RES MILITARIS
REVUE EUROPEENNE D ETUDES EUROPEAN JOURNAL OF MILITARY STUDIES
Social Science Journal

GRADATION IMPACT ON RUTTING PERFORMANCE OF BITUMINOUS CONCRETE MIX

Dhruva Singh, Vaibhav Dubey

Faculty of Engineering & Technology/Rama University Uttar Pradesh, Kanpur

Abstract

Flexible pavements, designed to withstand prevailing traffic loads, inevitably experience deterioration over time, leading to distress within their service life. Rutting and cracking, including fatigue and thermal cracking, are among the most significant issues in flexible pavement. Various factors in pavement design are taken into account with regard to rutting and fatigue performance, particularly in thick bituminous pavements and those exposed to high temperatures, heavy traffic, and overloading. Premature pavement failure can result from significant rutting distress. In India, flexible pavements adhere to the mechanistic-empirical pavement design philosophy outlined in IRC 37-2018, while bituminous mixes are designed according to specifications in MoRTH 2013, which includes gradation bands for different layer thicknesses and minimum bitumen content. Recognizing the difficulty in achieving target gradation in the field, MoRTH 2013 also provides tolerance limits for each sieve size.
This study aimed to assess how aggregate gradation tolerances affect mix rutting performance and to investigate potential causes for premature rutting failure on the NH-353C highway section. A forensic investigation was conducted, encompassing pavement assessment surveys, layer thickness measurements, and laboratory material testing. Rutting was found to be limited to the bituminous layer based on observations from test pit openings. Field cores were analyzed to determine the cause of mix rutting failure, revealing higher binder content in the bituminous mixes used in the field. Wearing course cores exhibited very low air voids in the wheel path, while mix instability was noted in the binder course due to variable air void levels. A laboratory study was undertaken to assess the impact of aggregate gradation tolerance on mix rutting performance, focusing on MoRTH BC-1 gradations. Twenty-one gradations were evaluated, and their rutting performance was assessed using wheel tracking tests. Data analysis aimed to identify relationships between rut depth and gradation parameters, as well as to evaluate variability in rutting performance across gradations using Bailey's ratio and changes in deformation rate with repeated load cycles.
Keywords: Rutting, Forensic investigation, Gradation, variability

I. INTRODUCTION

India boasts the world's second-largest road network, spanning around 5.898 million kilometers and expanding at a rate of approximately 27 kilometers per day. Given the substantial costs involved, it's crucial to economically design roadways that can serve their intended purpose effectively over their designated lifespan.
Pavement design is a critical aspect of road construction, involving the selection of appropriate materials and strict adherence to quality construction standards to create structures capable of efficiently distributing vehicle loads onto the underlying subgrade.
Two primary types of pavements are in use: concrete and bituminous. However, bituminous pavements are preferred by designers due to their cost-effectiveness, phased construction feasibility, and quicker road accessibility to traffic.
With time, pavements deteriorate, leading to various forms of distress, notably rutting and cracking (fatigue and thermal cracking) in flexible pavements.
Rutting, specifically, manifests as longitudinal depressions in wheel paths on bituminous pavements, primarily due to excessive consolidation and permanent deformations from repeated loads.
Rutting can be classified into two main types: subgrade rutting, caused by inadequate subgrade strength affecting all pavement layers, and mix rutting, impacting only the bituminous layer. Mix rutting can result from factors such as heavy loads, high tire pressures, improper aggregate type and gradation, and excessive binder content.
An illustrative example of premature rutting failure is evident on National Highway (NH-353C) in Telangana, India.

Objective of the study-

Examine Premature Rutting Failure Causes:
Evaluate Gradation Tolerance Impact on Rutting Performance:
Analyze how gradation tolerances influence the rutting performance of bituminous concrete mixtures.
These objectives highlight the study's primary focus on understanding the reasons behind pavement failure and exploring the relationship between gradation tolerances and rutting performance in bituminous concrete mixes.

Mechanism of Rutting

The cumulative effect of densification, lateral plastic flow and loss of materials within the wheel path due to repeated loading resulted in the accumulation of permanent deformation called rutting. (Chaturabong and Bahia, 2017) Among these, the material loss causes raveling but is not significantly contribute to rut depth, while the amount of densification and plastic flow governs rut depth. Densification is one-dimensional in-elastic displacement, while plastic flow refers to two-dimensional in-elastic displacements. These two types of rutting mechanisms are illustrated in Figure 2.1.

Figure 2.1 Mechanism of Rutting (NCHRP Report 1-37A, 2004)

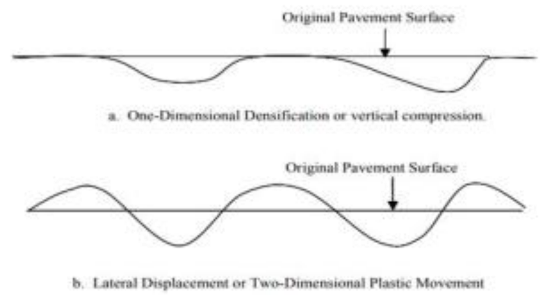

Figure 2.1 Mechanism of Rutting (NCHRP Report 1-37A, 2004)

4

Densification significantly contributes to rutting at the very early stage of opening bituminous pavement to traffic. Pavement is more susceptible to additional densification at high pavement temperature and excessive compressive stresses from traffic loading. Plastic flow of lateral distortion of the bituminous mix is caused by the formation of a shear failure plane due to the overloading of mixtures. The localized shear failure of mixes depends on factors such as high tire pressure, inadequate binder content, mix design, etc. In this kind of rutting, humps on either side of the depression bowl were observed. This kind of rutting can result in moderate to high severity rutting.

Elliott et al. (2016) examined six mixes for the effect of variation in the aggregate gradation on bituminous mix properties. They considered gradation by giving tolerance to the job mix formula. The five gradations were considered; (1) job mix formula (JMF) gradation, (2) a fine gradation, (3) coarse gradation, (4) a coarse-fine gradation, and (5) a fine-coarse gradation. They investigated several properties: creep stiffness, split tensile strength, resilient modulus, Marshall stability, Marshall flow, air voids and voids in mineral aggregate (VMA). Rutting performance was measured in terms of creep behavior. The creep stiffness was calculated by equation 2.1 for each interval of 5sec, 30 sec, 2min, 30min and 60 min.

$$Sx = l * \frac{h}{d} \qquad (2.1)$$

Where,

Sx = creep stiffness at time x;l = creep loading stress (15psi),h = original height of specimen; andd = vertical specimen deformation at time x.

Quan et al. (2020) studied the rutting potential of mixes concerning gradation and binder content variation. The study considered four key variables; 4.75 mm key sieve passing, Coarse particle gradation (>4.75 mm), Fine Particle gradation (< 4.75 mm) and binder content. Hamburg Wheel Tracking Test was used to determine rutting potential. The results showed that rut depth increases with an increase in 4.75 mm sieve passing percentage, and after a specific limit, the mix exhibits a significantly high amount of rutting. Skeletons composed of 13.2-9.5 mm aggregates outperformed 9.5-4.75 mm aggregates. Finer gradation in fine fractions improves the mix rutting resistance.

Radhakrishnan et al. (2018) evaluated the rutting performance and moisture resistance of asphalt mixes concerning gradation and design air void content. The different gradations provided by different agencies as shown in Figure 2.3. From those, a total of five gradations were considered. These gradations were designed for 3%, 4% and 5% air voids. As a result, they found that compared to design air voids, the aggregate gradation significantly affects the rutting performance of mixes. In contrast, both gradation and design air voids have a similar effect on the moisture resistance of mixes. Comparing the Marshall parameter and Rut Depth suggested that the current specification of 9kN stability and 4 mm maximum flow values are inadequate even for 10 msa traffic.

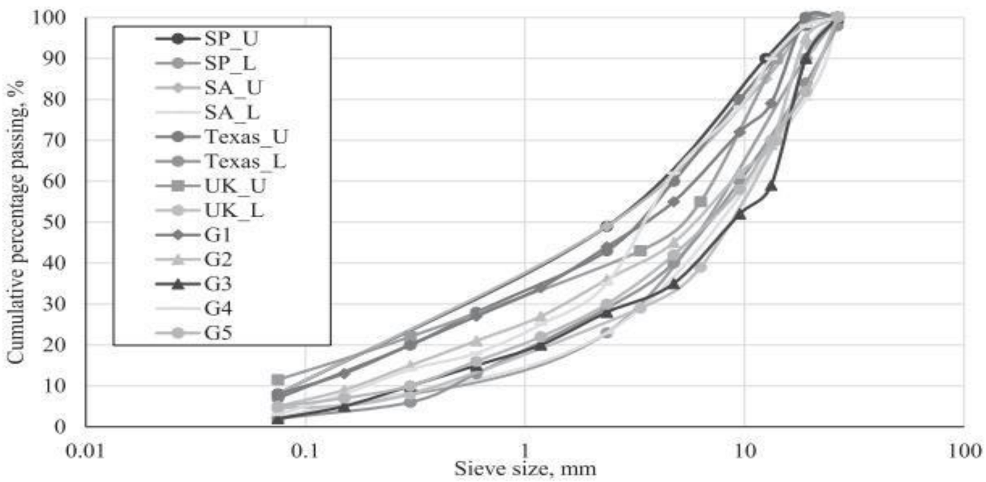

Figure 2.3 Different Gradation Provided by Researchers (Radhakrishnan et al. 2018)

1) Forensic Investigation of Premature Failure of Rutting

Button and Perdom(1990) investigated causes of rutting in bituminous pavements. and performance of bituminous mixes wtih increasing natural sand percentage in Texas, US. The carries out detail survey included test pits opening, axle load survey and core sample were taken. The pits are opened at location where rut depth is greater than 25 mm. The five cores were taken in tranverse direction. 25 cores were taken in 5 locations Field cores were tested for Bulk and Maximum Specific Gravity, Air Voids,Resilient Modulus At Five Temperatures, Marshall Stability,Tensile Properties – ITS,Resistance to Moisture, Binder Content, Aggregate Characteristic. The study found that air voids at each location were slightly low, particularly in binder coarse;Both surface and binder coarse indicated severe moisture susceptibility; Mixes used in Field have mixture deficiencies (excessive asphalt content, excessive fine aggregate and round shaped and smooth textured coarse aggregate).

Summary of Literature Review

From the literature review, several key points emerge:

- Rutting and deformation observed in the discussed locations were primarily attributed to factors such as heavily loaded trucks, steep gradients, high temperatures, and deficiencies in the mixtures used in the field.
- Deep ruts tend to be associated with pavements featuring fewer air voids and experiencing slow-moving, channelized traffic.
- The enlargement of the Nominal Maximum Aggregate Size (NMAS) of asphalt mixtures was found to amplify the aggregate contact action, characterized by interlocking force and friction.

- Regarding aggregate gradation, the values of Voids in Mineral Aggregate (VMA) initially decrease and then increase with an increase in the passing percentage of the 2.36 mm sieve. Meanwhile, the percentage of air voids decreases monotonically and tends to stabilize. Additionally, the fraction of aggregates in the 13.2-9.5 mm range was observed to have a greater impact on rutting performance compared to aggregates in the 9.5-4.75 mm range.

Pavement Condition Survey

A pavement condition survey is carried out to measure the extent and types of distress. This gives us an idea about pavement surface conditions concerning different chainages of the concern section. From the pavement condition survey data analysis, the locations which need to be addressed have been identified and based on those, further steps in evaluation are planned. In this study Network Survey Vehicle (NSV) was used to assess pavement condition. NSV, used in this study. The Network Survey vehicle has video cameras, a laser, a global positioning system, and video image processing techniques. From the NSV survey, rut depth, percentage cracking and variation in the International Roughness Index (IRI) along the stretch length can be obtained.

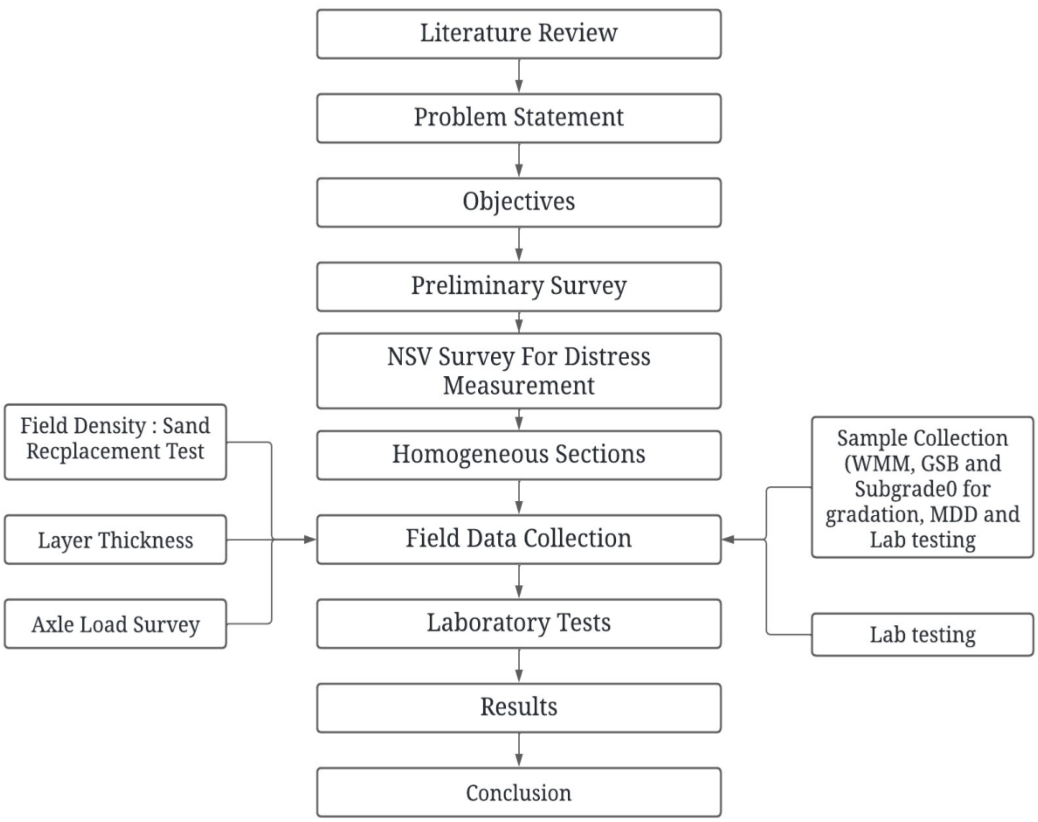

Figure 3.1 Flowchart for Forensic investigation of Premature Failure of Pavement

Wheel tracking test

The most common distress in bituminous pavements is rutting. This distress can be explained as a depression of material due to repeated wheel load on different pavement layers. Rutting is a depression in the longitudinal direction along with the wheels on the pavement. The rutting behavior of the bituminous mix is affected by gradation, aggregate type, type and quantity of binder content, air voids in the bituminous mixture, the surrounding temperature, and the loading on the pavement surface. The bituminous specimen's rutting can be analyzed per AASHTO T 324. According to AASHTO T 324, the rutting of the specimen can be tested using a wheel tracking machine. The Wheel tracking test was carried out using a dry wheel tracker. Figure 3.6 shows the test setup used for the wheel tracking test. It consisted of an arrangement for applying a normal load of 700±10 N on the specimens. The entire test setup was closed in an environmental chamber, where a constant test temperature could be maintained.

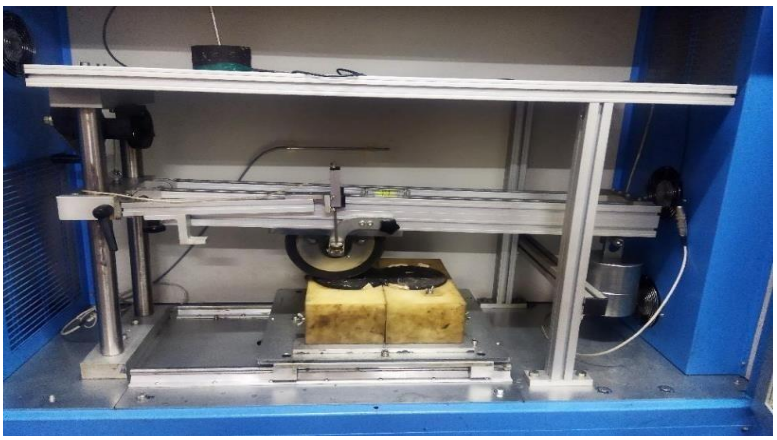

Figure 3.7 Wheel Tracking Apparatus

The specimens for the wheel tracking test were prepared to have an air void content of 7±0.5%. The mix was then short-term aged for 2 h, and cylindrical cast samples of 150 mm diameter specimens of 115 mm height were prepared using a Superpave gyratory compactor to achieve the target air void. Then the specimens were cut in D shape using a cutting machine. The specimen and the mold were placed in the wheel tracking device. The specimen was kept for 2 h to attain a temperature of 60°C. After 2 h, the computer was connected to the wheel tracking machine with the help of Hypertherm software. The input data related to the wheel tracking machines, such as temperature, number of cycles, maximum rut depth, and number of passes, were entered to record the rut depth at every 10-cycle interval, and the test was started. The test was automatically terminated as the number of passes reached 10,000 or rut depth reached 15 mm.

Conclusion

Excessive Binder Content (BC-1): The wearing course of the highway had a binder content ranging from 5.63% to 6.28%, which was higher than ideal. This excessive binder content led to increased lubrication effect and shear deformation under load. It was identified as the primary reason for mix instability, resulting in high densification and low air voids in the mixes.

Non-Uniform Air Voids in DBM-2 Mixes: The air voids in the DBM-2 mixes varied between 1.8% to 6.38%, indicating non-uniform compaction. This non-uniformity in air voids contributed to densification and shear deformation of the DBM-2 mixes.

Dry Aggregate Air Voids (DAAV) and Film Thickness: The study found a strong correlation between DAAV and film thickness with rut depth. Mixes with higher DAAV and thicker binder films exhibited greater rutting potential.

Gradation Impact: Relative coarser gradations showed a faster secondary stage of deformation compared to finer gradations. This was attributed to the aggregate packing characteristics and binder film thickness around the aggregates.

REFERENCES

1) Abadin, M. J., and K. Hayano. (2022). "Investigation of premature failure mechanism in pavement overlay of the national highway of Bangladesh." Construction and Building Materials, 318. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2021.126194.

2) Liu, S., L. Zhu, H. Zhang, T. Liu, P. Ji, and W. Cao. (2021) "Effect of Gradation Variability on Volume Parameter and Key Performances of HMA." Frontiers in Materials, 7. Frontiers Media S.A. https://doi.org/10.3389/fmats.2020.611409

3) Radhakrishnan, V., Ramya Sri, M., and Reddy, K. S. (2020). Sensitivity of rutting and moisture resistance of asphalt mixes to gradation and design air void content. International Journal of Pavement Engineering, 21(9), 1035–1043. https://doi.org/10.1080/10298436.2018.1517875

4) Yang, S., Braham, A., & Hossain, Z. (2020) "Relationship between Rank of Laboratory Testing Results and Field Performance of Asphalt Interstate Pavement" Journal of Materials in Civil Engineering, 32(9), 04020242.

5) Ali, Y., M. Irfan, S. Ahmed, and S. Ahmed. (2017). "Empirical Correlation of Permanent Deformation Tests for Evaluating the Rutting Response of Conventional Asphaltic Concrete Mixtures." Journal of Materials in Civil Engineering, 29 (8): 04017059. American Society of Civil Engineers (ASCE). https://doi.org/10.1061/(ASCE)mt.19435533.0001888.

6) Chaturabong, P., and H. U. Bahia. (2017) "Mechanisms of asphalt mixture rutting in the dry Hamburg Wheel Tracking test and the potential to be alternative test in measuring rutting resistance." Construction and Building Materials, 146: 175–182. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2017.04.080.

7) Elliott, R. P., M. Ford, Y. Ghanim, T. Fee, R. P. Elliott, and M. C. Ford. (2016) Effect of Aggregate Gradation Variation on Asphalt Concrete Mix Properties

8) Tapase, A. B., & Ranadive, M. S. (2016) "Performance Evaluation of Flexible Pavement Using the Finite Element Method" Geo-China 2016

9) Hand, A. J., Stiady, J. L., White, T. D., Noureldin, A. S., and Galal, K. (2001) "Gradation effects on hot-mix asphalt performance" Transportation Research Record: Journal of the Transportation Research Board, 1767(1), 152–157. https://doi.org/10.3141/1767-19

10) Mugume, R. B. (2020) "Effect of the unstable mix under severe traffic loading on the performance of asphalt pavements in tropical climate" Advances in Civil Engineering, 2020, 1–12.

11) Li, Jiange; Li, Peilong; Su, Jinfei; Xue, Yu; Rao, Wenyu (2019) "Effect of aggregate contact characteristics on densification properties of asphalt mixture." Construction and Building Materials, 204(), 691–702

12) Apeagyei, A. K. (2011). Rutting is a function of dynamic modulus and gradation. Journal of Materials in Civil Engineering, 23(9), 1302–1310. https://doi.org/10.1061/(ASCE)mt.1943-5533.0000309

13) NCHRP 1-37A (2004). "Guide for mechanistic-empirical design of new and rehabilitated pavement structures," Final Report, Prepared for National Cooperative Highway Research Program, National Research Council, Submitted by ARA, Inc., ERES Consultants Division, Transportation Research Board of the National Academies: Washington, DC.

14) khan, S., M. N. Nagabhushana, D. Tiwari, and P. K. Jain. (2013) "Rutting in Flexible Pavement: An Approach of Evaluation with Accelerated Pavement Testing Facility." Procedia - Social and Behavioral Sciences, 104: 149–157. Elsevier BV. https://doi.org/10.1016/j.sbspro.2013.11.107.

15) Lv, Q., W. Huang, M. Zheng, H. Sadek, Y. Zhang, and C. Yan. (2020) "Influence of gradation on asphalt mix rutting resistance measured by Hamburg Wheel Tracking test." Construction and Building Materials, 238. Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2019.117674.

16) Pérez, I., L. Medina, and J. Gallego. (2010) “Plastic deformation behavior of granular pavement materials under low traffic loading.” Granular Matter, 12 (1): 57–68. https://doi.org/10.1007/s10035-009-0154-2.

17) Ouf, M., and Abdolsamed, A. (2016). “Controlling Rutting Performance of Hot Mix Asphalt.” International Journal of Scientific & Engineering Research, Volume 6, Issue 12, December 2016.

18) Kandhal. P., and Cooley, A. (2002). “Coarse Versus Fine-Graded Superpave Mixtures: Comparative Evaluation Of Resistance To Rutting.” NCAT Report 02-02.

19) Vavrik, W. R., Pine, W. J., Huber, G., Carpenter, S. H., & Bailey, R. (2001). The bailey method of gradation evaluation: the influence of aggregate gradation and packing characteristics on voids in the mineral aggregate (with discussion). Journal of the Association of Asphalt Paving Technologists, 70

20) Roque, R., Huang, S. C., & Ruth, B. E. (1997). Maximizing shear resistance of asphalt mixtures by proper selection of aggregate gradation. In Eighth International Conference on Asphalt Pavements (Volume I), University of Washington, Seattle, WA.

21) Mahboub, K., Simpson, A., Oduroh, P., & Fleckenstein, J. (1992). Field performance of large-stone hot mix asphalt on a Kentucky coal haul road. Transportation Research Record, (1337).

22) Button, J.W., Perdomo, D. and Lytton, R.L., 1990. Influence of aggregate on rutting in asphalt concrete pavements. Transportation Research Record, (1259).

23) AASHTO T 324 (2019). “Standard methods of Test for Hamburg Wheel-Track Testing of compacted Hot Mix Asphalt.” Washington, DC.

24) ASTM C 29 (2016). “Standard test method for bulk density (“Unit weight”) and voids in aggregate.” ASTM International. West Conshohocken.

25) ASTM D 2493 (2016). “Standard Practice for Viscosity-Temperature Charts for Asphalt.” ASTM International. West Conshohocken.

26) ASTM D2726 (2014) “Standard Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Asphalt Mixtures.” ASTM International. West Conshohocken.

27) ASTM C-128 (2012). “Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate.” ASTM International. West Conshohocken.

28) AASHTO R 30 (2002). “Standard Practice for Mixture Conditioning of Hot Mix Asphalt.” Washington, DC