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"Effect of Coarse Aggregates Shape Factors on Rutting Characteristics of Bituminous Mixtures"

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ABSTRACT: Aggregates are the principal material in pavement construction. Conventional road aggregates in India are natural aggregates obtained by crushing rocks. The physical properties of coarse aggregate are more significant in new generation bituminous mixtures. Aggregate characteristics such as particle size, shape, and texture influence the performance and serviceability of hot mix asphalt pavement. The shape of aggregate particle has significant influence on performance of the Bitumen pavement. Particle shape can be described as cubical, blade, disk and rod .The strength serviceability requirements of Bitumen mixes such as stability, flow, voids in mineral aggregate (VMA), voids filled with bitumen (VFB) and air voids are highly depend on the physical properties of aggregate. Dense bituminous macadam (DBM) mixes were analysed with different proportions (10%, 20%, 30%, 40%, 50%) of different shape of aggregates were studied. Mixes with cubical and rod shape aggregates has been showed good results on stability. The parameters such as air voids and voids in mineral aggregate increases with increase in proportion of blade type of aggregates in DBM mixes.The particle shape determined how aggregate packed into a dense configuration and also determined the internal resistance of a mix. Mixes prepared by replacing 20% aggregates shown higher stability values. Cubical particles exhibit interlock and internal friction, and hence results in greater mechanical stability than the blade, rod, and disk shape aggregates. Particle shape parameter values obtained were higher for cubical shape aggregates and lower for blade shape aggregates.

KEYWORDS: Coarse aggregate, aggregate shape, hot mix asphalt

I. INTRODUCTION:

Aggregates are the principal material in pavement. Conventional road aggregates in India are natural aggregates obtained by crushing of rocks. In Hot Mix Asphalt (HMA), aggregates are combined with an asphalt binding medium to form a compound material. By weight, aggregate generally accounts for between 92 and 96 percent of HMA. They comprise the majority of pavement volume. Therefore, knowledge of aggregate properties is crucial in designing a high quality pavement.

Aggregates can either be natural or manufactured. Natural aggregates are generally extracted from larger rock formations through an open excavation (quarry). Usually the rock is blasted or dug from the quarry walls then reduced in size using a series of screens and crushers. Some quarries are also capable of washing the finished aggregate. Manufactured rock typically consists of industrial by-products such as slag (by-product of the metallurgical processing – typically produced from processing steel, tin and copper) or specialty rock that is produced to have a particular physical characteristic not found in natural rock (such as t low density aggregate)

Influence Of Aggregate Properties :

Aggregate particles can be defined in terms of three independent shape properties: shape (or form), angularity, and surface texture (Barrett, 1980). These three aggregate shape properties fully characterize particles based on their geometry. The form property characterizes aggregate particles based on ratios of particle dimensions. The angularity property measurement describes particles based on the variations at the edges of particles. This measurement defines particles in a range from rounded to angular.

The final property is surface texture. This property describes the surface roughness of a particle at a small scale, which is not influenced by changes in form or angularity. These three

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properties are independent of each other: an increase or decrease in one of these properties does not necessarily influence the other two properties (Rousan, 2004). A schematic diagram illustrating the differences between these three aggregate shape properties is shown in Fig 1. with flaky aggregates have been found to exhibit higher fatigue life than mixes with non flaky aggregates.

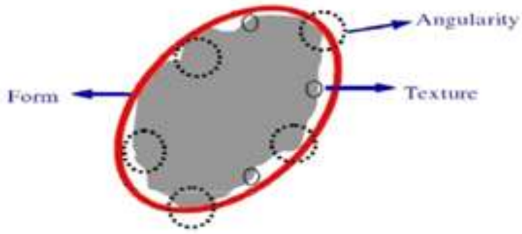

Fig : 1. Components of aggregate shape: form (shape), angularity, and texture

Significance Of Aggregate Shape On Bituminous Mixes

Aggregate shape properties are known to influence Bitumen pavement performance. Angularity and texture govern the frictional properties and dilation of the aggregate structure. Aggregate texture plays a major role in influencing the adhesive bond between the aggregate and the binder, while aggregate form influences the anisotropic response of Bitumen mixes

Aggregate characteristics such as particle size, shape, and texture influence the performance and service ability of hot-mix asphalt pavement (Brown et al. 1989, Kandhal et al. 1992). Flat and elongated particles tend to break during mixing, compaction, and under traffic. Therefore, aggregate shape is one of the important properties that must be considered in the mix design of asphalt pavements to avoid premature pavement failure.

The shape of aggregate particle has a significant influence on the performance of the bituminous pavement. Particle shape can be described as cubical, flat, elongated and round. The presence of flaky aggregates is considered as undesirable in bituminous mixtures because of their tendency to break down during construction and subsequent traffic operations. The voids present in a compacted mix depend on the shape of aggregates. Blade shape aggregates have more voids and reduce the workability. Hence it was felt that the study on the effect of the blade shape aggregates on bituminous mixtures is relevant and essential.

Krutz and Sebaaly (1993) found a direct correlation between the rutting potential of HMA mixtures and the shape and texture of coarse aggregate particles. Li and Kett (1967) concluded in their study that flat and elongated particles could be permitted in a mixture without adverse effect on its strength. Some mixes Oduroh et al. (2000) showed that the percentage of crushed coarse particles had a significant effect on laboratory permanent deformation properties. As the percentage of crushed coarse particles decreased, the rutting potential of the HMA mixtures increased. Huber and Heiman (1987) found that crushed aggregate containing 19% flat and elongated particles did not adversely affect the volumetric properties of HMA mixtures.

Approximately 85 percent of the total volume of bituminous concrete mixtures consists of aggregate. It is not surprising that the performance of asphalt concrete mixtures is influenced by the properties of their aggregate blends, such as gradation, shape (angularity and elongation), and texture (roughness). In asphalt concrete, numerous studies have related the gradation, shape, and texture of aggregate to durability, workability, shear resistance, tensile strength, stiffness, fatigue response, rutting susceptibility, and optimum binder content of the mixtures. In recognition of the importance of aggregate properties on pavement performance, limits on flat and elongated particles or the amount of natural sand typically are incorporated into specifications.

However, often there is a lack of consistency between the aggregate specifications and the ability to measure all the desired properties of aggregates. For example, the most common test methods for evaluating aggregate angularity and surface texture are indirect measures at best. Proper selection and evaluation of aggregate properties will remain necessary to produce high-quality asphalt concrete mixtures, particularly as traffic and loads increase. Quantification of aggregate properties with rational, objective characterization methods is desirable.

Visual examination is the most common method of judging aggregate shape, the main objective of this investigation is to explore the use of different aggregate shapes in DBM mixes. The performance of the aggregate shape factors is evaluated in terms of Marshall Stability test results.

II. MATERIALS AND METHODS

2.1 AGGREGATE

Aggregate influence, to a great extent the load transfer capability of pavements. Hence it is essential that they should be thoroughly tested before using for construction. Not only that aggregates should be strong and durable, they should also possess proper shape and size to make the pavement act monolithically. Aggregates are tested for strength, toughness, hardness, Shape and water absorption. Aggregates can either be natural or manufactured. Natural aggregates are generally extracted from larger rock formation through an open excavation (quarry). Extracted rock is typically reduced to usable sizes by mechanical crushing. Manufactured aggregate is often a bye product of other Manufacturing industries.

2.2 Bitumen Binder

The Bitumen binder component of a Bitumen pavement typically makes up about 5 to 6 percent of the total Bitumen mixture, and coats and binds the aggregate particles together. Bitumen cement is used in hot mix asphalt. Liquid asphalt, which is asphalt cement dispersed in water with the aid of an emulsifying agent or solvent, is used as the binder in surface treatments and cold mix asphalt pavements. The properties of binders are often improved or enhanced by using additives or modifiers to improve adhesion (stripping resistance), flow, oxidation characteristics, and elasticity. Modifiers include oil, filler, powders, fibers, wax, solvents emulsifiers, wetting agents, as well as other proprietary additives (AASTHO, 1993).

2.3 Quantification of Aggregates

Shape of Aggregates

Aggregates which happen to fall in a particular size range may have rounded, cubical, angular, flaky or elongated particles. It is evident that the flaky and elongated particles will have less strength and durability when compared with cubical, angular or rounded particles of the same aggregate. Hence too flaky and too much elongated aggregates should be avoided as far as possible. Visual examination is the most common method of judging aggregate shape and this method is adopted for this study.

The elongation index of an aggregate is defined as the percentage by weight of particles whose greatest dimension (length) is 1.8 times their mean dimension. This test is applicable to aggregates larger than 6.3 mm. This test is also specified in (IS: 2386 Part-1). However there are no recognized limits for the elongation index.

The coarse size fraction of DBM was evaluated for the influence of aggregate shape on engineering properties of HMA mix. Aggregate shape analysis was carried out through the use of the Zing diagram on the basis of the particle longest diameter (dL), the intermediate diameter (dl), ad the shortest diameter (dS). From figure we can observe to stretch the particle in one direction and keep other dimension constant value then it will convert to other shape.

The elongation ratio and the flatness ratio were used to define the aggregate shape as shown in Figure 3.4. The former is the ratio of dl to dL, and the latter is the ratio as dS to dl. Four different aggregate shapes were selected as follows: dist, blade, road, and cube. As both ratios are equal to or larger than 2/3, the cubical aggregate was selected for the HMA mix in order to contrast it with the mixes consisting of other shapes. The disk-shaped aggregate is flaky and oblate, the rod-shaped is elongated, and the blade-shaped is both flaky and elongated. Four type aggregates used for this study are shown in fig.2 and 3.

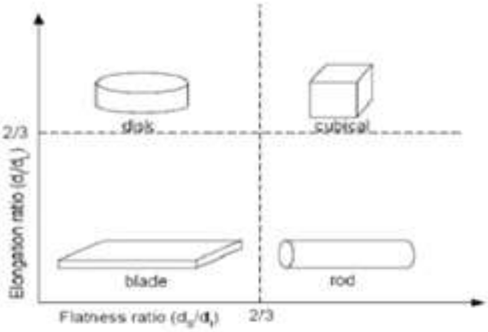

Fig : 2. Elongation ratio vs Flatness ratio

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Fig .3 Different Aggregate Shapes Used In This Study

III. RESULTS AND DISCUSSION

3.1 Particle Shape Parameters

The shape of a rock particle can be expressed in terms of overall shape, roundness or large scale smoothness, and surface texture. These properties are the geometrically independent properties of a particle shape although there might be a natural correlation between them due to the common physical factors. In this study, a total of four shape properties (angularity, convexity ratio, roughness, and elongation ratio) were calculated to seek for possible correlations with the compressive strength.

Angularity is an important particle parameter used to characterize surface smoothness of particles. It is defined as the square of the ratio of the convex perimeter of particle to the perimeter of fictitious equivalent ellipse having the same area and the aspect ratio of aggregate particle.

Elongation ratio is another fundamental particle parameter defined as the ratio of the particle maximum

dimension (length) to the maximum dimension in the plane perpendicular to the length (width).

3.2 Particle Index of Coarse Aggregate

The combined effects of particle shape and surface texture of aggregates were determined in accordance with ASTM Test Method for Index of Aggregate Particle Shape and Texture (D 3398). The equipment required for this test consists of basically a cylindrical steel mould 152mm (6 in.) in diameter by 178 mm (7 in.) high, and steel rod 16mm (5/8 in.) in diameter by 610 mm (24 in.) long with the tamping end rounded to a hemispherical tip.

A clean, washed, oven-dried, single-size aggregate fraction was used for this test. The mould was filled in three equal layers, with each layer compacted with 10 well-distributed blows of the tamping rod. Each tamp consisted of a drop with the tamping rod from 51 mm (2in.) above the surface of the layer being compacted. This procedure was repeated using the same material but applying 50 blows on each of the three layers. The weight of the contents of the mould in each case was determined and the corresponding percentage of voids was calculated using the bulk specific gravity of each aggregate fraction. The particle index (PI) is derived using the following equation 3.1

$$PI = 1.25\ V10 - 0.25\ V50 - 32.0$$

Where

V10 = percent voids in the aggregate compacted with 10 blows per layer,

V50 = percent voids in the aggregate compacted with 50 blows per layer.

Calculated voids

$V10 = [1-(M10/sv)] \times 100$

$V50 = [1-(M50/sv)] \times 100$

S = Bulk-dry specific gravity of the aggregate size fraction

Where

M10 = Average mass of the aggregate in the mold compacted at 10 drops
Per layer-„g"

M50 = Average mass of the aggregate in the mold compacted at 50 drops
Per layer -„g"

V = Volume of the cylindrical mold „mL"

3.3 Significance and Use

This test method provides an index value to the relative particle shape and texture characteristics of aggregates.

This value is a quantitative measure of the aggregate shape and texture characteristics that may affect the performance of road and paving mixtures. This test method has been successfully used to indicate the effects of these characteristics on the compaction and strength characteristics of soil-aggregate and asphalt concrete mixtures.

3.4 Marshall Test

The principle of the Marshall stability is the resistance to the plastic flow of cylindrical specimens of a bituminous mixture loaded on the lateral surface. It is the load carrying capacity of the mix at 60 C and is measured in KN. The desirable mix properties include stability, density, durability, flexibility, resistance to skidding and workability during construction.

In this study, the behaviour of DBM mixes was studied with aggregate having different shapes and different proportions (10%, 20%, 30%,40%, and 50%). Since the aim of this study is to quantify the effects of the different shape of the aggregates. The following properties were investigated in this study by conducting Marshall Tests. Stability, flow Percent of air voids (Va), Voids in Mineral Aggregate (VMA), Percent Voids Filled with Bitumen (VFB).

3.4 Sample Preparation

Mixture Designs were performed using the Marshall method by preparing and compacting samples with Bitumen content varied in 0.5% increments according to ASTM Test Method for Resistance to Plastic Flow of bituminous Mixtures Using Marshall Apparatus. Grade 60/70 Bitumen binder. Specimens were compacted with 75 blows on each side. Three samples were made for each Bitumen content. The optimum Bitumen content was chosen as the Bitumen content that produced 4% air voids. Further, two types of void were calculated for the compacted samples: the void in mineral aggregate (VMA), and the void space in coarse aggregate (VCA). The VCA"s were calculated in a way similar to the VMA"s by replacing percent of aggregate in the mix with percent of coarse aggregate in the calculation.

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3.5 Marshall Mix Design

Bituminous mixes are used in the surface coarse of road and airfield pavement, some type of Bitumen mixes are also used in base and/or binder course of flexible pavements. The desirable Bitumen mix properties include (i) stability (ii) density (iii) durability (iv) flexibility (v) resistance to skidding and (vi) workability during construction. Stability is defined as resistance of the paving mix to deformation under load is thus a stress level which causes strain depending upon anticipated field condition. Density is directly related to voids in the compacted mixtures. Stability and density in general are related terms. Durability is defined as the resistance of the mix against weathering which causes hardening and this depends upon loss of volatiles and oxidation.

Generally, the stability test is applicable to hot-mix design using Bitumen and aggregate with maximum size of 25 mm. There are two major features of Marshall method of designing mixes namely, (i) density-voids analysis (ii) stability-flow test. The Marshall stability mix is defined as a maximum load carried by a compacted specimen at a standard test temperature at 60 C. The flow value is the deformation the Marshall test specimen undergoes during the loading upto the maximum load, in 0.25 mm units. The proposed steps for the design of bituminous mixes are given below.

a) Select grading to be used
b) Select aggregates to be employed in the mix
c) Determine the proportion of each aggregate required to produce the design grading
d) Determine the specific gravity of the aggregate combination and Bitumen
e) Determine the specific gravity of each compacted specimen
f) Make stability tests on specimen
g) Calculate the percentage of voids ,VMA and the percentage voids filled with asphalt in each specimen. Select optimum Bitumen content from the data obtained.
h)Check the values of Marshall stability,flow,voids in total mix and voids filled with Bitumen obtained at the optimum Bitumen content
i) Dense Bituminous Macadam (DBM) grading-II as specified by MoRT&H (2004) and 60/70 penetration grade Bitumen have been used to prepare bituminous mix samples in this study.

3.6 Stability and Flow Analysis

Optimum Binder Content (OBC) has been obtained by taking average of the bitumen contents 3.5 to 5.5 at which the mix has maximum bulk density, maximum stability and 4.5 % design air voids. Trials on grading-II conventional bitumen mixes have resulted in OBC for DBM layer.

3.7 Quantification of Aggregates

Particle shape analysis was carried out in terms of elongation ratio, flatness ratio, shape factor, and sphericity by direct methods. The shape parameters can be determined from the following equations.

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The mean value for each aggregate size is listed in Table 1.

Shape	Elongation	Flatness	Shape	Sphericity
Cube	0.81	0.73	0.66	0.87
Rod	0.70	0.71	0.60	0.84
Disk	0.78	0.66	0.58	0.83
Blade	0.72	0.55	0.46	0.77
Normal	0.75	0.59	0.50	0.79

Table.1. Aggregate Geometric Characteristics from direct measurement

The flatness, elongation ratio values obtained for cubical shape aggregates are 0.73, 0.81 and both the values are larger than 2/3. Sphericity of blade shape aggregate is low comparative to the other shapes and the sphericity value higher indicates the roundness of the aggregate. Shape factor is generally in between 0.3 to 0.8 for pavements. For all the shapes it falls within the limits only.

1. Elongation ratio = dI/dL
2.Flatness ratio = dS/dl
3. Shape factor = ds/√ (dL x dI)
4. Sphericity = 3√ (ds x dI /d L)

Data obtained from Table .1 indicates that the higher the shape factor, the more nearly cubical the aggregate.

3.8 Marshall Design Values

The Marshall test is a routine test that enables one to determine strength indexes such as stability and flow for the design of a HMA Mixtures. Other Mixtures design criteria such as Density, Air Voids ,Voids filled with bitumen (VFB) & voids mineral aggregate (VMA) are also Obtained from this test. Below table list to mixture Characteristics of Different aggregate shapes.

Stability

The stability value obtained from the Marshall stability test indirectly represents the strength of the paving mix ,which is the critical showing the variation of shape to other shape of aggregates cubical aggregates attains the maximum stability value then the rod, disk, blade. For all type of aggregates attains maximum stability at 20% replacement with cubical, rod ,disk shapes but for blade type aggregates non significant values were stability values with different type of aggregate shapes obtained, the reasons may be while compaction of the specimen and the orientation of the particles in specimen.

Percentage Air voids in Total mix

Air voids are necessary in bituminous mixes to allow densification under traffic loads and to prevent bleeding of bitumen during hot climates. Higher percentage of air voids obtained by increasing the percentage of replacement of aggregates with all shapes except for rod shape, because the same type of particles will not replace the gaps between the bituminous mixtures, but for rod type aggregates the air voids reduces by increasing the replacement of aggregates.

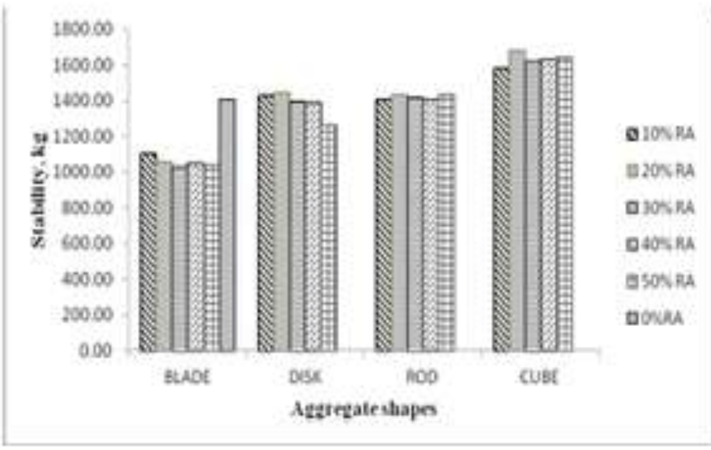

Fig . 4. (Replacement of original aggregates with 0% to 50% of different aggregate shapes)

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ROD						**DISK**				
	10	20	30	40	50	10 50	20		30	40
Stability	1405.92	1434.62	1415.48	1405.53	1435.00	1425.43	1444.57	1396.73	1387.17	1261.27
Flow	2.17	2.17	2.03	1.80	1.53	2.17	2.00	1.97	1.92	1.90
Air voids	4.02	4.06	4.03	4.00	3.88	3.45	3.73	3.69	4.19	4.16
Density	2.455	2.459	2.464	2.467	2.478	2.468	2.467	2.473	2.465	2.470
VFB	72.77	72.57	72.77	72.35	73.56	75.84	74.28	74.53	71.91	72.10
VMA	14.78	14.81	14.79	14.87	14.68	14.30	14.52	14.48	14.93	14.89
CUBE						**BLADE**				
	10	20	30	40	50	10	20	30	40	50
Stability	1580.03	1677.23	1619.06	1632.61	1638.58	1105.14	1056.16	1027.08	1048.97	1037.03
Flow	2.63	2.83	2.07	2.03	1.90	1.97	1.67	1.73	2.07	2.13
Air voids	3.32	3.66	3.65	3.89	4.10	3.35	3.52	3.54	3.56	3.80
Density	2.473	2.470	2.475	2.474	2.473	2.472	2.472	2.477	2.482	2.480
VFB	76.51	74.63	74.69	73.40	72.28	76.37	75.44	75.31	75.21	73.94
VMA	14.14	14.42	14.41	14.61	14.79	14.17	14.32	14.34	14.35	14.58
DBM										
Stability	Flow	Air voids	Density	VFB	VMA					
1405.73	2.9	4.01	2.47	71.95	14.30					

Table 2. Marshall Design Values & Characteristics of Different aggregate shapes

Flow

The flow value is measured as the deformation between no load and maximum load carried by the specimen during the test. Lower flow value occurs by increasing the percentage of cubical, disk type aggregates. Maximum flow value obtained at 20% replacement with cubical shape aggregates and lower value for 20% replacement with blade shape aggregates.

From the above graph showing the replacement of original aggregates with cubical, rod, disk and blade shape of aggregates. Comparative to one will not replace the gaps between the bituminous mixtures, but for rod type aggregates the air voids reduces by increasing the replacement of aggregates.

Density

Density is directly related to voids in the compacted mix. Maximum density attained for the cubical shape of aggregates, with 30% replacement of cubes and lower densities for the disk shape particles and for blade and rod shapes are not following the trend.

Percentage Aggregate Voids Filled by Bitumen

Certain amount of air voids are present in the aggregate and the bitumen is expected to fill up to 67 to 75 percent of these voids filled by the bitumen, increases with an increases in the surface area by different shape of aggregates or fillers to the mix and decreases with further increase in the surface area by adding different shape of aggregates and filler. Voids filled by bitumen with different types of aggregates. Voids filled with bitumen more for rod shape aggregates and it increases with replacement of aggregates and for disk blade, cube shapes decreases with increases the replacement of aggregates.

Voids in Mineral Aggregates

The primary purpose of the VMA is to ensure reasonably high bitumen content. This can be accomplished by specifying minimum bitumen content or a minimum VMA. Cubical shape aggregates attains the maximum % VMA, and blade shape aggregates attains the lower values because of the aggregates tend to break down excessively during compaction.

4. Limitations

The following are the limitations of the present study.

1. The present study is limited to single gradation i.e dense bituminous macadam of MORTH specifications.
2. The present work is limited to the use of 60/70 penetration grade bitumen and by adding different binders can give different results.
3. Though extensive laboratory experimentation has been carried out in terms of characterizing the DBM mixes with respect to performance characteristics, the present study is silent in the areas of testing the DBM mixes with respect to fatigue, rutting and other important characteristics.

IV. CONCLUSIONS

Following conclusions are drawn from this study

1. Higher Marshall Stability values were obtained from the mixes prepared with cubical shape aggregates i.e. 16.77kN. It is observed that stability increases with increase in proportion of cubical aggregates up to 20%. Cubical particles exhibit interlock and internal friction, which results in higher mechanical stability than the flat, thin, and elongated particles.
2. The parameters such as stability, flow and voids filled with bitumen increases with increase in proportion of cubical aggregates for DBM mixes.
3. The parameters such as air voids and voids in mineral aggregate increases with increase in proportion of blade type of aggregates in DBM mixes, because the same type of particles will not replace the gaps between the bitumen mixes.
4. Mixes prepared with replacement of 20% cubical, blade, rod and disk aggregates shown higher stability values.
5. The stability of mix with different type of aggregates is shown good results, against satisfying the minimum requirement of 9kN.
6. Cubical shape aggregates attains the maximum percentage VMA, and blade shape aggregates attains the lower values because of the aggregates tend to break down excessively during compaction.
7. Particle shape parameter, higher sphericity value obtained for cubical shape aggregates and lower value for blade shape aggregate, because the sphericity value higher indicates the roundness of the aggregate. Obtained particle index values satisfying the minimum requirement for cubical particles i.e more than 18.

Some Of The Advanages From The Above Results

a) Eliminates time and cost factor.
b)It can make the Angularity Index value relatively accurate.
c) Rutting characteristics can be defined.

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