Effect of Aggregate Gradation and Binder Parameters on Rutting of Bituminous Pavements

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Abstract: **Rutting (permanent deformation) of bituminous pavements is one of major types of distress experienced in the service life of pavements. Bituminous mixes are composed of three components: aggregate, binder, and air voids. In the process of plant production and construction, the mix quality can vary in the three components and their variability can further affect a pavement performance. Aggregates are one of the major building materials which are used in the construction industry and the major portion in the construction of highway pavements. Therefore, aggregate properties affect the performance of bituminous pavements. Aggregate Gradation is one of the important characteristics of aggregates affecting rutting of hot mix asphalt. The objective of this research is to investigate how aggregate gradation and binder content can impact individually and collectively, the performance characteristics (rutting, cracking) of bituminous concrete in the context of construction variations.**

Key words: **Rutting, Hot Mix Asphalt, Aggregate Gradation, Bituminous concrete**

I. INTRODUCTION

Most of the flexible pavements, currently constructed 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. Preeminent deformation and fatigue cracking are the common types of distresses noticed on several sections. This indicates that the bituminous mixes currently being used are inadequate for heavy axle loads, higher tire pressures and climatic conditions generally encountered in India. To improve the rutting and fatigue performance of bituminous mixtures, it is necessary to clearly understand the characteristics of binders and mixtures. Performance of the bituminous mixes can be defined by their ability to resist rutting, fatigue cracking, moisture induced damage, thermal cracking, and the overall stiffness of the mix. Aggregate gradation can affect these and other properties such as skid resistance and the bituminous binder aging characteristics. Bituminous mix design to meet the needs of a particular project requires careful selection of the aggregate gradation and bitumen to be used. An appropriate bitumen content and grade must be selected. A compatible source of aggregate and aggregate gradation must also be chosen to meet the needs of that project. All the properties will affect the overall performance of the bituminous mix. Bituminous mix is composed of approximately 95%, by weight, or 80%, by volume of aggregate. Therefore it is very important to see how aggregate gradation will affect the fundamental properties of bituminous mix. Two mechanisms are involved in the rutting formation: material lateral movement and traffic densification. Densification in a bituminous layer occur in the first few summers after opening to traffic and degree of densification depends on the initial compaction level. The material lateral movement is related to the shear resistance of a bituminous mix. Further the rutting performance of a bituminous mix depends not only on the of the aggregates properties and binder, but also on how these materials interact in the mix. Bituminous mix rutting is controlled by the characteristics of the binder and aggregates and their interaction.

Most of the roads in India are flexible pavements. Rutting is the most serious concern of hot mix asphalt (HMA) pavements as it affects the safety and serviceability of the pavement (Marks et al, 1990). Furthermore, reducing the potential of rutting development will have enormous economic benefits due to extension of the service life of the road and reduction of maintenance costs. Even though designing the pavements by following IRC pavement design practices and MORTH specifications, many of the bituminous pavements are showing premature signs of distresses (MORTH, 2013). And majority of the pavements in India fails by permanent deformation. The depth and rate of rutting depend on internal and external factors. Internal factors include pavement thickness, bitumen, aggregate and mix properties External factors include load and truck traffic volume, tire pressure, temperature and construction practices. (Zaniewski and Srinivasan, 2004). Superpave design uses binder parameter according to rutting susceptibility at higher pavement temperatures. National Co-operative Highway Research Program (NCHRP) also uses different mixture parameters to control rutting. In this context, it is required to recheck the existing rutting controlling parameters and to think of a new parameter which can explain rutting more reliably.

II. OBJECTIVE

The objective of this study is to evaluate the effect of aggregate gradation and binder parameters on rutting performance of bituminous mixes commonly used in India.

1. To evaluate the effect of aggregate gradations on bituminous mixture rutting.
2. To evaluation of various rutting parameters for binders and to identify the most appropriate binder parameter that can be used to control mixture rutting.

III. LITERATURE REVIEW

The road transportation infrastructure is expanding rapidly with the ambitious road networks development under National Highways Development Programme(NHDP), State Highways Improvement Programmes, etc. Fast growing Indian economy will further demand for road transportation network with a high quality pavements as the important corridors need to cater to heavy traffic: both in terms of number and axle loading. Further these road development projects helps in adding infrastructural assets, but construction and subsequent maintenance phases requires huge amount of suitable pavement materials. Majority of the Indian roads are flexible pavements as they are less expensive with regard to initial investment. Flexible pavement structure is typically composed of several layers of materials, each layer receives the loads from the top layer, spreads them out, and then passes on these loads to the bottom layer. A typical flexible pavement structure consists of the surface course and the underlying base and sub-base courses. The top layer is the surface course 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 different kinds of pavement distresses but most of the roads in India fail by preeminent deformation and fatigue cracking. Fatigue cracking occurs due to repeated traffic loads. Rutting is the surface depression along the wheel path. There are two basic types of rutting: sub-grade or structural rutting and mix or non-structural rutting. Mix rutting occurs when the sub-grade does not rut yet the pavement surface exhibits depressions along wheel path. Sub-grade rutting occurs when the sub-grade exhibits wheel path depressions due to traffic loads. In this case, the pavement settles into the sub-grade ruts causing surface depressions along the wheel path. In summer the pavement temperature in India goes as high as 60°C, HMA at the top of pavement layer softens at higher temperature 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. Even though flexible pavement design are practiced according to existing IRC and MORTH guidelines, pavements are failing by rutting at a premature stage indicating problem in mix design. So, to improve rutting performance of bituminous mixtures, it is necessary clearly understand the characteristics of binders and mixtures to recheck the existing parameters for controlling rutting and to reconfirm in Indian context.

The factor that is usually noticed as the most effective parameter causing rutting is the aggregate characteristics. Ahlrich (1996) also mentioned that HMA properties are highly affected by their aggregate characteristics. Button et al. (1990) have indicated nine possible factors cause rutting, but they stated that the aggregate characteristics is the primary quality of material factor influencing rutting susceptibility. Stakston and Bahia (2003) also indicated that rut resistance is ‘highly dependent on aggregate gradation’, and mixes made with the best possible materials would fail without a proper aggregate gradation.

Numerical modeling and experimental works shown that shear stresses caused by vehicle tire loads introduce significant amount of external energy to the mix which leads to permanent deformations. There are three different mechanisms causing these deformations. The first one is to reduce the friction between aggregates coated with bitumen. The frictional resistance in these aggregates like all other granular materials is related to their mineral components, roughness and also the properties of bitumen. The second mechanism is defeating the interlocking between aggregates that it pushes the aggregates away from each other. Increasing air-void in bituminous mix is the result of this kind of dilatory behaviour. The quantity of expansion depends on aggregate gradation, angularity and the shape of the aggregates. The third mechanism is the loss of adhesion between bitumen and aggregate in bituminous mix. It is expected that the effect of each of these mechanism depends on design mix and thickness of pavement layers. For thin pavement layer, stone-on-stone friction and aggregate interlocking are the principal mechanisms against rutting. By increasing the thickness of pavement layer will reduce the friction effect and aggregate interlocking and therefore deformation properties of binder has the most effect on the resistance to failure in cohesion and continuity between binder and aggregates (Jung and Young, 1998). The internal resistance of HMA is affected directly by the properties of bituminous mix. However, there is often a lack of consistency between the aggregate specifications and mix performance. It seems, there is an appropriate internal strength range for materials for defined maximum nominal size. Also internal resistance of HMA can be increased by aggregate interlock (stone-on-stone). The internal contact of coarse aggregate is considered to be the main source for the internal resistance, further it is imperative that the mix is placed with a strong coarse-aggregate skeleton. Altering the fine aggregate volume (large-stone asphalt mixes, (LSAMs)) will have the effect on the internal resistance and load-carrying capacity of HMA. Stone on stone contact is started while aggregate skeleton gets to a constant condition. Studies have indicated that susceptibility to plastic deformation increases dramatically when natural fine aggregate particles are replaced by crushed particles in a given aggregate gradation.(Chen and Liao, 2002; Krutz and Sebaaly, 1993; Elliot et al., 1991; Button et al., 1990; Mahboub and Allen, 1990; Brown and Bassett, 1990).

IV. BINDER PARAMETER

The test carried out on binder for controlling rutting is Dynamic Shear Rheometer (DSR). Two parameters G* (complex shear modulus) and δ (phase angle), are found out from this 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 higher pavement temperatures. This parameter is measured using a DSR, in which a sample of binder is placed between two parallel plates to oscillatory shear. Tests are performed on both fresh and aged binders. The binder parameter G*/Sin (δ) is based on dissipated energy. With each cycle of loading, the work done in deforming an bitumen or an bituminous pavement at high temperatures is partially recovered by the elastic component of the strain and partially dissipated by the viscous flow components of the strain and any associated heat generation.

Many researchers have conducted studies to identify a binder parameter for explaining the rutting behaviour of the binders. Leahy and Quintus (1994) have studied the effect of binders on rutting performance of bituminous mixtures, results indicated that the G*/sin (δ) has a weak relationship with the results obtained from the shear test and wheel track. Bahia et al (2001) studied the effect of rheological parameters for predicting the rutting performance of modified binders. The results indicated that the mix rutting indicators have a very poor correlation with the G*/sin (δ). Said S. F.(2005) concluded that the creep deformation and stiffness modulus of the bituminous layers can significantly change during the early life of the pavement and this change should be considered in pavement analysis and performance specifications. D'Angelo et al (2007) has performed the Multiple Stress Creep Recovery(MSCR) test on different types of modified binders and correlated it with the rutting observed in the accelerated load facility sections, G*/sin(δ) has shown very poor correlation with rutting in bituminous mixes as compared to correlation with non-recoverable creep compliance obtained from the MSCR test. The non-recoverable creep compliance obtained at 3200 Pa has shown a better correlation with mixture rutting as compared to G*/sin(δ) (D'Angelo et al 2007). At high stress levels the non recoverable creep compliance of bitumen has shown a better correlation with the mixture rutting. Knowing the Performance Grade (PG) as determined by G*/sin(δ) or with non recoverable creep compliance (Jnr) value at lower stress levels, it does not guarantee that binder will resist rutting under heavy traffic loading conditions (Reinke, 2010). Kumar and Veeraragavan (2011) studied the influence of binder aging on the rheological properties of modified bituminous binders and influence of temperature and aging on the rut resistance of modified bituminous mixes. It is observed that from aging and rutting indices rubber modified bituminous binder is more susceptible to aging than unmodified bituminous binder. Modification of bituminous binder and aging has significant influence on the rheological properties and rutting characteristics of bituminous binders and mixtures. The Jnr obtained from MSCR test 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 that much effective for evaluating the rutting performance of modified binders(D"Angelo,2010). Further more studies have indicated that compared to zero shear viscosity, multiple stress creep recovery value of the binder is very useful tool to predict the creep performance of modified binders (Zoorob et al, 2012)

V. MIX PARAMETER

The mix parameter used for rutting is determined from the Simple Performance Test (SPT). For linear visco elastic 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 visco elastic material subjected to continuous sinusoidal load in the frequency domain. The AASHTO new Mechanistic Empirical Pavement Design Guide includes a procedure for predicting bituminoust pavement permanent deformation. A joint research study was undertaken to develop rutting resistance criteria for Superpave and other bituminous mixes, this study used the new SPT test and an accelerated laboratory wheel rutting resistance test. The SPT is included in AASHTO 2002 as a means of bituminous mix characterization. The SPT test was performed using the University of Waterloo's asphalt and soil testing apparatus. Vivar and Haddock (2006) have studied the pavement performance in terms of rutting, dynamic modulus was used as a measure of HMA performance and durability. HMA mix 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. For moisture conditioning, the samples were partially saturated and placed in a water bath maintained at 60°C for 24 hours prior to testing. Conditioning in air was completed by placing the specimens at 85°C forced draft oven for 5 days prior to testing. Moisture conditioning tends to promote the moisture damage, thereby enabling 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 samples were conditioned in the water at the test temperature for 20 minutes. During the test the computer records the number of wheel passes, deformation and the elapsed test time. The test ends automatically when 20 mm rut depth is reached or 20,000 wheel passes are applied, whichever occurs first. It was observed that air void content provided the highest differences in dynamic modulus values, frequency did not appear to be significant. Further, in some cases, the change in air voids content does appear to increase the moisture damage. At lower frequency the correlation of stiffness rut factor and rutting was good for air void of 4% for air conditioned sample, but for moisture conditioned sample correlation factor was as low as 0.48. According to Roberts et al. (1996) rutting can be reduced by increasing the voids in the mineral aggregate, establishing minimum and maximum air void content, limiting the amount of natural sand, establishing a minimum percentage of crushed coarse and fine aggregates, using stiffer binder, or by the use of coarser mixture gradations. Fred (1967) reported that aggregate gradation have more influence than aggregate type, he also concluded that the temperature susceptibility characteristics of the bitumen appear to have more influence at longer time of loading. Bitumen binders are visco elastic materials whose resistance to deformation under wheel load is very sensitive to temperature and loading time (Ramond et al., 1999). The viscosity of bitumen directly affects the strength of bituminous concrete in compression (rutting) for the practical range of temperatures. The log of pavement resistance and of cohesion varies directly with the log of viscosity of bitumen. Modulus of elasticity in compression was influenced by the type of binder, temperature and amount of lateral confinement (William et al., 1967). Brown and Snaith (1974) suggested that at higher temperatures the increase in deformation is related to the decrease in binder viscosity, thereby leading to a lower interlock between the aggregates. The contribution of the aggregate skeleton towards the behaviour of the mix becomes more significant at higher temperatures.

VI. SUMMARY

1. It is observed from the literature that significant amount of research has been carried out on the performance of bituminous pavements and climate parameters. Bituminous binder, being a key constituent of the mix, has significant influence on the performance of the mix.
2. Parameters obtained from rheological evaluation of the binders using DSR over a wide range of temperatures and frequency are being used to study rutting performance of bituminous mixes. Rutting occurring in the bituminous layers was considered as a major distress in bituminous pavements especially when subjected to high temperatures and heavy axle loads.
3. Repeated load test (flow number) is the commonly adopted parameter for evaluation of the permanent deformation characteristics of bituminous mixes.
4. From the above literature, it appears that MSCR test better represents the rutting potential of the modified binders compared to other binder parameters.
5. The review of the literature presented was been useful in identifying the critical procedures and understanding the effect of different bituminous mix parameters, traffic loading and climatic parameters on the performance of bituminous pavements.
6. The review is also useful for selecting appropriate test procedures for evaluating the characteristics of binders and mixes.

REFERENCE

[1] Bahia, H.U., Hanson, D.I., Zeng, Zhai, H., Khatri, M.A., Anderson, R.M (2001), Charecterization of modified binders in Superpave mix design‖ Transportation Research Board, Washington D.C.

[2] D’angelo J., Kluttz R., Dongre R., Stephens K. and Zanzotto L (2007). ―Revision of the Superpave high temperature binder specification: The Multiple Stress Creep Recovery Test‖, Journal of Association of Asphalt Paving Technologists, Vol. 76, pp. 123-162.

[3] D’angelo J. (2010). ―New high-temperature binder specification using multiple stress creep and recovery‖, Transportation Research Circular E-C147, pp. 1-13.

[4] Dressen S., Planche J.P.and Gardel V (2009). ―A new performance related test method for rutting prediction: MSCRT.‖Advanced Testing and Characterization of Bituminous Materials-Loizos, Partl, Scarpas and AlQuadi (eds),Taylor and Francis Group, ISBN 978-0- 41555854-9.

[5] Kumar, S.A. and Veeraragavan, A.(2011), ―Rheological and Rutting Characterization of Asphalt Mixes with Modified Binders‖, Journal of Testing and Evaluation, vol.40,No.1.

[6] Leahy R.B., and Quintus H.V. (1994). ―Validation of relationship between Specification Properties and Performance‖, Report No.A- 409, Strategic Highway Research Program, Transportation Research Board,Washington D.C.

[7] MoRT&H (2013), *Specification for Road and Bridge Works*, 5th Edition, Ministry of Road Transport and Highways, Indian Roads Congress, New Delhi, India.

[8] Said S.F. (2005).―Aging effect of mechanical characteristics of bituminous mixes‖, Journal of Transportation Research Board, No. 1901, Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 1–9.

[9] Principles of Construction of Hot-Mix Asphalt Pavements (1983). The Asphalt Institute Manual Series No.22 (MS-22).

[10] Chowdhury A., Joe W.B., and Jose D.C.G. (2001). Effects of Superpave restricted zone on permanent deformation, Report no. 201–202, Texas A&M University.

[11] Kim, Y.R., Park H., Aragao, F., and Lutif, J.E.S. (2009). Effects of aggregate structure on hot-mix asphalt rutting performance in low traffic volume local pavements, Construction and Building Materials Journal.

[12] Shashidhar, N., XiaoxiongZhong, Aroon V. Shenoy and Ernest J. Bastian Jr. (2000). Investigating the role of aggregate structure in asphalt pavement, International Center for Aggregates Research 8th Annual Symposium: Aggregates -Asphalt Concrete, Bases and Fines.

[13] Coenen A, PhD Dissertation, University of Wisconsin-Madison, Image Analysis ofAggregate Structure Parameters as Performance Indicators of Rutting Resistance, (2011).