Establishing the Rutting Threshold for Marshall Samples Using HWTT

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ABSTRACT: The study proposes a threshold value for selecting rut-resistant Marshall-designed bituminous mixtures. The study also determines the correlation between 100 mm and 150 mm Hamburg Wheel Tracking Test (HWTT) samples. Samples of 100 mm and 150 mm diameter comprising different binder grades (VG-30, VG-40 and PMB-40) and compactive efforts (35, 75 and 110 blows) were tested using HWTT. The study emphasizes the stronger correlation ($R^2 \geq 0.85$) between 100mm and 150mm samples in HWTT results providing useful information to pavement engineers. The test result also shows that polymer-modified mixtures have better rutting resistance because of their increased viscosity while higher compactive efforts improve resistance by minimizing air voids. Overall, the study emphasizes the significance of performance testing and specification (rut depth=6.5mm at 20000 passes for the Marshall mixtures) in pavement design for ensuring resilience and durability. These findings provide valuable guidance for engineers and researchers aiming to increase the performance of bituminous pavements through effective material selection and design strategies.

1 INTRODUCTION

Rutting in road pavements is a common distress that occurs due to various factors such as heavy traffic loads, high temperatures and the properties of the materials (aggregate and binder) used in the pavement (Zheng *et al.* 2015). It is characterized by the deformation/displacement of the pavement surface particularly in bituminous layers, leading to a significant reduction in the pavement's service life and posing risks to drivers (Nahi *et al.* 2016). Understanding and addressing rutting in road pavements is crucial for ensuring the longevity of transportation infrastructure (Haider and Harichandran 2009). Also, by implementing appropriate materials, design considerations, and maintenance strategies, it is possible to minimize rutting and enhance road pavements overall performance and durability.

As we are moving toward the balanced mix design (BMD) concept (Yin *et al.* 2021), there is a need to incorporate simple performance tests at the design stage and for quality assurance and checks during production. It is important to note that while Marshall stability and flow tests assess strength and deformation, there are currently no standardized performance tests designed to evaluate rutting resistance for 100 mm diameter Marshall samples despite their widespread use in many countries (Hwang *et al.* 2004, Chakroborty *et al.* 2010, Hesami *et al.* 2013). Therefore, the motivation of this study lies in addressing the shortcomings of relying solely on volumetric properties, through the integration of a performance test in the current Marshall mix design method. Table 1 presents the HWTT Performance Specifications for different DOT's using different BMD approaches for 150 mm samples.

Since Marshall mixes are still used, we need to find the correlation of 100 mm diameter samples with the 150mm ones. To move forward in that direction, the main objectives of the present study are defined as follows:

- To establish the threshold specification for HWTT for 100mm Marshall samples.
- To determine the association of 100 mm and 150 mm Marshall samples by the HWT test.
- To evaluate the effect of binder grade and compaction levels on the rutting potential of bituminous mixtures.

2 RESEARCH METHODOLOGY

Twenty-seven specimens (1 Design Aggregate Gradation × 3 Binder Content × 3 Binder Grade × 3 Replicates) of bituminous concrete (BC-1) gradation having a Nominal maximum aggregate size (NMAS) of 19 mm were prepared. As a result, 3 OBC's were obtained for different combinations of mixtures. Further, using obtained OBC's, specimens were thereby made at three different levels of compactive efforts i.e., 35, 75 and 110 blows. This was done for replicating the primary and secondary compaction that occurs during the service life of the road. The air voids were

measured at 35 and 110 blows to validate the estimated density levels. The results aligned with expectations, confirming that 35 blows corresponded to approximately 7% air voids (initial compaction), while 110 blows resulted in around 2.5% air voids (long-term densification) simulating the effects of traffic-induced secondary compaction over time. Thereby HWTT was performed on 72 samples (100mm and 150 mm samples) to evaluate the rutting resistance.

3 MATERIAL SELECTION

3.1 *Aggregate and Binder*

Granite aggregates were used for the study. It was selected because of its higher strength and low absorptive characteristics which make it more durable and watertight. Mixtures were prepared using viscosity graded and polymer modified binders namely VG-30, VG-40 and PMB-40. These binders were selected based on their common use in road construction applications so that the results of this study could be extended to standard paving industry practices. The physical and mechanical properties of aggregate and binders have been evaluated as per the Bureau of Indian Standards and the Ministry of Road Transport and Highways (MoRT&H) specifications (MORT&H Guidelines 2013) .

Table 1. HWTT Performance Specifications for different DOT's using different approaches

Approach	**DOT's**	**Mixture type**	**HWTT Performance Specifications**
Approach A: Volumetric Design with Performance Verification	Illinois (Barry 2016)	Hot Mix Asphalt	The minimum number of wheel passes required to achieve **12.5 mm** rut depth, corresponding to various binder grades as indicated: PG58-xx (or lower)-5000 passes PG64-xx-7500 passes PG70-xx- 15000 passes PG76-xx (or higher)-20000 passes
	Texas (Alkhayat 2020)	Surface Mix	The minimum number passes to **12.5 mm** rut depth for the different virgin grade binders as: PG64-xx (or lower)-10000 passes PG70-xx- 15000 passes PG76-xx (or higher)-20000 passes
Approach B:Volumetric Design with Performance Optimization	Missouri (Yin *et al.* 2021)	Stone Matrix Asphalt	The minimum number of wheel passes required to achieve **12.5 mm** rut depth, corresponding to different binder grades as given under: PG58S-xx-5000 passes PG64S-22-7500 passes PG64H-22-15000passes PG64V-22- 20000passes
Approach C: Performance-Modified Volumetric Design	California (Yin 2018)	Surface Mix	The number of wheel passes to **12.5 mm** rut depth is greater than 20,000
Approach D: Performance Design	Tennessee (Yin *et al.* 2021)	All mixtures	≥ 10,000 passes to 12.5 mm rut depth for ADT < 10000; ≥ 15,000 passes to 12.5 mm rut depth for ADT & ≥ 20,000 passes to **12.5 mm** rut depth for Interstates and controlled access State Routes

4 EXPERIMENTAL INVESTIGATION

4.1 *Gradation*

Aggregate gradation is one of the most important properties which affect the final behavior of the mix (Kandhal and Mallick 1999). This study considered bituminous mixes prepared using bituminous concrete (BC-1) gradation. The choice of the gradation is consistent with the MoRT&H specifications. Figure 1 shows the design aggregate gradations i.e., mid-gradation for the bituminous mixes (BC-1) incorporated in the study. It is anticipated to have a similar trend even if the aggregate gradation changes. The primary reason for this expectation is that the underlying mechanisms governing rutting behavior such as the properties of the binder, the compaction effort, and the environmental conditions which would still apply across different gradations. While the absolute values of rut depth might vary with changes in aggregate gradation due to differences in particle size distribution, shape, and texture, our study's relative performance trends and correlations are likely to remain consistent. This is because the fundamental interactions between the binder and aggregate and the load distribution characteristics would still follow the same principles.

4.2 *Bituminous mix design*

This study employed Marshall mix design methodology following Indian standards to design the bituminous mixtures (IRC:111-2009 *Specifications for Dense Graded Bituminous Mixes*, 2009). The OBC was identified at 4% air voids in line with the MS-2

guidelines (*MS-2 7th Edition Asphalt Mix Design Methods* 2009). Following this, the Marshall parameters were evaluated at the established OBC's. Three different OBC's were determined for VG-30, VG-40 and PMB-40. While there were slight variations due to differences in binder viscosity and stiffness, these changes were minimal and followed expected mix design behavior. The resulting parameter values conform to the IRC:111-2009 specifications. To keep the manuscript concise, Marshall parameters have not been presented. Table 2 represents the different OBC's for various combinations of mixtures.

Table 2. OBC (%) of Mid Gradation for different Binder grades

Design Aggregate Gradation (DAG)	**BC-1 (NMAS-19mm)**		
Mid Gradation	**VG-30**	**VG-40**	**PMB-40**
	5.01	5.09	5.21

4.3 *Test Methods*

4.3.1 *Hamburg Wheel Tracking Test*

HWTT was performed at 60°C in a dry environment in accordance with AASHTO T324-2017. Four samples (for two sets) were evaluated. The HWTT specimens were prepared with a height of 62 ± 2 mm for 100 mm diameter samples and 95 ± 2 mm for 150 mm diameter samples, ensuring uniformity in testing and facilitating direct comparison of results. A load of 705 N was put on the compacted specimen by a steel wheel. Linear Variable Differential Transformers (LVDTs) were used to detect the rut depth. The termination criteria were 20,000 passes or 12.5 mm rut depth whichever happened first (Figure 2).

5 RESULT AND DISCUSSION

HWTT methods assess the rut depth of the bituminous mixture wherein a higher value of permanent deformation/rut depth indicates lower rutting resistance and conversely. Figure 3 illustrates the rut depth values at 20000 passes obtained for various combinations of bituminous mixes encompassing varied compactive efforts for different binder grades. It was seen that the 100 mm samples exhibited a lower rut depth than the 150 mm samples in the HWTT test because the strain rate for both size samples was significantly different (Brown and Bassett 1990). Further, Figure 4 shows the association between 100 mm and 150 mm Marshall samples. The relationship between HWTT results and sample dimensions can be described using the linear regression equation (1): $y = 1.9466x - 0.3634$

where y represents the predicted performance value in millimeters and x is the independent variable, likely related to HWTT parameters. The regression model has a strong correlation, as indicated by $R^2 = 0.98$. While the regression theoretically should pass through (0,0), the slight offset may be attributed to experimental variations or material inconsistencies. However, the strong correlation ($R^2 = 0.98$) confirms a reliable relationship between the rutting performance of 100 mm and 150 mm specimens. For 150 mm HWTT samples, the performance specification is set at 12.5 mm as outlined in Table 1. Using this model, the corresponding HWTT result for 100 mm Marshall samples can be calculated. Based on the regression and the established correlation, the predicted value for the 100 mm samples is approximately 6.5 mm for 10000 cycles or 20000 passes. This calculation helps in establishing performance equivalence between samples of different sizes. Further, the test result indicates that the polymer-modified mixes outperformed the mixtures prepared with viscosity graded binders (VG-30 and VG-40) for a particular DAG and compactive effort. This can be due to polymer modified binders increased viscosity (Habeeb *et al.* 2014). It was also found that for a given DAG and binder grade, the rut depth increases with decreasing compactive effort. Bituminous mixes with a higher percentage of air void have a higher rutting potential due to increased ductility and porosity (Barry 2016). Conversely, stiffness increases with increased compactive effort which improves the rutting resistance.

6 CONCLUSION

The study evaluates the resistance of the Marshall mixes against rutting using HWTT. This study examined Marshall compacted samples of 100 mm and 150 mm diameter comprising different binder grades (VG-30, VG-40 and PMB-40) and compactive efforts (35, 75 and 110 blows) for the HWTT. 100 mm samples correlate well ($R^2 \geq 0.98$) with 150 mm samples of HWTT. The regression analysis indicates that 100 mm Marshall samples can demonstrate comparable performance to 150 mm samples, with a predicted HWTT rut depth of approximately 6.5 mm at 10000 cycles/20000 passes. This supports the feasibility of using smaller sample dimensions under the same test conditions. These findings provide valuable guidance for engineers and researchers aiming to increase the performance of bituminous pavements through effective material selection and design strategies.

Results also indicate that polymer-modified mixtures have improved rutting resistance due to their increased viscosity. Additionally, increased compactive efforts improve the rutting resistance. This was so because the bituminous mixes with a higher percentage of air void have a higher rutting potential due to increased ductility and porosity. Conversely, stiffness

increases with increased compactive effort which improves the rutting resistance. While this study establishes a threshold for HWTT performance of 100 mm Marshall samples based on a single aggregate gradation (BC-1), future research should explore a wider range of gradations, including SMA and gap-graded mixes, to enhance applicability.

7 REFERENCES

Al-khayat, H., 2020. Balanced Mix Design for Asphalt Mixtures, (March).

Barry, M.K., 2016. An analysis of Impact Factors on the Illinois Flexibility Index Test (Master's thesis).

Brown, E.R. and Bassett, C.E., 1990. Effects of maximum aggregate size on rutting potential and other properties of asphalt-aggregate mixtures. *Transportation Research Record*, (1259), 107–119.

Chakroborty, P., Das, A., and Ghosh, P., 2010. Determining reliability of an asphalt mix design: case of marshall method. *Journal of Transportation Engineering*, 136 (1), 31–37.

Habeeb, H., Chandra, S., and Nashaat, Y., 2014. Estimation of moisture damage and permanent deformation in asphalt mixture from aggregate gradation. *KSCE Journal of Civil Engineering*, 18 (6), 1655–1663.

Haider, S.W. and Harichandran, R.S., 2009. Effect of axle load spectrum characteristics on flexible pavement performance. *Transportation Research Record*, (2095), 101–114.

Hesami, S., Roshani, H., Hamedi, G.H., and Azarhoosh, A., 2013. Evaluate the mechanism of the effect of hydrated lime on moisture damage of warm mix asphalt. *Construction and Building Materials*, 47, 935–941.

Hwang, S.-D., Yoon, A.-S., and Kim, B.-I., 2004. Improvement of Marshall Mix Design and Comparative Evaluation with Current Marshall Mix Design Method. *Journal of the Korean Society of Road Engineers*, 6.

Kandhal, P.S. and Mallick, R.B., 1999. Evaluation of Asphalt Pavement Analyzer for HMA Mix Design. *NCAT Report 99-04*, (99).

MORT&H Guidelines, 2013. Specifications for Road and Bridge Works for State Road Authorities, Fifth Revision, 448.

MS-2 7th Edition Asphalt Mix Design Methods, 2009. Asphalt Institute.

Nahi, M.H., Kamaruddin, I., and Napiah, M., 2016. Rutting Prediction in Asphalt Pavement Based on Viscoelastic Theory. *MATEC Web of Conferences*, 78.

Specifications for Dense Graded Bituminous Mixes, 2009.

Yin, F., 2018. Development of a Framework for Balanced Mix Design.

Yin, F., West, R., and Technology, A., 2021. *DESIGN*. NAPA IS-143 BMD Resource Guide.

Zheng, M., Han, L., Wang, F., Mi, H., Li, Y., and He, L., 2015. Comparison and analysis on heat reflective coating for asphalt pavement based on cooling effect and anti-skid performance. *Construction and Building Materials*, 93, 1197–1205.

8 FIGURES

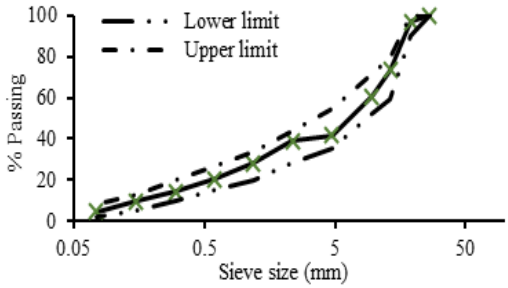
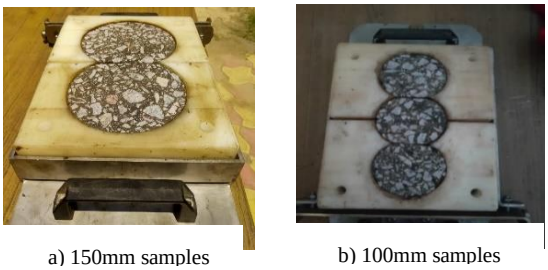
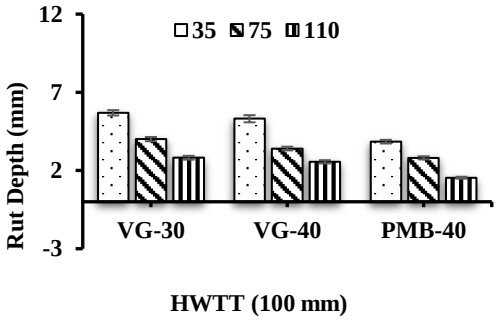


Figure 1. Design Aggregate Gradation (Mid Gradation) for the Bituminous Mix (BC-1)

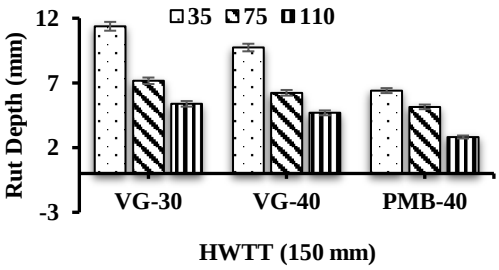


a) 150mm samples b) 100mm samples

Figure 2. Specimens for performance tests



a) Rut depth of HWTT samples of 100 mm



b) Rut depth of HWTT samples of 150 mm

Figure 3. Rut Depth values obtained for different bituminous mixtures

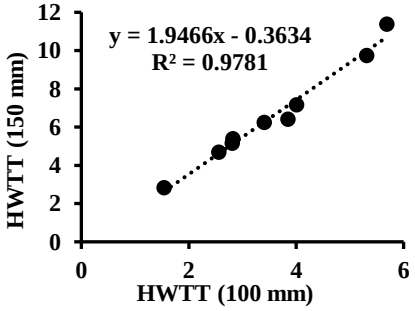


Figure 4. HWTT (100 mm) Vs HWTT (150 mm)