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Evaluation of factors that affect rutting resistance of asphalt mixes by orthogonal experiment design

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Abstract

Rutting has been one of the major distresses observed on asphalt pavement in China, due to increasing traffic volume, heavy axle load, continuous hot weather, etc., especially in long-steep-slope section, bus stops, etc. Many factors would affect rutting resistance of asphalt pavement, including material properties, climatic condition, traffic volumes, speed, and axle types, and construction quality.

The orthogonal experimental design method was used in this study to reduce the number of tests required, without comprising the validity of the test results. The testing variables and their levels were selected according to investigations and field test results. Effects of various factors on asphalt pavement rutting performance were evaluated, including the asphalt binders, mixture type (aggregate gradation), axle load, vehicle speed and temperature.

In this study, the wheel tracking test was used to evaluate rutting performance, as represented by the parameter Dynamic Stability (DS), of the various asphalt mixes. Test results were analyzed using range analysis and analysis of variance (ANOVA). All four factors evaluated in this study had significant effects on pavement rutting performance. The ranking of the significance was asphalt mixture type, temperature, loading frequency, and tire-pavement contact pressure. Asphalt mixture type was the most important factor that affects rutting resistance. Within the asphalt mixtures, asphalt binder had significant effects on rutting performance of mixes more than aggregate gradation. Rutting resistance of SBS modified asphalt mixes was significantly better than neat asphalt mixes, and skeleton dense structure mixes were better than suspended dense structure mixes.

Keywords: Asphalt mixes; Rutting resistance; Effect factor; Orthogonal experiment design

1. Introduction

Rutting has been one of the primary factors that affected asphalt pavement performance and has resulted in many premature pavement failures. In the 1990s, Japanese highway authority conducted a survey of asphalt pavement performance for its expressways. The results showed that the primary type of distress was rutting that required significant resources for repair and maintenance [1]. Rutting has also been a common distress observed in asphalt pavement in China, even in the cooler Northern provinces. In some instances, severe rutting occurred in the first summer after opening to traffic, as shown Fig. 1 near a toll station. In 2003, after opening to traffic only for a few months, portions of Jingzhu expressway in Guangdong Province exhibited severe rutting, with a maximum depth of 100 mm [2].

In a study performed by the National Center of Asphalt Technology (NCAT) in US in 1992, performance of 42

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Fig. 1. Rutting.

primary highways in 14 states was evaluated. The study showed that rutting occurred mostly in the surface course of asphalt pavement, especially within the top 7.6–10.2 cm. In most cases, underneath layers did not contribute to the occurrence of rutting [3]. In a long-term study on American Association of State Highway and Transportation Officials (AASHTO) and WesTrack Test Roads, Epps et al., reported in 1998 that, with base/subbase layer of adequate strength, rutting was primarily caused by shear flow deformation in the asphalt. Direct compression did not cause rutting [4]. For an asphalt pavement with a surface layer of 15 cm, rutting occurred within the top 5.0–7.5 cm. A study of highway pavement in Lethbridge area, Alberta, Canada also indicated that shear flow deformation was the primary cause of rutting in asphalt pavement layer [5]. From above studies, it was clear that improving the rutting characteristic of the asphalt layer would be the most effective way in improving the rutting resistance of the asphalt pavement structure.

The factors that influence the pavement rutting performance can be categorized into three groups: material properties, such as property of bitumen, binder content, aggregate property, etc.; climatic and traffic; and construction quality.

Since many factors can affect the pavement rutting performance, the number of specimens required to fully evaluate their effects will be huge. In this study, orthogonal experimental design technique was used to quantitatively evaluate the effects of various factors on pavement rutting performance. The various factors and their levels were selected based on past researches. The factors studied included type of bitumen, type of mixture, traffic weight and speed, and temperature.

2. Materials and methods

2.1. Materials

In this study, a conventional asphalt binder, A-70, and Styrene–butadiene-styrene (SBS) modified asphalt binder were used. A-70 indicated that the quality of asphalt was grade A with a penetration degree of 70 at 25 °C. The properties of SBS modified and conventional asphalt binders are shown in Table 1.

Table 1
Properties of asphalt binders.

Properties	Unit	A-70	SBS Modified
Penetration (25 °C, 100 g, 5 s)	0.1 mm	68	47
$T_{R\&B}$	°C	47.5	78.0
Ductility (5 °C, 5 cm/min)	cm	—	31
Ductility (15 °C, 5 cm/min)	cm	>100	—
Elastic recovery (25 °C)	%	—	89
$\eta_{60°C}$	Pa·S	273	—
$\eta_{135°C}$	Pa·S	0.43	2.38

Two types of aggregate (AC-13 and SMA-13) with different gradations were used in the study. The gradations of aggregate are shown in Table 2.

2.2. Orthogonal experiment design

Orthogonal experimental design is commonly used in studying behaviors of materials, structures, etc. that involve multivariate and multilevel factors. Based on orthogonality, representative samples of test points were selected from comprehensive test variables. These representative test points were generally uniformly dispersed and neatly comparable. This statistical analysis technique has been demonstrated to be a highly efficient, fast, and economical experimental design method in evaluating effects of various factors on pavement performance [6–9], and other scientific researches [10,11]. In Civil Engineering, the Orthogonal Experimental Design has been generally used in hydraulic cement concrete studies; its application in asphalt concrete has been less often.

In this method, representative levels of factors having stronger influences to a property to be studied were selected based on Normalized Orthogonal Table. By understanding the importance of the various factors and the interactions among them, the major advantage of the method was to reduce the number of tests required but still provide the best level of combination of factors. The Orthogonal Experimental Design was used in this research to study the influences of various factors on rutting resistance of asphalt pavement.

2.3. Factors and levels

Factors considered in this study included types of asphalt mixtures, temperature, loading frequency, and axle weight. The selection of appropriate levels of the variables is discussed below.

2.4. Types of asphalt mixture

To reduce number of specimens to be tested, types of asphalt mixture included a combination of various types