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A Review on Evaluation Effect of Aggregate Gradation and Binder Parameters on Bituminous Mix Rutting

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***Abstract*—Bituminous pavements are composed of three components: aggregate, binder, and air. In the process of plant production and on site construction, the construction quality can vary in the three components and the variability can further affect a pavement's future performance. This research identifies aggregate gradation, binder content, and air voids content as the fundamental parameters. Understanding the fundamental parameters influence on the Hot Mix Asphalt (HMA) mixture's performance properties can provide valuable information on how to improve the current quality practice. The objective of this study is to investigate how mix gradation, air voids and small range binder content deviation from design binder content can affect, individually and collectively, the performance properties (rutting, cracking, and moisture susceptibility) of asphalt concrete in the context of construction variations.**

***Index Terms*— Hot Mix Asphalt, Rutting, Gradation, Air voids, Bituminous concrete.**

I. INTRODUCTION

A. Background

India has a road network with 4.23 million km length of roads. The National Highways Development Project (NHDP), initiated by Indian Government, is a project to upgrade, rehabilitate and widen major highways in India. Recently NHDP (phase III) was taken up to upgrade about 10,000 km of the existing national highway to four lane facility at an estimated cost Rs. 55,000 crores. This project also aimed at providing the connectivity to the state capitals and connectivity to centres of economic importance covering around 2000 km.

Most of the pavements, currently built in India under national highway development program (NHDP), have bituminous layers with dense bituminous macadam (DBM) and bituminous concrete (BC) as binder and wearing courses respectively. Rutting and fatigue cracking are the most common distresses observed on several sections. This indicates that the bituminous mixtures currently being used are inadequate for heavy axle loads, high tire pressures and climatic conditions generally encountered in India. To improve rutting and fatigue performance of bituminous mixes, it is necessary to have a clear understanding of the characteristics of binder and mixes.

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Performance of the bituminous mixes can be defined by their ability to resist permanent deformation, fatigue cracking, moisture induced damage, thermal cracking, and the mixture's overall stiffness. Aggregate gradation can affect all these and other properties such as skid resistance, field constructability, and the asphalt binder aging characteristics. Designing a bituminous mixture to meet the needs of a particular paving project requires careful selection of the aggregate and bitumen to be used. An appropriate bitumen grade and content must be selected. A compatible aggregate source and gradation must also be chosen to meet the needs of the project. All four properties will affect the overall performance of the bituminous mixture.
Bituminous mixture is composed of approximately 95%, by weight, or 80%, by volume, mineral aggregate. Therefore it is important to see how aggregate gradation can affect the fundamental properties of bituminous mixture.
Two mechanisms are involved in the formation of rutting: traffic densification and material lateral movement. Densification in a layer occurs in the first few summers after opening to traffic and the degree of densification depends on the initial compaction level. The lateral movement of material is related to the shear resistance of a bituminous mixture material. The rutting performance of a bituminous mixture depends not only on the properties of the aggregates and binder, but also on how these materials interact in the mixture. Rutting in bituminous mixes is controlled by the characteristics of the binder and aggregates and their interaction

B. Problem Statement

Majority of the roadways in India are flexible pavements. Rutting is the most serious concern as it affects the serviceability and safety of the road. Not only that, reducing the potential of rutting development will have enormous economic benefits due to reduction of maintenance costs and extension of the service life of the roadway. In spite of following IRC type pavement design practices and MORTH specifications, many of the bituminous surfaces have started showing premature signs of distresses (MORTH, 2013). And majority of the roadway in India fails by rutting. Superpave uses binder parameter according to rutting susceptibility at high pavement temperatures. National Co-operative Highway Research Program (NCHRP) also uses different mix parameters to control rutting. In this context, it is necessary to recheck the existing rutting controlling parameters and to think of a new parameter which can explain rutting more reliably.

II. OBJECTIVE

The main objective of the study is evaluation of the effect of aggregate gradation and binder parameters on rutting of bituminous mixes commonly used in India.

a. To evaluate the effect of aggregate gradations on bituminous mix rutting.
b. Evaluation of various rutting parameters for binders to identify the most appropriate binder parameter that can be used to control mix rutting (in India).

III. LITERATURE REVIEW

A. Literature Background

Indian road transportation infrastructure is rapidly expanding with the ambitious development of road networks under National Highways Development Programme (NHDP), State Highways Improvement Programmes, etc. The fast growing Indian economy will further demand for road transport network with a high quality pavement structure as the main corridors are required to cater to very heavy traffic-both in terms of number and axle loading. While these road development projects help in adding considerable infrastructural assets, their construction and subsequent maintenance phases require huge amount of suitable pavement materials.
Currently, majority of the Indian roads are flexible pavements since these are less expensive with regard to initial investment and maintenance. Flexible pavements are so named because the total pavement structure deflects, or flexes, under loading. A flexible pavement structure is typically composed of several layers of materials. Each layer receives the loads from the above layer, spreads them out, and then passes on these loads to the next layer below. A typical flexible pavement structure consists of the surface course and the underlying base and sub-base courses. Surface course is the top layer which comes in contact with the traffic. It may be composed of one or several different HMA sub-layers. Base course is the layer directly below the HMA layer and generally consists of aggregates. Sub base course is the layer under the base layer.

There are many kinds of pavement distresses but most of the roads in India fail by rutting and fatigue cracking. Fatigue cracking occurs due to repeated traffic loading. Rutting is surface depression in the wheel path. There are two basic types of rutting: structural or subgrade rutting and non-structural or mix rutting. Mix rutting occurs when the subgrade does not rut yet the pavement surface exhibits wheel path depressions. Subgrade rutting occurs when the subgrade exhibits wheel path depressions due to loading. In this case, the pavement settles into the subgrade ruts causing surface depressions in the wheel path.

As the pavement temperature in India goes as high as 60°C, HMA at the top of pavement layer softens and under the wheel load pavement, shows HMA rutting. There are binder parameters (Superpave) as well as mix parameters (NCHRP) to control the rutting phenomenon of HMA. Though flexible pavements are practiced according to existing IRC guidelines and MORTH, pavements are showing failure by rutting at a premature stage indicating problem in mix design. So, to improve rutting performance of bituminous mixes, it is necessary to have a clear understanding of the characteristics of binders and mixes to recheck the existing parameters for controlling rutting and reconfirm in Indian context. In the following sections of this chapter a brief review of literature has been presented on the parameters of both binder and the mix which are used for controlling rutting.

B. Binder Parameter

The test carried out for controlling rutting is dynamic shear rheometer (DSR). Two parameters G* (complex shear modulus) and δ (phase angle), are found out from the test conducted at different temperatures and frequencies. Super pave binder specification uses the parameter G*/Sin (δ) to specify binders according to rutting susceptibility at high pavement temperatures. This parameter is measured using a dynamic shear rheometer (DSR), which subjects a sample of binder placed between two parallel plates to oscillatory shear. Tests are performed on both fresh binder and aged binder. The binder parameter G*/Sin (δ) is based on dissipated energy. With each cycle of loading, the work done in deforming an asphalt or an asphalt pavement at high temperatures is partially recovered by the elastic component of the strain and partially dissipated by the viscous flow component of the strain and any associated generation of heat.

A number of researchers have carried out studies on identifying a binder parameter for explaining the rutting behaviour of the binders. Leahy and Quintus (1994) studied the effect of binders on rutting performance of bituminous mixes. The results indicated that the G*/sin (δ) has a weak relationship with the results obtained from the wheel track and shear test. Bahia et al (2001) studied the effect of different rheological parameters for predicting the rutting performance of modified binders. The results indicated that the mixture rutting indicators have a very poor correlation with the G*/sin (δ). Said S. F.(2005) has shown that the stiffness modulus and creep deformation of the bituminous layers can change significantly during the early life of the pavement and this change should be considered in performance specifications and pavement analysis.

D'Angelo et al (2007) has performed the MSCR test on different types of modified binders and correlated it with the rutting observed in the accelerated load facility sections. The G*/sin (δ) has shown very poor correlation with rutting in bituminous mixes as compared to correlation with non-recoverable creep compliance obtained from MSCR test. The non-recoverable creep compliance obtained at 3200 Pa has shown a better correlation with mix rutting as compared to G*/sin(δ) (D"Angelo et al 2007). At high stress level the non-recoverable creep compliance of bitumen has shown a better correlation with the mix rutting. Knowing the PG grade as determined by G*/sin (δ) or with Jnr value at a lower stress level, it does not guarantee that the binder will resist rutting under heavy traffic loading conditions (Reinke, 2010).

Kumar and Veeraragavan (2011) studied the influence of aging on the rheological properties of modified asphalt binders and the influence of temperature and aging on the rutting resistance of modified asphalt mixes. It was observed from aging and rutting indices that rubber modified asphalt binder is more susceptible to aging than unmodified asphalt binder. Modification of asphalt binder and aging has significant influence on the rheological properties and rutting characteristics of asphalt binders and mixes. The non-recoverable creep compliance (Jnr) obtained from MSCRT is a better alternative to replace the G*/sin(δ) for the prediction of rutting since it differentiates binders having penetrations, softening points or G*/sin(d) in the same range (Dreessen et al,2009). G*/sin(d) specifications are based on the testing of unmodified binders, so these are not effective for evaluating the rutting performance of modified binders(D"Angelo,2010). Also studies have shown that compared to zero shear viscosity, the multiple stress creep recovery value of the binder is very useful tool for predicting the creep performance of modified binders (Zoorob et al, 2012).

C. Mix Parameter

Mix. parameter used for rutting is determined from the Simple Performance Test (SPT). For linear viscoelastic material, such as HMA mixes, the stress-to-strain relationship under constant sinusoidal loading is defined by complex dynamic modulus (E*). It relates stress to strain for linear viscoelastic materials subjected to continuous sinusoidal loading in the frequency domain.

The AASHTO new "Mechanistic Empirical Pavement Design Guide" includes a procedure for predicting asphalt pavement permanent deformation (rutting). A joint research study was undertaken to develop rutting resistance criteria for SuperpaveTM (Superpave) and other asphalt mixes. The study used the new Simple Performance Test (SPT) and an accelerated laboratory wheel rutting resistance test. The SPT is included in AASHTO 2002 as a means of asphalt mix characterization. The SPT‟s were performed using the University of Waterloo‟s Interlaken asphalt and soil testing apparatus.

Vivar and Haddock (2006) studied the pavement performance in term of rutting. The dynamic modulus was used as a measure of HMA performance and durability. HMA mixture samples were tested in both unconditioned and conditioned states. Two types of specimen conditioning were used for the study, moisture and air with varying air void. For moisture conditioning, the samples were partially saturated and placed in a 60°C water bath for 24 hours prior to testing.

Conditioning in air was completed by placing the specimens in an 85°C forced draft oven for 5 days prior to testing. Moisture conditioning tends to promote moisture damage, thereby enabling the decrease in performance and durability due to this damage to be quantified by the dynamic modulus. Rutting was measured by the Purdue laboratory wheel tracking device (PurWheel). In this test, load is applied with a pneumatic tire typically inflated to produce a contact pressure of 0.69 MPa. Prior to testing, the samples were conditioned in the water at the test temperature for 20 minutes. During the test, the computer records the number of wheel passes, the deformation and the elapsed test time. The test ends automatically when a 20 mm rut depth is reached or 20,000 wheel passes are applied, whichever occurs first.

It was found that air voids contents provided the highest differences in dynamic modulus values. Frequency did not appear to be significant. However, in some cases, the change in air voids content does appear to increase the moisture damage. For lower frequency the correlation of stiffness rut factor and rutting was good for air void 4% for air conditioned sample. But for moisture conditioned sample, correlation factor was as low as 0.48.

IV. Conclusion

It is seen from the literature that significant amount of research has been carried out on the performance of bituminous pavements and climate parameters on the performance. Bituminous binder, being a key constituent of the mix, has significant influence on the performance of the mix. Parameter obtained from rheological evaluation of the binders using dynamic shear rheometer (DSR) over a wide range of temperature and frequency are being used to study rutting performance of bituminous mix.

Rutting occurring in the bituminous layers has been considered as a major distress in bituminous pavements especially when subjected to high temperatures and heavy axle load. Repeated load test (flow number) is the commonly adopted parameter for evaluation of the permanent deformation characteristics of bituminous mix. From the above literature, it appears that MSCR test better represents the rutting potential of the modified binders compared to other binder parameters. The review of the literature presented in the chapter has been useful in identifying the critical bituminous procedures and understanding the effect of different bituminous mix parameters, traffic loading and climatic parameters on the performance of asphalt pavement. The review is also useful for selecting appropriate test procedures for evaluating the characteristics of binders and mixes.

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