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Shape Analysis of Bituminous Mixes With SBR

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***Abstract*—The importance of the shape of aggregate particles is given the highest priority in terms of engineering properties. Other than specific gravity of the aggregate; Toughness, Abrasion and other properties are heavily dependent on the shape of the aggregate particles. The objectives of the study are to evaluate the strength characteristics for different shapes of aggregate and to find out the variation in stability, flow and other related properties using unmodified bitumen (conventional bitumen) and Styrene-Butadiene Rubber (SBR) modified bitumen. Out of the four particle shapes, Cubical aggregate showed the maximum stability and the Blade shaped aggregate showed the least stability value in the HMA mix.**

***Index Terms*—Aggregate shapes, Hot mix Asphalt (HMA mix), polymer modified bitumen, SBR, Unmodified Bitumen.**

I. INTRODUCTION

Mineral aggregates constitute 92 to 96% of the Hot-Mix Asphalt (HMA). Maximum part of the mineral aggregate constitutes of coarse aggregate. It has been proved that aggregate characteristics such as particle size, shape and texture influence the performance and serviceability of the hot mix asphalt pavement [8]. Visual examination of the aggregate is the most common method of judging aggregate shape.

On the majority of roads, conventional asphalts perform well. In order to reduce the dependence on natural sources of bitumen [9] and to reduce the usage of pure bitumen as the binder, there is wide range of polymer based modifiers being used for modifying the properties of the conventional bitumen, making it more durable and reducing its temperature susceptibility.

The modifier being used in the work is Styrene Butadiene Rubber (SBR) Latex. SBR is widely used as a modifier, usually as dispersion in water (Latex form). The benefit of latex is that the rubber particles are extremely small and regular which can easily disperse in bitumen rapidly and uniformly throughout the material and form a reinforcing network structure [17].

The objectives of the work are

i. To determine the engineering properties of the coarse aggregate with respect to the shapes (Blades, Cubical, Disks and Rods).
ii. To determine and compare the Stability, Flow and other related properties by conducting Marshall Stability Test on different shapes of aggregate using unmodified bitumen and with SBR modified bitumen.

II. MATERIALS AND METHODS

A. Aggregate

The aggregate were obtained from Rapaka (a small village, 10 Kms. away from Rajam). The coarse aggregate were sieved and partitioned into four size fractions as, 25 to 20mm, 20 to 12.5mm, 12.5 to 10mm and 10 to 4.75mm. The fine aggregate are also partitioned as shown in ***Table I***.

***Table I*. Physical Properties and Aggregate Gradation**

Specific Gravity of aggregate	Size distribution (Percentage passing by weight)									
	25 mm	**19 mm.**	**12.5 mm.**	**10 mm.**	**4.75 mm.**	**2.36 mm.**	**0.6 mm.**	**0.3 mm.**	**0.15 mm.**	**0.075 mm**
2.835	100	90.45	73.2	66.21	47.36	34.57	18.67	13.67	10	7.32

The four different shapes of coarse aggregate which were selected are as follows: Blade, Disk, Cubical and Rod. The *Disk* shaped aggregate is flaky and oblate, the *Rod* shaped aggregate is elongated, the *Blade* shaped aggregate is both flaky and elongated and the *Cubical* shaped aggregate is rounded. The Aggregate shape analysis was conducted using the Zingg diagram based on which the longest particle diameter (d_L), intermediate diameter (d_I) and the smallest diameter (d_S) were measured. Elongation ratio (d_I/d_L) and Flatness ratio (d_S/d_I) were used to define the shape of the aggregate as shown in ***Fig. 1***.

Shape analysis was conducted for a sample of 50 particles of coarse aggregate containing particles of size starting from 19mm. to 4.75mm. The dimensions of each of the particle were measured using a Vernier callipers and based on the shape analysis, large scale sorting of aggregate into four shapes was performed.

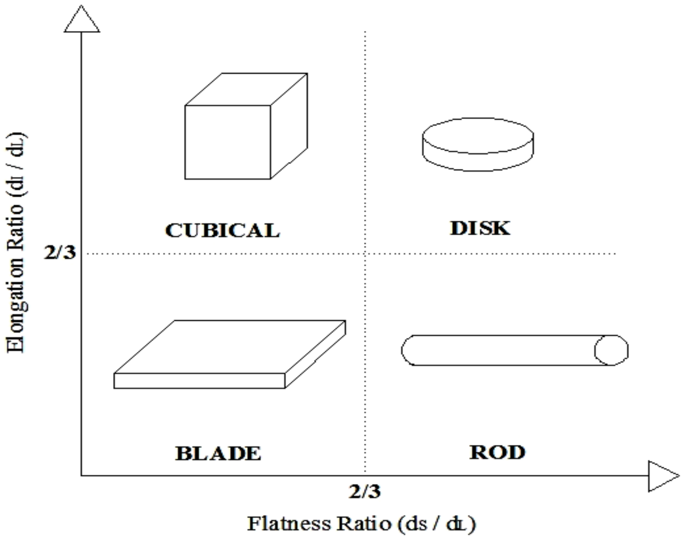

Fig. 1 **Different Shapes of Aggregate Used in the Work**

B. Binders

Bitumen of 80/100 penetration grade was used as the binder. The bitumen used for conducting the tests was obtained from HPCL, Visakhapatnam, Andhra Pradesh, India. SBR by trade name Nitobond SBR® of FOSROC Chemicals (India) Pvt. ltd. was used as bitumen modifier. The **Softening point** and **Penetration** obtained for Unmodified bitumen are ***51.5˚C*** and ***8.34mm.*** respectively.

C. Marshall Mix design

Marshall Mix Designs were performed using Marshall method for preparing and compacting samples with bitumen content variation of 0.5% from 3.0% to 4.5%. Bituminous mixture for the Marshall Test samples was designed as per IRC 29 – 1988. Optimum Binder Content (OBC) was chosen as the average value of the bitumen content at 4% of Air Voids, Maximum Unit weight and Maximum Stability.

D. Marshall Design Values

The Marshall test enables us to determine the strength indices such as stability, flow and other related properties such as optimum binder content, void content, etc. The bituminous mixes containing flaky aggregate (Blade and Disk shaped aggregate) produce the lower values of Marshall Stability.

III. RESULTS AND DISCUSSION

A. Shape Analysis for aggregate particles

Particle shape analysis was performed on aggregate to find out Elongation Ratio, Flakiness ratio, Shape factor and Sphericity of the selected aggregate. The values obtained are listed in ***Table II***. From the table, the Elongation and Flakiness ratio values obtained are 0.8 and 0.74 and both the values are larger than 2/3. The shape factor is generally between 0.3 and 0.8. The higher the shape factor, the more cubical are the aggregate. The sphericity value is between 0.5 and 0.9. Cubical particles possess higher sphericity value.

Hence, the aggregate which are selected for use in this study fall within the range.

Table II. **Aggregate Geometric Characteristics from Shape Analysis**

SHAPE	Sieve size, mm.	d_L (mm.)	d_I (mm.)	d_S (mm.)	Elongation Ratio	Flatness Ratio	Shape Factor	Sphericity
Blade	25-20	39.36	24.7	10.05	0.63	0.41	0.32	0.54
	20-12.5	23.19	14.96	6.73	0.65	0.45	0.36	0.57
	12.5-10	18.58	12.49	6.4	0.67	0.51	0.42	0.61
	10-4.75	15.53	9.87	4.21	0.64	0.43	0.34	0.56
Avg.					**0.65**	**0.45**	**0.36**	**0.57**
Cubical	25-20	26.75	22.71	18.67	0.85	0.82	0.76	0.84
	20-12.5	21.63	16.96	12.29	0.78	0.72	0.64	0.76
	12.5-10	19.24	13.66	10.09	0.79	0.74	0.66	0.75
	10-4.75	12.92	9.89	6.86	0.77	0.69	0.61	0.74
Avg.					**0.80**	**0.74**	**0.67**	**0.77**
Disk	25-20	31.46	22.82	14.19	0.73	0.62	0.53	0.69
	20-12.5	22.51	15.62	8.74	0.69	0.56	0.47	0.65
	12.5-10	19.12	13.45	7.78	0.7	0.58	0.49	0.61
	10-4.75	14.2	9.81	5.43	0.69	0.55	0.46	0.64
Avg.					**0.70**	**0.58**	**0.49**	**0.65**
Rod	25-20	38.59	27.52	16.45	0.71	0.6	0.5	0.67
	20-12.5	30.68	20.83	10.97	0.68	0.53	0.43	0.62
	12.5-10	26.24	18.2	10.16	0.69	0.56	0.47	0.64
	10-4.75	19.53	13.33	7.14	0.68	0.54	0.44	0.63
Avg.					**0.69**	**0.56**	**0.46**	**0.64**

Where,

$$\text{Elongation ratio} = d_I/d_L \qquad (1)$$

$$\text{Flatness Ratio} = d_S/d_L \qquad (2)$$

$$\text{Shape Factor} = d_s/\sqrt{(d_L \cdot d_I)} \qquad (3)$$

$$\text{Sphericity} = \sqrt[3]{(d_S \cdot d_I) / d_L^2} \qquad (4)$$

B. Abrasion and Impact tests on aggregate

After the sorting of aggregate is performed based on shape, tests such as Specific Gravity and water absorption test, Aggregate Impact value Test (AIV Test, IS: 2386 (Part IV) - 1963), Los Angeles Abrasion test (LAA Test, IS: 2386 (Part IV) - 1963) were conducted to find out the properties of the aggregate. The **Specific Gravity** of the aggregate used is ***2.835*** which showed **water absorption** of ***0.2%***. The results for LAA and AIV tests are provided in ***Table III***. A comparison graph for Los Angeles Abrasion test and aggregate Impact value test with respect to shape of the aggregate is provided in ***Fig. 2***.

Table III. **Results for Aggregate Impact Value and Los Angeles Abrasion Test for Different Shapes of Aggregate**

Shape	Aggregate Impact Value Test (%)	Los Angeles Abrasion Test (%)
Blade	30.16	24.44
Rod	21.55	21.28
Disk	26.19	22.94
Cubical	20.50	21.04

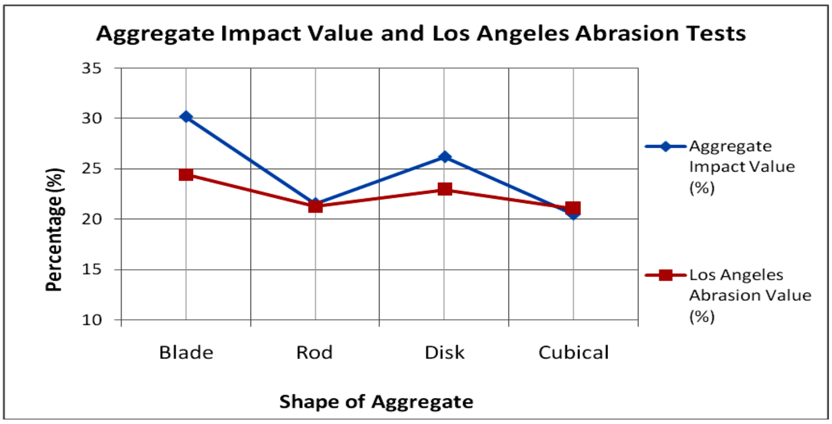

Fig. 2 **Results of Aggregate Impact Value and Los Angeles Abrasion Tests**

C. Flakiness and Elongation Test

Flakiness and Elongation Index Test (IS: 2386 (Part I) - 1963) was performed. The results obtained are as tabulated in ***Table IV***.

Table IV. **Results for Flakiness and Elongation Index for Different Shapes of Aggregate**

Sieve Size, mm.	Flakiness Index, %				Elongation Index, %			
	B	**C**	**D**	**R**	**B**	**D**	**C**	**R**
25-20	100	50.10	1.62	26.79	21	7.8	0	38.29
20-12.5	93.46	44.85	1.62	6.23	47.71	42.27	27.94	98.27
12.5-10	82.76	51.4	1.52	2.15	54.02	54.21	38.64	100
10-4.75	-	-	-	-	-	-	-	-

B –Blade, **C** –Cubical, **D**-Disk **R**-Rod

D. Softening Point Test

Softening point test was performed with varying percentages of SBR. The results are tabulated in ***Table V***. A graph for the softening points is shown in ***Fig. 3***.

Table V. **Results for Softening Point for SBR Modified Bitumen**

Binder	Percentage of modifier by weight of bitumen (SBR)				
	1%	**2%**	**3%**	**4%**	**5%**
Softening Point (˚C) (SBR as modifier)	47	51	52	51.5	50.5

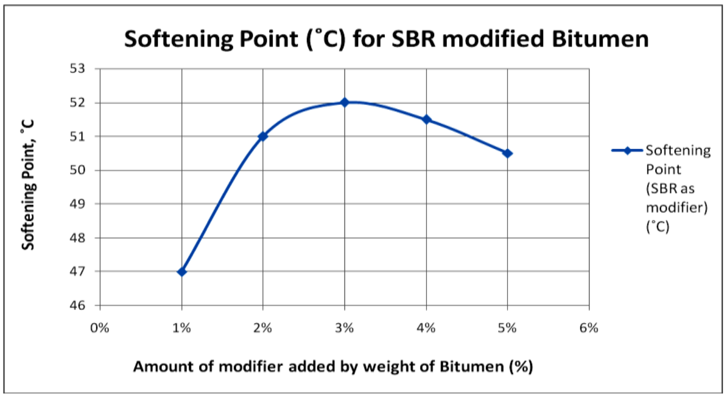

Fig. 3 **Softening Points for SBR Modified Bitumen**

E. Penetration Test

The results of Penetration test for SBR modified Bitumen is given in ***Table VI***. A graph for the Penetration test is shown in ***Fig. 4***.

Table VI. **Results of Penetration Test for SBR Modified Bitumen**

Binder	**Percentage of modifier by weight of bitumen (SBR)**				
	1%	**2%**	**3%**	**4%**	**5%**
Penetration (mm.) (SBR as modifier)	10.1	12.68	13.71	10.98	9.86

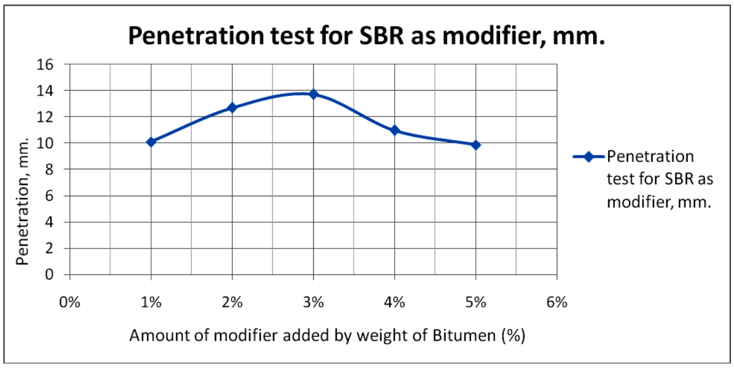

Fig. 4. **Penetration Values for SBR Modified Bitumen**

F. Marshall Test results

Marshall Stability Test was performed to find out the strength characteristics such as Stability, Flow, Voids, etc. Marshall samples were casted using unmodified bitumen for percentages of 3 to 4.5 with a 0.5% increment in bitumen content and are tested. Samples of bitumen modified with SBR with percentages of 1 - 4 with an increment of 1% were also casted and tested (SBR content was taken by weight of Bitumen) for binder content of 3 to 4.5 percent with increment of 0.5%.

The results for ***Stability*** (KN) are tabulated in ***Table VII***. A comparison graph is also provided based on shape of the aggregate in ***Fig. 5***.

Table VII. **Results for Stability (KN) in Comparison to Different Shapes of Aggregate and Binder Material**

Shape	**Blade**	**Cubical**	**Disk**	**Rod**
Unmodified Bitumen	21.43	31.4	22.01	26.44
Bitumen + 1% SBR	10.82	30.24	27.24	31.7
Bitumen + 2% SBR	28.23	44.15	26.73	37.04
Bitumen + 3% SBR	20.62	33.17	24.55	29.35
Bitumen + 4% SBR	19.17	40.61	26.98	26.46

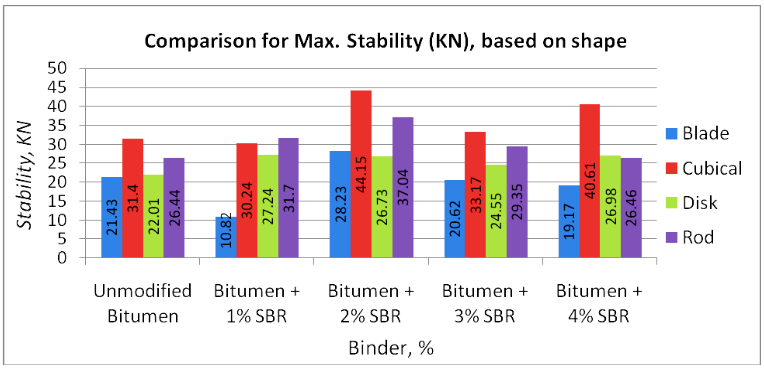

Fig 5. **Stability (KN) in Comparison to Different Shapes of Aggregate and Binders**

The results for ***Flow*** *(mm.)* are tabulated in ***Table VIII***. A comparison graph is provided in ***Fig. 6***, based on shape of the aggregate.

Table VIII. **Results for Flow (mm.) Based on Shape and Different Binder Material**

Shape	**Blade**	**Cubical**	**Disk**	**Rod**
Unmodified Bitumen	3.45	3.78	3.55	3.93
Bitumen + 1% SBR	3.83	3.63	3.45	3.9
Bitumen + 2% SBR	3.925	3.55	3.95	3.95
Bitumen + 3% SBR	3.78	3.43	3.68	3.43
Bitumen + 4% SBR	3.1	3.85	3.925	3.525

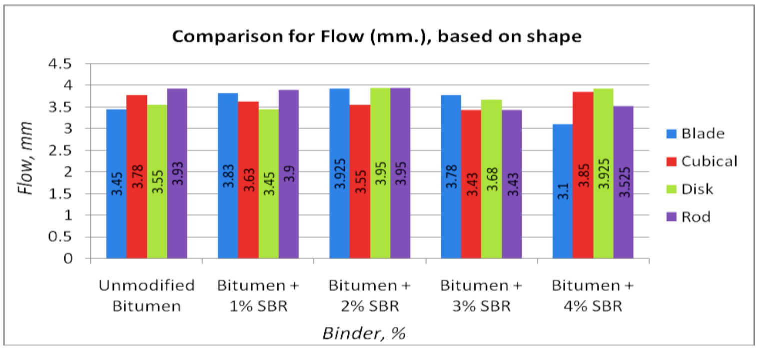

Fig. 6. **Flow (mm.) in Comparison to Different Shapes of Aggregate and Binder Material**

The results for ***Voids** (%)* are tabulated in ***Table IX.*** A comparison graph is provided in ***Fig. 7***, based on shape of the aggregate.

Table IX. **Results for Voids (%) Corresponding to Maximum Unit Weight Based on Shape and Binder Material**

Shape	**Blade**	**Cubical**	**Disk**	**Rod**
Unmodified Bitumen	4.582	3.771	4.428	3.886
Bitumen + 1% SBR	3.937	4.399	3.776	3.308
Bitumen + 2% SBR	4.616	4.798	4.37	5.012
Bitumen + 3% SBR	4.096	4.586	5.073	4.07
Bitumen + 4% SBR	4.738	4.07	4.096	3.823

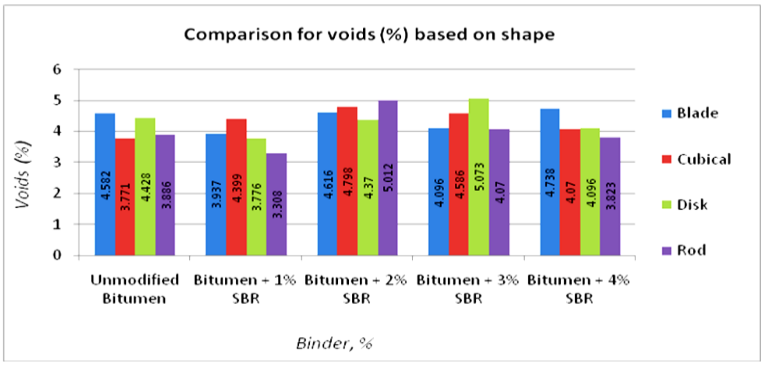

Fig 7. **Voids (%) in Comparison to Different Shapes of Aggregate and Binder Material**

The results for ***Unit Weight*** *(KN/m^3)* are tabulated in ***Table X***. A comparison graph is provided in ***Fig. 8***, based on shape of the aggregate.

Table X. **Results for Maximum Unit Weight (KN/m^3) Based on Shape and Different Binder Material**

Shape	**Blade**	**Cubical**	**Disk**	**Rod**
Unmodified Bitumen	24.934	24.947	24.984	24.923
Bitumen + 1% SBR	25.112	24.991	24.946	25.067
Bitumen + 2% SBR	24.935	24.887	24.999	24.831
Bitumen + 3% SBR	25.07	24.942	25.024	25.077
Bitumen + 4% SBR	24.904	25.077	25.07	25.142

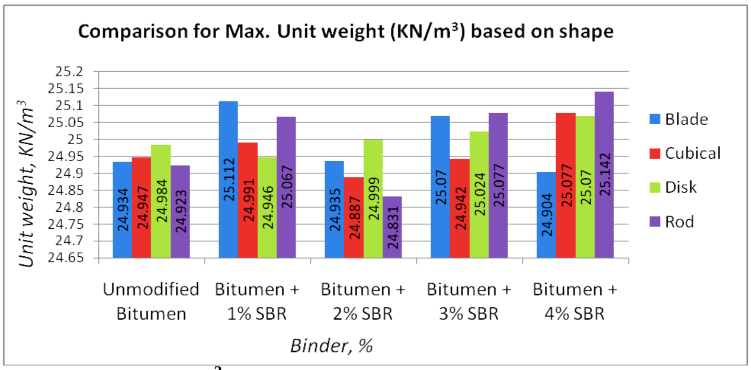

Fig. 8. **Maximum Unit Weight (KN/m^3) in Comparison to Different Shapes of Aggregate and Binder Material**

The ***OBC*** obtained for different binders are as tabulated in ***Table XI***. A comparison graph is provided in ***Fig. 9***, based on shape of the aggregate.

Table XI. **Results for OBCs (%) Based on Shape and Different Binder Material**

Shape	**Blade**	**Cubical**	**Disk**	**Rod**
Unmodified Bitumen	3.87	3.99	3.84	4.1
Bitumen + 1% SBR	3.71	3.95	3.99	3.83
Bitumen + 2% SBR	3.94	3.9	3.8	4.02
Bitumen + 3% SBR	3.71	3.88	3.81	3.58
Bitumen + 4% SBR	3.74	3.7	3.68	3.68

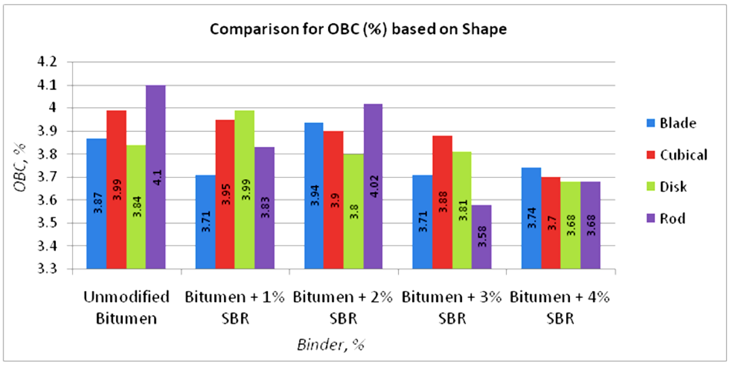

Fig. 9. **OBC (%) in Comparison to Different Shapes of Aggregate and Binder Material**

IV. CONCLUSIONS

Four different shapes of aggregate were evaluated for determining the engineering properties of Hot – mix asphalt. Out of the four shapes, the highest values for Abrasion and Impact were obtained for Blade shaped aggregate and the least values were obtained for Cubical aggregate. Unmodified bitumen and SBR modified bitumen were used to as binders. There was an improvement in Softening point and Penetration values on usage of SBR as modifier.

From the Marshall tests performed, the following are the conclusions obtained from the study.

1. The Highest Marshall Stability values were obtained for mixes which were prepared using Cubical aggregate and the lowest value was obtained for Blade shaped aggregate.
2. The highest Stability value for samples prepared using Unmodified Bitumen was 31.40KN (Cubical) and the lowest value was 21.43KN (Blade).
3. For samples where SBR was used as modifier, the highest Stability value obtained was 44.15KN (Cubical at 2% SBR modified bitumen) and the lowest value was 10.82KN (Blades at 1% SBR modified bitumen).
4. For unmodified bitumen, the lowest value of OBC of 3.84% was obtained by Disk shaped aggregate. And the highest of 4.1% was obtained by Rod shaped aggregate.
5. For SBR modified bitumen, the lowest value of OBC of 3.58% was obtained by Rod shaped aggregate at 3% SBR content and the highest value of OBC of 4.02% was obtained by Rod shaped aggregate at 2% SBR content.
6. The maximum unit weight obtained for unmodified bitumen was 24.984KN/m^3 (Disk shaped aggregate) and for SBR modified bitumen, it is 25.142KN/m^3 (Rod shaped aggregate at 4% SBR content).
7. The lowest amount of Voids for unmodified Bituminous samples was 3.771%, obtained by Cubical aggregate and for SBR modified bitumen, the value is 3.308% obtained for Rod shaped aggregate at 1% SBR content.
8. The lowest value for Flow obtained was 3.45mm. (Blade shaped aggregate) for unmodified bitumen. And for SBR modified bitumen, a value of 3.1mm. (Blade shaped aggregate) was obtained at 4% SBR content.

Therefore, the Cubical aggregate provide more strength when compared to other shapes of aggregate. From the tests performed, it is clear that there is an improvement in the properties on addition of SBR as modifier to the Conventional Bitumen.

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