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Influence of Size and Shape of Aggregate on the Mechanical Response of Bituminous mixes: A-Review

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Abstract - *Road Transport is critical infrastructure, it impacts the pace, structure, and model of advancement for a country. Along with this the road and highway sector perform a critical task in the economic growth of a country. In India, around 64.5 percent of goods are transported via road and nearly 90 percent of passenger traffic is by road. Due to an increased number of heavy vehicles, especially in Tropical regions, causes several performance problems asphalt pavements, which is the most common type of pavement in India, therefore in asphalt pavement wheel loads are delivered by particle-to-particle through the point of contact in the granular combination, by volume, granular combination generally accounts for 92 to 96 percent of asphalt mixture. The asphalt mixture produced in different aspects relates to the characteristic of the granular materials used in the mixes such as the physical characteristics and chemical characteristics of aggregates. The physical properties of the aggregates (gradation, fracture percentage, shape, texture), are among the factors effects on the mechanical property of the structure such as durability, performance, shear resistance, rutting, fatigue reaction, and OBC (optimum banding content) of the mixture. These parameters have long been studied by researchers and numerous validated experiments have been designed and developed to measure them. The present paper introduces an overview of various researches related to the mechanical response of asphalt mixtures by changing the size and shape of aggregate.*

Key Words: Aggregate Size and Shape, Bituminous Mixes, Mechanical Response.

1. INTRODUCTION

The important practice in flexible pavement mix design is the determination of the proportion bitumen binder, filler material, coarse, and fine aggregates, aggregates form a major portion of the bituminous pavement structure. The physical requirement of the aggregates, further its shape (i.e. form and angularity), texture and gradation, significantly have an effect on the all over performance of the mixtures. Aggregates in the mixture are essential to follow out a certainly suggested granular size distribution, that is identified as aggregate gradation (A depository of aggregate, obtained from a stone crusher, contains an aggregate of different dimensions in varied proportions, aggregates are sieved through a standard mesh system and the cumulative percent passing value is plotted against the sieve size (generally in logarithmic scale) and a curve is obtained, curve is known as the aggregate gradation (or particle size distribution) curve). The aggregate morphologies (shape, angularity, and texture), the shape is one of the most important and fundamental tests in the physical requirements for the coarse aggregate of bituminous mixes. IS: 2386 (Part1)-1999 measure the entire aggregate shape by specifying aggregate flakiness and elongation index and angularity number, ASTM D 3398 – 2000 purpose a parameter named particle index to determine the shape and texture, ASTM D 4791–2005 flat and/or elongated particles are evaluated applying a particular caliper. But these tests may not be suitable for materials that tend to be round or cubic. In most of these experiments, one has to estimate the parameters by touching the materials one by one, so they take more time and effort. Because of the mentality involved, test outcome may vary from one person to another (Janoo 1998). There are a variety of innovative ways to simplify the shape of the whole, such as using new technology. Recently various characterization methods used to analyze whole shape indices in wide scales like (DIP) Digital Image Processing techniques such as X-ray Computed Tomography, Aggregate Imaging Measurement System 2 (AIMS2) and Optical Scanning, (See Fig. 1).

1.1 AUTOMATIC CHARACTERIZATION OF AGGREGATE SHAPE PROPERTIES

Due to introduction and advancement of digital image processing (DIP) methods, research scholars attempt to use an automatic characterization of aggregate shape approach. Some of the DIP methods, such as X-ray Computed Tomography, laser profiling, Aggregate Imaging Measurement System 2 (AIMS2) and photogrammetry have been tried [23]. This method has these advantages:

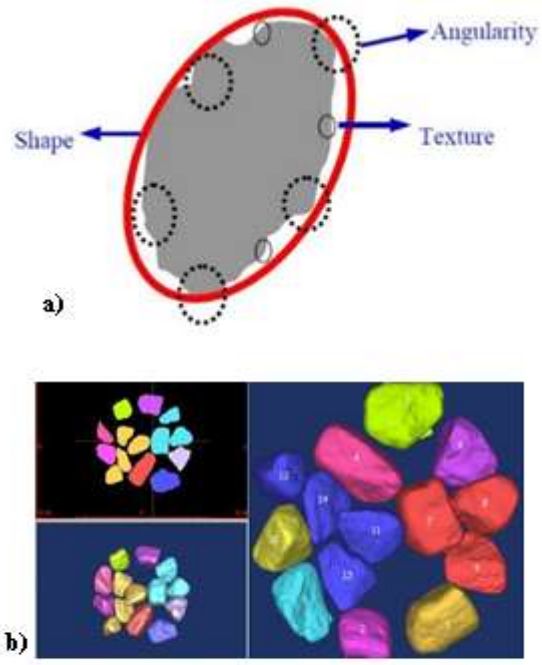

Fig-1: (a) Ingredient of Aggregate Shape Properties (E. Masad 2001) & **(b)** Three-dimensional model of gravel aggregate (**Jiangfeng Wu et al., 2017**)

a) This technique is fast and requires less time, so the real-time quality control and thus, settings can be implement to the crusher or sieve.
b) It is an automatic process, it is devoid of the mentality associated with human judgment.
c) By using this technique, many other geometrical properties of other aggregates such as cross-sectional area, perimeter, orientation, size distribution and even volume parameters of the mixture are measured.

Hence, however trying to determine aggregate shape, the research scholars were encouraged to use numerous shape factors, more than the conventional ones. A partial list of different such shape parameters, Table-1. Parameters are in based of using normal geometric criteria circumscribe an aggregate by regular shape and in the second stage evaluating the volume or surface. The conditions of the parameters are not restricted, the different researchers suggest and use several alternative terms (Janoo 1998). Similarly, researchers have proposed several criteria for quantifying angularity as shape parameters, for example (i) the angle of the corner (ii) Height of the corner (iii) radius of curvature of the corner (iv)concavity or convexity of the corner, etc.

Table -1: Equation of different shape parameters

Shape Parameter	Equation	Reference
Elongation	$\frac{Length}{Width}$	Kuo and Freeman et al. 2000
Flatness	$\frac{Width}{thickness}$	Masad, 2004
Flakiness	$\frac{thickness}{breadth}$	Masad, 2004
Sphericity	$\sqrt[3]{thickness\ x\ \frac{width}{length^2}}$	Seracetin Arasan., et al., 2011
Roundness	$\frac{perimeter}{\pi\ x\ average\ diameter}$	Kuo and Freeman et al. 2000, Masad, 2004
Shape factor	$\frac{thickness}{\sqrt{length\ x\ width}}$	Kuo et al. 1988
Form factor	$\frac{4\pi\ x\ area}{primeter^2}$	Kuo et al. 1988
Convexity ratio	$\frac{projected\ area}{convex\ area}$	Mora and Kwan 2000
Fullness ratio	$\sqrt{convexity\ ratio}$	Mora and Kwan 2000

2. LITERATURE SURVEY

(Robert P. Elliott., et al., 1991) Evaluated the influence of variations aggregate grade in bituminous concrete. Six bituminous mixes were tested for inspection of the aggregate gradation variance on the mix characteristic, five gradations for each mix (job mix formula (JMF) gradation, fine gradation, coarse gradation coarse-fine gradation, and fine-coarse gradation) the gradation is based on typical construction work. The mix design was done by the job mix formula. The result showed that fine-coarse grade causes the highest Marshall AV (Air Void) and VMA (Void Mineral Aggregate) and Coarse-fine grade the lowest Marshall AV and VMA , creep stiffness result was Lowe for both coarse-fine and fine-coarse grade.

(Craig M. Newtson & John P. Turner., 1993) Investigated the effects of two kinds of aggregate surface size on the bituminous concrete hardness and persistence to permanent deformation. The samples are two alluvial and one crushed limestone aggregate with top sizes of (19.1 mm, 25.4 mm, and 31.8 mm), traffic assumed "heavy". The following tests, creep rebound and resilient modulus test were performed on bituminous concrete specimens. The result showed decrement stiffness and resistance rutting with increment surface tope size with alluvial aggregates and increment with crushed limestone.

(C.-Y. Kuo and R. B. Freeman., 1998) To evaluate the characteristics of aggregate such as classification, texture, shape (elongation and angularity) on the efficiency of bituminous concrete mixes. The recent technologies (digital image analysis techniques) were used to characterize

aggregates morphologic properties (flatness, elongation) of coarse aggregate, to find characteristic of fine aggregate and to make relation between technical properties of bituminous concrete mixtures and aggregate properties and about the shape, classification and orientation of coarse aggregate in the mixes. The result show that comprehensive and accurate quantification of aggregate characteristics is necessary to find their effect on the bituminous concrete and to choose aggregate for high-quality pavement.

(A. K. H. Kwan., et al., 1999) The shape characteristics of aggregate significantly have its own impact on the durability, resistance and workability of the bituminous concrete mixes. In this research various rock types and gradation (25 samples) were analyzed and the outcome associated with the conventional techniques, strong relationship among DIP and conventional measurement obtained, as well as DIP techniques is more faster and maybe a best alternate to measure the shape characteristic. Generally, DIP technique present more evidence about the shape than the conventional method and also directly the ratio of thickness/width and length/width of the aggregate, instead of just the proportion of squamous or elongated particles according to arbitrary definitions.

(Adam J. Hand., et al., 2001) Evaluated aggregate gradation effects on HMA performance, 21 Superpave mixtures designed, the nominal maximum size and gradation are typical gradation used in the U.S. investigation consisted of both lab and prototype – scale loading. AASHTO and MP2 manual were used for Superpave mix design. Tests were conducted Air-dry triaxial, wheel track, and APT TEST (rutting performance). The result showed volumetric mixture and nominal maximum size did not importantly affect the rutting behavior. Laboratory tests suggested Sufficient rutting performance obtained for grade plot above and though the restricted zone gradations, than below.

(C. Chandan., et al., 2004) this article used form digital image analysis method to specify morphologic characteristic of aggregate (texture, angularity and form) in road construction. Wavelet analysis carried out on the grayscale particle image. The results show that the representation of multiscale wavelets is a strong tools for detection of texture. Angular and particle shape analyzes are carried out by binary images analysis on bases of gradient-based method. Particle shape analysis containing computation of the form factor and sphericity index based on measurements of the shortest, middle, and the longest axis of the shape and the details software developed to compute the various aggregate form factor. The results indicate that these computed dimensions values of the particles correspond very closely to the values that were measured manually using a digital calibrator.

(Jian-Shiuh C., et al., 2005) Studied an impact of aggregate shape on the strength SMA and typical gradation in Taiwan of asphalt concrete mixtures. DIP (Digital Image Processing) technique had been used for aggregate characterization, for analysis process Optima's image analyzer, is versatile software able to providing full mensuration of coarse aggregate is used. Four shapes of aggregate cubical, rod, disk, and blade (cubic, flaky & elongated) specified by the Zingg diagram were used. SMA as open-graded and dense-graded is typical gradation which is used in Taiwan are reviewed, Marshall Mix design was according to ASTM D-1559.The result showed cubic shape aggregate had best rutting resistance, while flaky and elongated aggregate showed lower compatibility and higher breakage.

(Tongyan Pan., et al., 2006) Investigated the influence morphologic characteristic of coarse aggregate on the permanent deformation properties of hot mix asphalt. UIAIA imaging-based morphological indices used in the bituminous mixes. The eighteen bituminous mixes were investigated via regression analyses. The result shows the flakiness and elongated ratio had no computable influence on permanent deformation but the influence of angularity index and surface texture indices particularly significant.

(Saad Abo-Q & Haider Al-S, 2007) Studied the influence of aggregate chemical and physical properties on the creep and stripping performance of HMA. Limestone and basalt with three gradations as per ASTM specification Upper limit (Dense Gradation), mid limit (Dense Gradation), mid limits (Open Gradation) and two types of penetration grade 70–10, 60/70, and AC-20 viscosity grading were investigated. Results show HMA specimens in unconditioned situations showed basalt resist creep better than limestone and conditioned mixes with Basalt were more resistant to creep than Limestone. The upper limit introduced great resistance to stripping.

(Seracetin Arasan., et al., 2011) This paper found out the connection between aggregate shape and mechanical behavior of bituminous concrete. DIP (Digital Image processing) used for characterization of aggregate in flat, elongation, spherical for images utilized form Nikon D80 Camera, Image analyzed by Image Java program. The effect of flat, elongation, spherical shapes and mix of them evaluated Marshall Stability, flow, and Marshall Quotient (MQ) in bituminous concrete mixes. Specimens made in accordance with ASTM D 1559. The results represent a pleasant relationship among aggregate shape index and BC, shape trace on variant properties such as strength, workability, shear resistance, tensile strength, hardness, fatigue reaction and OBC (optimum binder content) of BC.

(Amir G., et al., 2012) Investigated influence of aggregate grade on the rutting of bituminous pavement based on Asphalt Institute Manual gradation range divided into three variations (upper, middle & lower). Asphalt bitumen grade 60/70 which is commonly used in the region (near north-east of Iran). Samples were prepared using the Marshall method. The result presents that upper limit gradation present great Performance versus rutting whereas the lower limit has the highest rutting value.

(Ashok Singh., et al., 2012) The researcher used numerical investigation on the influence of aggregate gradation on the mechanical response of the bituminous mix. A numerical analysis is the study of algorithms that use numerical approximation for mathematical analysis problems the input data depended on past experiments. The binder has been modeled as rigid visco-plastic material, Synthetic aggregate considered as an elliptical. The analysis process followed by finite element software (ABAQUS 6.4.1) according to constitutive behavior incorporating equations. The result shows aggregate gradation and shape effect on the load transfer and with simulation technique considerable time and effort were saved as compared to analyzed laboratory study.

(Kalhan Mitra., et al., 2012) Evaluated the mechanical performance of a bituminous mix base of empirical and numerical investigation. Aggregate gradation was based on MORTH for the bituminous concrete layer and the modeling part is based on the modeling of real asphalt binder, modeling of binder mix and modeling of an asphalt mix by using tow sample, synthetic sample, and Actual sample. The cross-sectional images processing of the predictions bituminous mix model specimens matched well with the experimental results. The initiation position of crack strongly belongs to aggregate morphology (shape and size) of the aggregates and also the load-transfer capability.

(Manal A. A & Mohamed I. E. A, 2013) investigated the influence of aggregate gradation according to Egypt specification and aggregate type on HMA rutting, the mix design was according to the Marshall Design method. The outcome of the truck wheel test demonstrates, (3A) coarser grade showed the highest resistance and open-graded the lowest (2C) to rutting for all types of aggregate, and Dolomite present highest resistance for all types of gradations. The highest stability value related to Limestone with dense gradation (4C) and the lowest to Basalt of open gradation (2C).

(Anirudh N., et al., 2014) Determined the particle index based on fractured faces or the influence of coarse aggregate particle index on the characteristic of bituminous concrete. The requirement as per MORTH grade-II and evaluated with the Marshall Stability, indirect tensile strength (ITS) and Fatigue tests. Bituminous mix with crushed aggregate showed higher stability values with the increase in the PI (Particle Index) value and also a decrease in optimum asphalt content, increment fractured face and increment stiffness ratio (TSR).

(Lee P. Leon & Raymond Charles, 2015) Evaluated the influence of aggregate particle angularity on HMA and its relevance to the permanent deformation resistance. Natural quartzite, and crushed limestone the two types of aggregate were investigate, and also (AIMS) Aggregate Imaging System was used for characterization. The result showed an increment in aggregate angularity it will be increased in the strength rutting. An evaluation among the measured and anticipated data, permanent deformation anticipated models present the limits of existing anticipated models. The numerical analysis explained the rutting regions and determined that angularity has an impact on the beginning of these regions. Forecast of rutting helps road organizations and by development economists and engineers specify the best method for maintenance, renovation, and also new structure of the road infrastructure.

(Iuri S. B., et al., 2015) The shape properties and their effects on HMA behavior have been investigated. AIMS2 (Aggregate Image Measurement System2) used for the characterization and for Image Processing analysis of aggregate researcher used from System (iPas). Aggregate under investigation was formed three different mineralogical sources. After arranging the samples and performing tests resilient modulus (RM), indirect tensile strength (ITS) and fatigue life a satisfactory, the main result would be aggregated with various method but with the same shape and other characteristics are presumably to lead to a similar mechanical response.

(Jiangfeng Wu., et al., 2017) studied the analysis of mineralogical combination with two methods XRD and SEM which were used for specifying microstructure of gravel aggregate. As it has become clear that the microstructure of gravel material has an important effect on macro service presentation. In this research variable gravel aggregate, namely gneiss, quartzite, sandstone, gneiss, and basalt are selected for XRD data are analyzed by JADE 6.0 software and SEM experiments. The research findings show that the composite of these two methods can be used in chemical composition and aggregation morphology characteristics determination.

(Sumanth S., et al., 2017) Investigated the influence of coarse aggregates shape on the strength of DBM, Aggregate classify as largest, smallest and intermediate diameter using Vernier Calipers. With these diameters, the elongation ratio and flatness ratio is calculated with which the aggregate shape is specified. Aggregate shape classified by Zingg diagram as rod, disc, blade & cube. Aggregate gradation of DBM is according to MORTH, for this study proportion of 10%, 20%, 30% 40% and 50% of different shape is prepared and the mix evaluated Marshall Test and wheel truck test. Results obtained that cube shape with 20% and 50% has higher strength and more rutting resistance potential than the conventional mix, blade shape with 30% in the mix has the least strength.

(Changhong Zhou., et al., 2017) This study took a new approach to specify the influence of aggregate shape on the strength of SMA-20 gradation mixes. The glue-sphered ellipsoid particle were used to construct cylinder sample and triaxial tests simulated by Discrete Element Method. The main discussed point is (i) Creating ellipsoid aggregate by glued spheres and control its size (ii) simulate the triaxial performance of bituminous mixes skeleton; and (iii) choose coarse aggregates for hot mix asphalt according to shape

factors. Therefore calculation, a nephogram of triaxial strength variable with shape factors Flatness and Elongation was finally obtained. The results showed that cubical and part of rod aggregate work much better in strength than others, which were proved to be consistent with that of experimental results.

(Can Jin et al., 2018) Studied characterization of aggregate shape with the virtual 3D solid models produced with X-ray CT which were very similar to real aggregates laboratory measurement. The following are some of the major findings of this study the 3D solid models established are very near to actual aggregates, and include intact geometric border data in their 3D interior structure. Lab measurement demonstrate that the simulated measurement technique can automatically simplify the accuracy level, efficiency, and computerization of aggregate shape categorization.

(Jiangfeg Wu et al., 2018) Investigated on gravel aggregate using digital image processing by using the CT scanning methodology. In the current research quartzite gravel investigated by CT scanning technique. MATLAB applied to record and analysis of aggregate morphology properties. The 3D aggregates recreated by applying MIMICS soft the achieved 3D aggregates imported into GEOMAGIC STUDIO soft lastly the 3D info achieve by analysis. The findings of this study introduced the new method of study aggregate with the produced 3D model and the investigation is still in the initial stage for 3D indexes of aggregates.

(Lee P. Leon & Derek Gay., 2019) Evaluated angularity influence of aggregate on permanent deformation of asphalt mixtures by Gene expression programming. Three kinds of local aggregates river gravel, limestone, sharp sand with a nominal maximum aggregate size of 12.5 mm and asphalt binder penetration grade 60/75. AIMS were used for aggregate characterization into four different categories of rounded, subrounded, subangular and angular. After various levels of angularity evaluated and analyzed by the GEP model, it shows Coarse aggregate angularity importantly influence on the permanent deformation strains.

3. ANALYSIS OF LITERATURE

According to following figure 4.1, which is taken from the research paper understudy, shows the amount of work on the influence of aggregate size and shape on the mechanical response of bituminous mixes, from 1991 to 2019. Respectively 2012,2015,1998,1999, 2017, 1993, 1991 and 2018 with the highest rates percentage of work completed at the top and respectively 2005, 2014, 2013, 2006, 2007, and 2011 were ranked second with the least work done, (See Fig. 2).

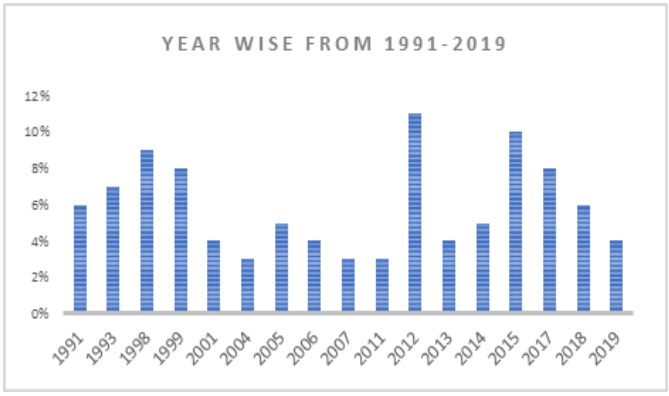

Fig. 2. Year Wise Publication From 1991 - 2019

The importance of aggregate characterization such as its shape, size, and texture and its effect on asphalt mix behavior has been discussed previously and detailed in the context of the study performed by the researcher in different ways for aggregate particle characterization. Respectively DIP, AIMS and X-ray CT with the highest rates percentage of work completed at the top and respectively manual measurement, Zing Diagram, and UIAIA were ranked second with the least work done, (See Fig. 3).

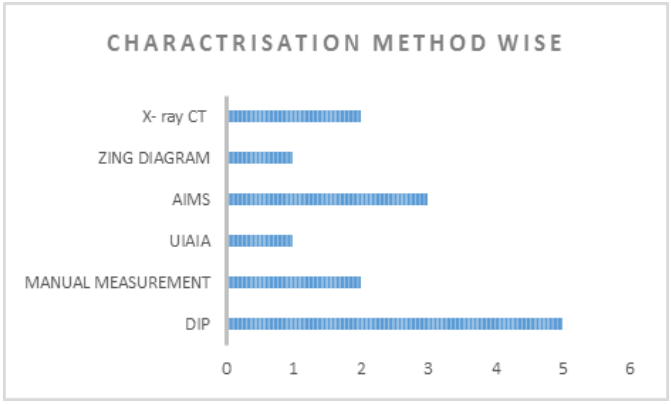

Fig. 3. Characterization Method Wise Publication From

As can be seen below, the amount of work done country-by-country, based on research papers previously studied in literature survey, the US, India, and China, respectively, with the most of the work being done, Egypt, Brazil, Iran, Turkey and Jordan rank second with the lowest rates, respectively, (See Fig. 4).

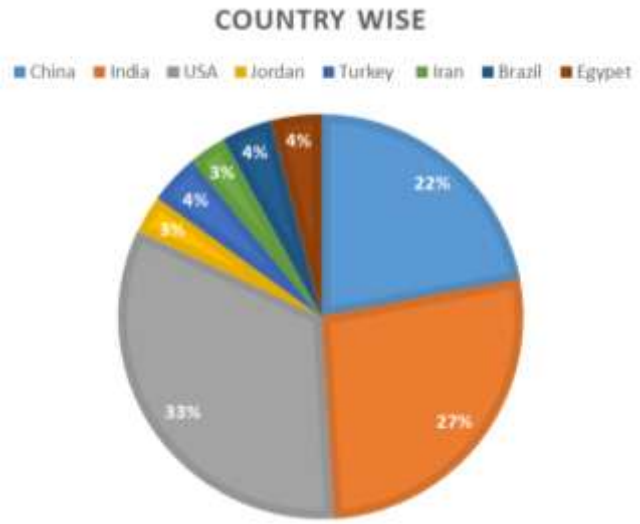

Fig. 4. Country Wise Publication From 1991 - 2019

4. Objective

Particle size and shape influence the characteristics of HMA more than the other properties of aggregate. The objectives of the study are as follows:

1. To analyze a suitable way for aggregate characterization in hot mix asphalt.
2. To review previous research work conducted on the effect of size and shape of Aggregate on the mechanical properties of hot mix asphalt.

5. DISCASION AND CONCLUSIONS

Aggregates make up the largest portion of the road pavement structure. The technical properties of aggregates as well as their shape (i.e. form and angularity), texture and gradation have a considerable effect on the overall performance of the bituminous mixtures [14] [23]. Several researchers reported that the shape, texture, and gradation of the aggregates have a significant impact on the mechanical properties of bitumen mixtures, e.g. shear resistance, durability, stiffness, fatigue resistance, rutting resistance, workability, OBC (Optimum Bitumen Content). According to Ministry of Road Transport & Highways annual report 2018-19, worth of highways Projects in the North-East India 1, 90,000 crores have been sanctioned for the construction of roads for over 12,000 km to preserve the national capital and to present a durable and resistant structure, it is considered necessary to focus on the research carried out by different researchers on this topic and their suggestions, therefore it will change the existing standards and specification of highway construction increase the life cycle, reduce the maintenance cost of project and increase the road safety quality. By examining all the previous research works and processes on the aggregate size and shape impact on the Mechanical Response of bituminous mixes. The observations are summarized below:

1. Many evaluating techniques and equipment are available for morphological characterization the main challenge is how to use the present resources to maximize the level of practical usage to achieve improvement in the current situation.
2. Several researchers have suggested that aggregate with various sizes and shapes present various task in specifying the mechanical characteristic of bituminous mixes, further confirmation is desired to substantiate this hypothesis.
3. Laboratory studies have sometimes been the same and sometimes contradictory to simulated methods.
4. By using new technology the investigators are capable to rebuild the bituminous mixes structure for further analyze and expand specific factors to measure the microstructural properties of the bitumen mixture.
5. Numerical models like (DE) discrete element method and (FE) finite element method, have been created, accredited and implemented in modeling Marshall Stability, fatigue, and rutting. However, few studies have focused on the implementation of the FE or DE model.
6. Further efforts are needed to persuade stakeholders to change existing standards and specifications used in the road construction industry that will create a durable and load-resistant pavement.

6. FUTURE SCOPE

1. A further and more detailed study using advanced technology to understand the role of aggregate size and shape in bitumen mixing.
2. Trying to increase a better understanding of how bituminous mixes properties (size, shape, retention time of asphalt glue and air void) affects mechanical behaviors.
3. Study of Chemical Properties of Bituminous mix, interactions, Aggregate Temperature and Angle of repose on the Mechanical Properties of bituminous mixes.

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