



Significance of initial rutting in prediction of rutting development and characterization of asphalt mixtures



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HIGHLIGHTS

- Primary rutting contributed a significant percentage of the final rutting.
- Effect of temperature and stress on rutting became significant at $T > 50\text{ }^{\circ}\text{C}$ and $N > 1000$ cycles.
- An applied stress increment of 0.2 MPa at a constant temperature increased rutting by 1.35 times.
- Analytical rutting models based on initial rutting could predict rutting development.
- Threshold initial rutting values were recommended for mixture optimization.

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ABSTRACT

Wheel tracking testing on AC-20 limestone and AC-13 basalt asphalt mixtures was carried out to investigate the significance of initial rutting in prediction of rutting development and characterization of asphalt mixtures. Stress, temperature and moisture affected rutting, however, the effect of temperature and stress on rutting became significant at temperatures higher than $50\text{ }^{\circ}\text{C}$ and loading cycles greater than 1000. Short-term and long-term rutting development could well be predicted from initial rutting values using linear and exponential functions respectively, with 1000 cycles considered the shift loading cycles for rutting prediction. Threshold initial rutting values for mixture characterization were determined based on past studies and JTG E20-2011 standard. They were validated using wheel tracking results of AC-25 recycled hot mix asphalt and AC-20 mixtures under water immersion, and could thus be used for quick rutting prediction and mixture optimization.

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1. Introduction

Rutting is a major distress which occurs in asphalt pavements especially in summer, and is significantly affected by increased axle loading, tire pressure, pavement temperature and loading repetitions. Ruts increase the difficulty of vehicle steering as they deepen, and water trapped in them increases the likelihood of hydroplaning particularly for passenger cars. Therefore, highway specifications such as JTG E20-2011 and Texas Department of Transportation (TxDOT – 2004) standards, recommended that rutting be considered at mixture design, so as to mitigate potential pavement safety problems [1–3]. The laboratory testing approaches widely used for rutting investigation include uniaxial and triaxial repeated load testing, asphalt pavement analyzer test-

ing (APA), Hamburg wheel tracking device testing (HWTDT) and flat rubber loaded wheel testing (FLWT).

Carvalho [4] reported that asphalt pavements were likely to be rehabilitated prior to reaching their tertiary stage, or the rutting thresholds established by different highway agencies. The purpose was to minimise their structural damage and to avoid unsafe trafficking conditions. Because of that, majority of the rutting models and rutting indicators proposed in the past studies were developed based on rutting results from the secondary stage of deformation. The commonly used rutting indicators which were developed based on the steady regime of deformation included: flow number, dynamic stability (DS), complex stability index (CSI) and average dissipated energy per cycle (W_o) [5–8]. Based on the aforementioned indicators, initial densification was considered to be of least significance in characterisation of asphalt mixtures.

Tarafder [9] showed that the rate of rutting decreased with increasing loading cycles after the initial densification stage. The secondary rutting slopes of the different asphalt mixtures that

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were investigated had little variation, and as a result, it became clear that primary rutting contributed a significant percentage of the rutting recorded after 8000 cycles. An analytical rutting model that related the rutting at 8000 cycles to rutting at 500 cycles was proposed, and had a correlation coefficient (R^2) of 0.78. It was one of the earliest models for predicting rutting development based on early age deformation. Under a coupled effect of heavy traffic loading and high temperatures, significant rutting was observed on different pavements in China within the first two years of service [10,24]. This implied that significant rutting capable of causing hydroplaning had occurred in the first one year of service, a time postulated to include the primary rutting stage [4]. Therefore, investigations of the contribution of the primary stage of rutting to the rutting expected prior to rehabilitation, would be an important consideration at mixture design and during pavement maintenance planning.

Loaded wheel testers (LWT) such as APA, HWT and FLWT are among the laboratory testing devices which are commonly used for investigating rutting development in mixtures. The highway design guide of China recommends FLWT device as suitable for rutting investigation. Mixtures under FLWT testing are subjected to a compressive contact stress under the wheel, and the confinement stress is induced by the surrounding mixture and the fixed metallic sides [11]. The stress state of the mixtures during the LWT rutting testing has been considered to be roughly similar to the actual stress state in asphalt pavements, and rutting results from LWT testing devices could be well correlated with the actual in service pavement performance [12,13]. Other rutting testing methods which include the uniaxial static and repeated loading tests do not consider the effect of confinement stress during loading. Triaxial testing considers a fixed confinement stress, however the confinement stress in pavements vary with temperature and applied stress [14–16]. Accordingly, FLWT testing offers a better simulation of the actual pavement loading history in the laboratory.

In this paper, the significance of initial rutting values in the prediction of the short and long term rutting development of asphalt mixtures, was investigated using FLWT testing on AC-13 and AC-20 asphalt mixtures under 5 different temperatures and 3 different stresses. Linear and exponential functions based on primary rutting were found to accurately predict rutting development. Threshold initial rutting values for mixture characterization were determined and could be used for mixture performance optimisation.

2. Experimental details

In this study, traditional AC-13 and AC-20 asphalt mixtures which are widely used in China were selected for rutting analysis. AC-13 mixtures were prepared with basalt aggregates while AC-20 mixture with limestone aggregates. Table 1 lists the properties of

the selected aggregates and filler as according to JTG E42-2005 [17]. SBS modified asphalt binder was used for both AC-13 and AC-20 mixtures and had a penetration of 72.6 (units in 0.1mm), softening point of 52.1 °C, ductility of 52.1cm at 5 °C and a viscosity of 644.5cP at 135 °C. Table 2 shows the composition of the asphalt mixtures. The optimum asphalt contents (OAC) of AC-20 and AC-13 mixtures were determined as 4.4% and 4.7% respectively, based on Marshall design. Marshall specimens were compacted with 75 blows per face to simulate heavy traffic greater than 1 million equivalent single axle load (ESAL).

The rutting resistance of AC-20 limestone and AC-13 basalt asphalt mixtures was investigated using FLWT wheel tracking device. This device is commonly used for investigating the rutting potential of asphalt mixtures under conditions that simulate the effect of traffic and pavement temperature [18,19,22]. The degree of compaction was expected to have a great effect on the initial rutting values, therefore FLWT mixture slabs of size 300mm length $\times$ 300mm breadth $\times$ 50mm height, were carefully prepared and compacted in a steel mold with a steel roller compactor according to JTG E20-2011 standard. Before testing, all asphalt mixture specimens were conditioned for at least 5 h to ensure they reached the target testing temperature. A wide range of loading stresses varying from 0.5 MPa to 0.9 MPa were designed. It was believed that these stresses reflected the loading levels varying from light to heavy traffic in reality. A wide temperature range from 30 °C to 70 °C was also considered during design. 30 °C and 70 °C are the extreme cases of temperatures reported to cause rutting in China [20]. FLWTs loading was applied at a rate of 42 cycles/min and the resulting rutting depth was recorded automatically for rutting analysis.

For the purpose of validating the proposed threshold initial rutting values for mixture characterisation, wheel tracking rutting results of AC-25 recycled hot mix asphalt mixtures (RHMA) and AC-20 mixtures tested under water immersion were used. AC-25 RHMA contained virgin limestone aggregates, limestone filler, base bitumen as well as 30% by weight of RAP aggregates. Detailed material information and FLWT rutting results of AC-25 RHMA could be found in a study by Yan [21]. The water immersion rutting tests on AC-20 limestone mixtures were carried out to examine the sensitivity of water on rutting development. Specimens were conditioned in hot water at temperatures of 50–70 °C for 5 h before wheel tracking testing. More information on immersion wheel tracking testing could be found in a study by Mo et al. [18]. The first 24 rows of Table 3 shows the detailed testing program for AC-13 and AC-20 asphalt mixtures under air dry conditions. The testing program of AC-20 mixtures under water immersion testing was also added to Table 3 as the last four rows namely, 25th to 28th. Three replicate specimens were tested per designed test condition of temperature and stress, and the average rutting values were recorded. The variation of the rutting results per testing condition was kept below 15% as recommended by JTG E20-2011.

Table 1
Properties of aggregates and mineral filler.

Property	Measured value		
	Basalt	Limestone	Limestone filler
Los Angeles abrasion (%)	7.8	22.1	
Crushed stone value (%)	12.0	21.5	
Flakiness and elongation (%)	12.5	17.0	
Water absorption (%)	0.363	0.360	
Course aggregate specific gravity (g/cm ³)	2.961	2.703	
Fine aggregate specific gravity (g/cm ³)	2.872	2.688	
Specific gravity of filler (g/cm ³)			2.703
Filler percent passing (%)			100
			93
			85.9

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