | 3.03 |
| I2 | | 2.532 | | | | | 19.36 | | 3.30 | |
| I3 | | 2.526 | | | | | 18.55 | | 2.80 | |
| J1 | 5.60 | 2.530 | 2.534 | 3.27 | 15.82 | 79.30 | 18.55 | 18.15 | 3.20 | 3.20 |
| J2 | | 2.538 | | | | | 18.15 | | 3.10 | |
| J3 | | 2.535 | | | | | 17.75 | | 3.30 | |
| K1 | 5.70 | 2.544 | 2.539 | 2.92 | 15.77 | 81.46 | 19.36 | 18.55 | 3.30 | 3.30 |
| K2 | | 2.536 | | | | | 18.55 | | 3.20 | |
| K3 | | 2.536 | | | | | 17.75 | | 3.40 | |

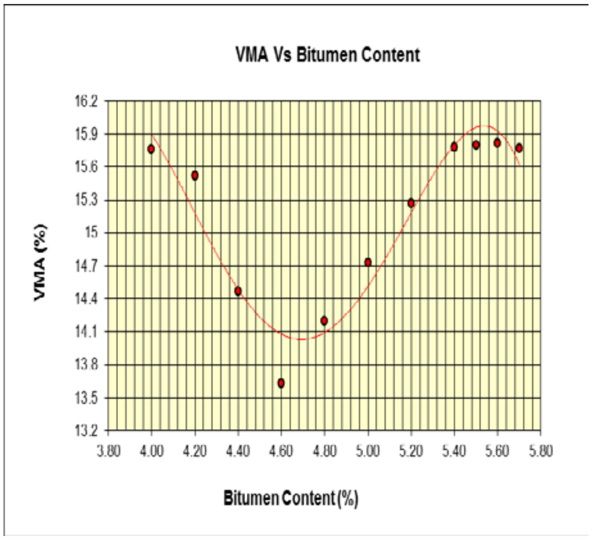
**GRAPH NO. 11**
**(MARSHALL TRAIL IN BC WITH HIGHER LIMIT)**

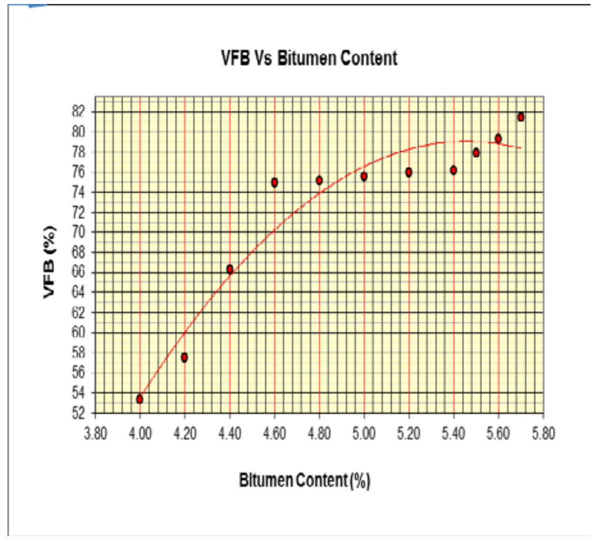


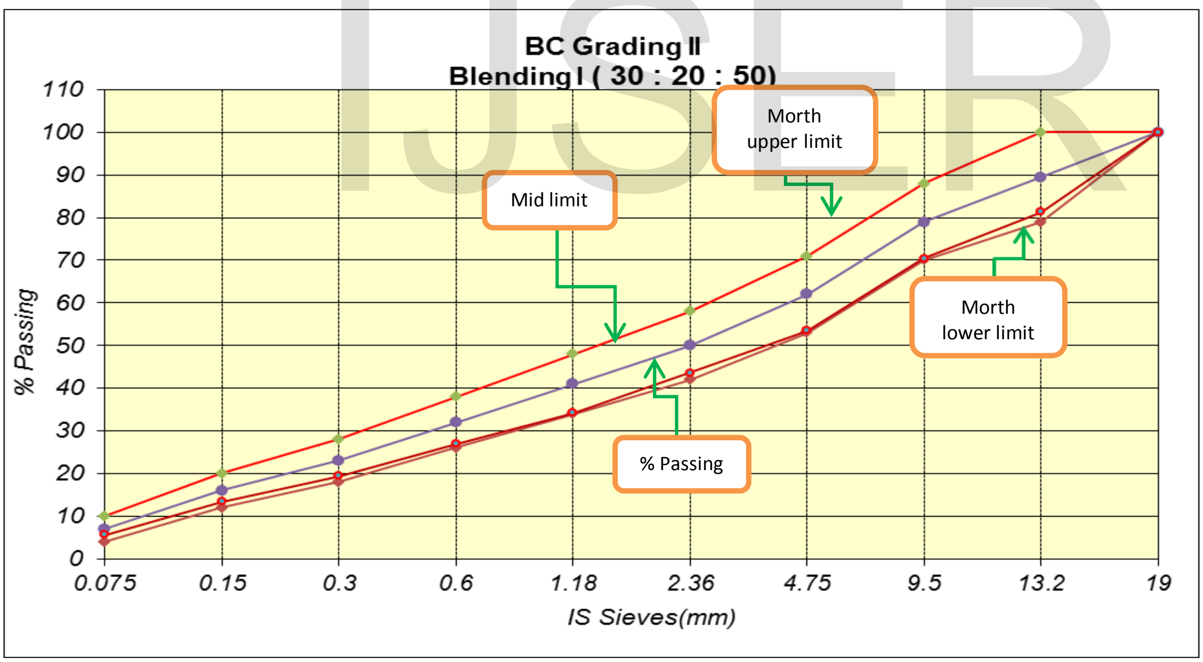



**(b) Using Lower Limits**

The lower limits of size of aggregates as given in Table No. 8 are taken in the trail and their variation from the limits in the specifications is shown below in Graph No. 12:

**Graph No. 12**
**(Gradation of Aggregates with Lower Limit in BC)**



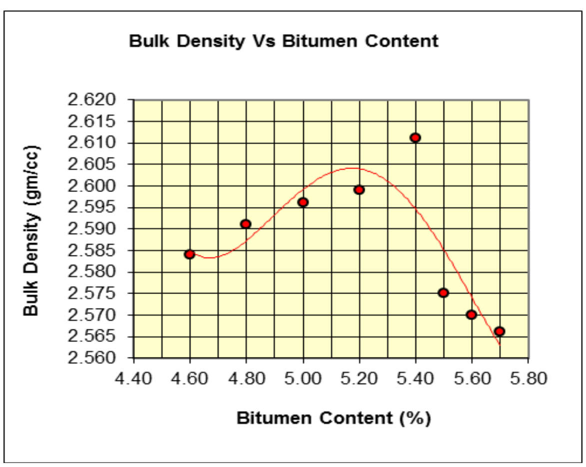

The Marshall tests are conducted as shown in Table No. 10 & the results are graphically presented in Graph No.13:

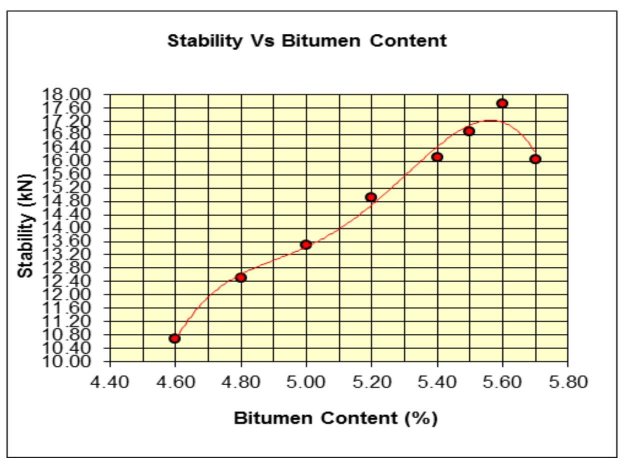
**TABLE NO. 10**
**(MARSHALL TRAIL IN BC WITH LOWER LIMIT)**

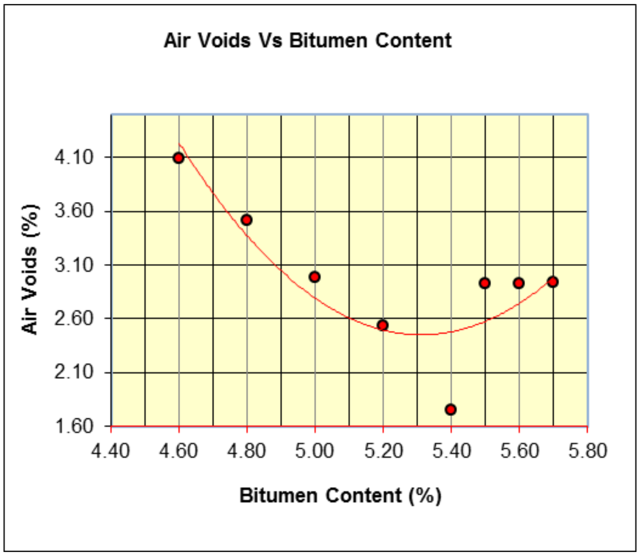
| Test No. | Bitumen Content (%) | Bulk Density (g/cc) | Average bulk density (g/cc) | Air void's (Va) (%) | Void's in Mineral Aggregate (VMA) (%) | Void's filled by Bitumen (VFB) (%) | Marshall Stability | | Flow (mm) | Average flow (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Corrected Load (KN) | Average Load (KN) | | |
| A1 | 4.60 | 2.583 | 2.584 | 4.09 | 13.39 | 69.42 | 10.55 | 10.69 | 3.00 | 2.83 |
| A2 | | 2.584 | | | | | 10.97 | | 2.60 | |
| A3 | | 2.585 | | | | | 10.55 | | 2.90 | |
| B1 | 4.80 | 2.595 | 2.591 | 3.52 | 13.35 | 73.63 | 12.65 | 12.51 | 2.30 | 2.47 |
| B2 | | 2.584 | | | | | 12.23 | | 2.60 | |
| B3 | | 2.593 | | | | | 12.65 | | 2.50 | |
| C1 | 5.00 | 2.588 | 2.596 | 2.98 | 13.34 | 77.65 | 13.50 | 13.50 | 2.70 | 2.70 |
| C2 | | 2.604 | | | | | 13.92 | | 2.30 | |
| C3 | | 2.597 | | | | | 13.08 | | 3.10 | |
| D1 | 5.20 | 2.591 | 2.599 | 2.54 | 13.42 | 81.09 | 14.34 | 14.90 | 3.10 | 2.97 |
| D2 | | 2.605 | | | | | 15.18 | | 3.00 | |
| D3 | | 2.602 | | | | | 15.18 | | 2.80 | |
| E1 | 5.40 | 2.621 | 2.611 | 1.75 | 13.23 | 86.77 | 16.73 | 16.12 | 2.10 | 2.67 |
| E2 | | 2.597 | | | | | 15.61 | | 2.90 | |
| E3 | | 2.614 | | | | | 16.03 | | 3.00 | |
| F1 | 5.50 | 2.575 | 2.575 | 2.93 | 14.49 | 79.81 | 16.87 | 16.87 | 3.90 | 3.90 |
| F2 | | 2.568 | | | | | 17.72 | | 4.10 | |
| F3 | | 2.583 | | | | | 16.03 | | 3.70 | |
| G1 | 5.60 | 2.570 | 2.570 | 2.93 | 14.74 | 80.13 | 18.56 | 17.72 | 3.40 | 3.43 |
| G2 | | 2.575 | | | | | 17.72 | | 3.60 | |
| G3 | | 2.566 | | | | | 16.87 | | 3.30 | |
| H1 | 5.70 | 2.567 | 2.566 | 2.94 | 14.97 | 80.38 | 16.03 | 16.05 | 3.00 | 3.00 |
| H2 | | 2.551 | | | | | 16.94 | | 3.20 | |
| H3 | | 2.580 | | | | | 15.18 | | 2.80 | |

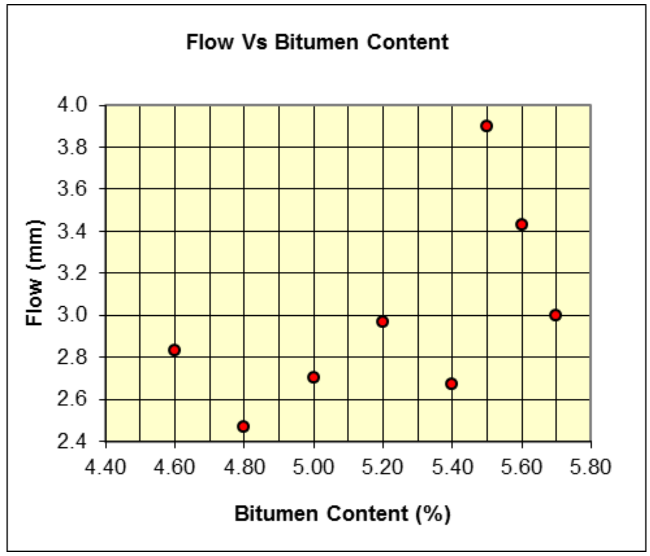


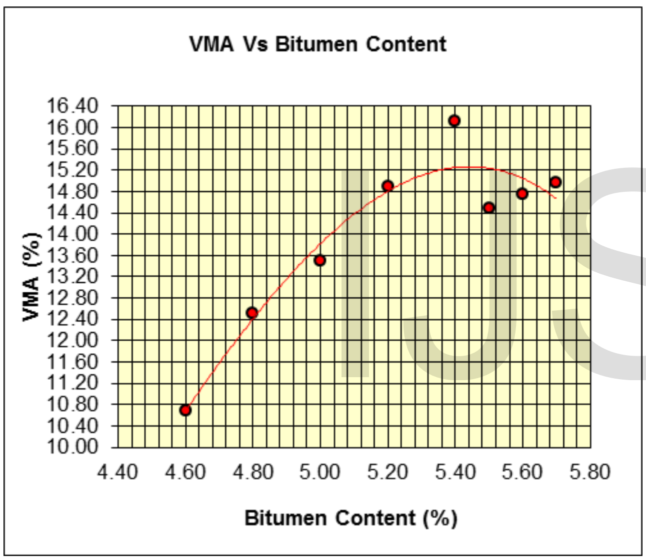
**GRAPH NO. 13**
**(MARSHALL TRAIL IN BC WITH LOWER LIMIT)**

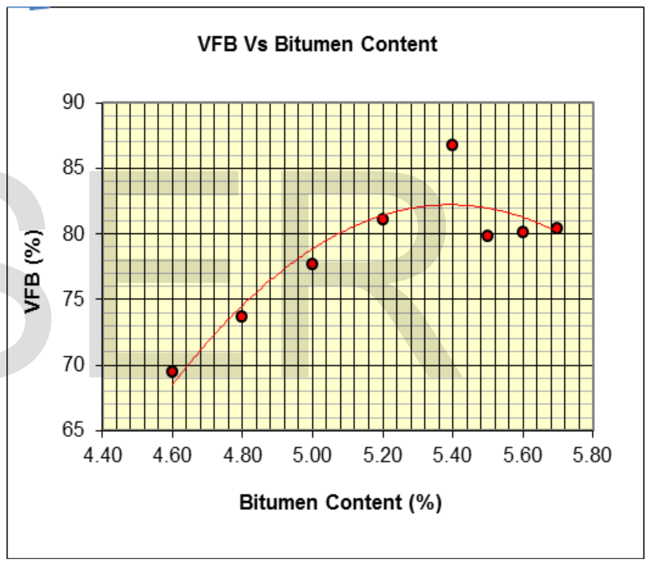





## 5. Results and Discussions

On analysing the data given in Table 4, it is observed that the increase in the percentage of flaky particles has negative affect on bulk density, water absorption, crushing value, angularity number and impact value of the aggregates. Higher the percentage of flaky particles, lower is the bulk density of aggregate as shown in Graph No.2 which indicates more volume is occupied per unit mass of aggregates. The impact value & crushing value also increases from 13% to 22% & 21% to 28% respectively with increase in the percentage of flaky particles in aggregates as shown in graph no. 1 & 3 which indicates the aggregates have less resistance to impact and crushing. Due to more surface area of flaky aggregates the water absorption also increases in flaky aggregates as shown in Graph No.5. The angularity number also increases with higher percentage of flaky particles as shown in Graph No. 4 indicating the presence of more voids in aggregates which will require more bitumen content in the mix.

Job Mix Formula (JMF) for bituminous mixes is established for a given set of material ingredients having specific properties of aggregate grading, FI, EI, specific gravity, water absorption etc. However when we use the upper limits of sizes of aggregates in DBM given in the specifications as given in Table-5, the bitumen content required is 4.30% for maximum density (refer Table No. 6 & Graph No.7) where as in case of use of lower limits in the specifications, it is 3.90% (refer Table No.7 & Graph No.9). Similarly in case of BC, the bitumen content required for upper limits is 4.60% (refer Table No.9 & Graph No.11) & 5.20% in case of lower limits for maximum density (refer Table No.10 & Graph No.13). These results indicted that the surface area of

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aggregates increases considerably during actual mix production due to increase in FI and EI or due to aggregate grading going finer and the designed bitumen content would not be sufficient to coat all aggregate surfaces adequately making the mix harsh and the finished work less durable. This condition would result in poor compaction, high air voids, insufficient void filled with bitumen, poor stability and flow in the finished work. Consequently, the finished work would be pervious, less elastic, prone to early cracking and disintegration and hence poor in durability. This shows that the use of grading of aggregates even within the specifications can largely affect the design of the mix. So it is desirable to reduce the range of the tolerance limits in the specifications. With use of e-quality control system and sophisticated machinery such as cone crusher etc., there is less variation in the %age of aggregates passing through various sieves from the designed one [5]. It also controls the size & shape of aggregate particles & thus upgrades the properties of aggregates in respect to impact value, crushing value, specific gravity, water absorption & angularity number etc. by reducing FI & EI. Thus, the gradation of the aggregates can be controlled more precisely with e-quality control system and lower tolerance limits can be adopted than prescribed limits in the codes. The lesser variation in the sizes of aggregates than the designed one, will give a durable mix with proper strength. The mix will also be more economical with optimum bitumen content.

## 6. Conclusion

Bituminous mixes are designed with a particular size & shape of aggregates and are very sensitive to change in aggregate shape, size and grading. The variation in aggregate shape, size and grading even within the tolerance limits in the specification may upset a well-designed mix and hence quality of end product. This is because change in aggregate shape, size and grading changes aggregate surface area per unit weight and change the requirements of bitumen in of bituminous mix, strength and durability but workability also. It is also concluded from the study that there is negative effect of flaky particles on the properties of the aggregates. With the use of e-quality control system with modern machinery having electronic control such as cone crusher, bay batch type hot mix plant etc., the ingredients of aggregates can be well controlled with grading close to the designed grading in the job mix formula. It controls the shape, size and proportion of aggregates and thus upgrades the properties of aggregates such as impact value, crushing value, water absorption and angularity number etc. also.

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