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Identifying optimal polymer type of modified asphalt based on damping characteristics

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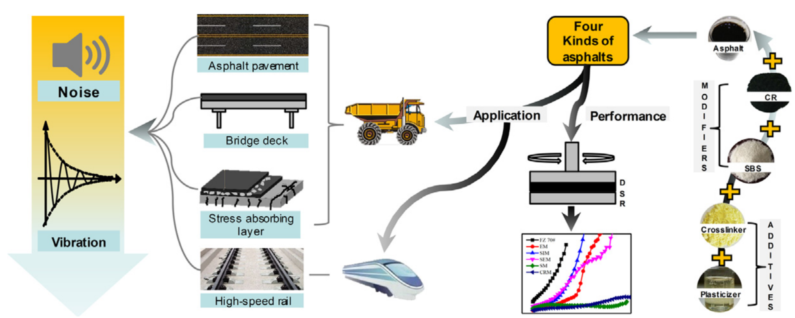
HIGHLIGHTS

- Four criteria for good damping performance of pavement asphalt were developed.
- SBS and CR were the optimal polymers to improve the damping performance of asphalt.
- SBS and CR showed a complementary effect for asphalt damping performance modifying.
- Crosslinker and plasticizer enhanced the damping performance of SM and CRM asphalts.
- Stress-absorbing modified asphalts held a good damping performance.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper first presents the evaluation of damping performance of four types of asphalts: base, non-polymer modified, polymer modified, and stress-absorbing modified asphalts using the temperature spectra of the loss factor (*LF*) based on dynamic shear rheometer. The results showed that the styrene-butadiene-styrene (SBS) and crumb rubber (CR) were the optimal polymers to improve the damping performance of the base asphalt based on four criteria. The damping performance of SBS and CR modified asphalts was further improved by the proper addition of crosslinker and plasticizer, and the SBS/CR compound modified asphalts held good damping performance for a complementary effect. A high damping capacity of stress-absorbing modified asphalts was observed.

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1. Introduction

With the rapid development of economy and urbanization, the transportation convenience is unprecedented. However, increasing traffic flow and vehicle load also brings about worldwide severe city noise and vibration of structures [1–6]. Physiological and psychological welfare of an increasing population is being adversely affected by the long-term exposure to high noise, particularly in the neighborhoods of highways and arterial roads [1,4,7,8]. In addition, long duration of high traffic volume and vehicle load are definitely leading to premature damage and durability reduction of structures (such as bridges and high-speed rail), thereby requiring additional infrastructure investment and even influencing traffic patency and producing safety issues [9,10]. Although there are some solutions to reduce noise and vibration, such as soundproof walls, most of them are not economical or practical [11].

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Luckily, several researchers found that asphalt pavement is the quietest type of pavement structure due to its evident damping performance (reduction in vibration and noise). For example, Biligiri and Way (2014) conducted noise evaluation of 11 pavement types and stated that the asphalt pavement was the quietest one [12]. Boodihal, et al. (2014) observed that asphalt pavement was quieter than Portland cement pavement about 4–6 dB [13]. Zhao, etc. (2009) quantitatively analyzed vertical vibration of pavements and the results showed that the vibration in asphalt-concrete pavements was less than that of cement-concrete pavements by at least 9.0% [14]. Overall, the previous studies indicate that asphalt pavements are effective in reducing noise and vibration in urban cities.

Damping is the ability to reduce movement (e.g. vibration and noise) and physically convert mechanical vibration energy into internal energy [15–18]. As a typical damping material, asphalt has been extensively applied in transportation engineering and plays an important role in vibration reduction of bridge deck, reflection cracking delay in asphalt pavement overlay on old cement pavement, and vibration reduction of superstructure on the base course of high-speed rail [12,19–24]. In addition, asphalt materials have higher damping capacity compared with other engineering materials [15,18]. Therefore, proper application of asphalt materials can result in significant engineering and economic benefits, like quieter living environment, safer travel conditions, and less infrastructure investment.

Asphalt damping is primarily generated from the viscoelasticity of asphalt or polymer instead of the rigid fillers or stones. Researchers have reported a strong relationship between asphalt binder and its mixture [25,26]. Therefore, to explain the good damping performance of the asphalt pavement, research should focus on the asphalt binder itself. However, previous studies on asphalts have paid more attention to low and high-temperature performance, anti-aging property, and compatibility [27–29], and limited work has been done regarding its damping performance [10,30–37]. Therefore, to take full advantage of the asphalt damping capacity, there is a need to evaluate its damping performance. Specifically, the following questions should be answered: what are the criteria for good damping performance of asphalt? How to select appropriate modifiers to improve the damping capacity of the base asphalt? These questions are rarely discussed in the literatures. Clearly, the answers to these questions would significantly promote the development and application of asphalt damping capacity.

The purpose of this study is to evaluate the damping characteristics of asphalt using damping temperature spectra. The objectives of the study are three-fold: (1) to establish a set of criteria for selecting asphalts with good damping performance, (2) to evaluate the damping performance of four types of widely used asphalts (base, non-polymer modified, polymer modified, and stress-absorbing modified), and (3) to select the appropriate modifier (polymers, non-polymers and additives) that best improves the damping performance of asphalt.

2. Experimental design

The experimental design is presented in Fig. 1. The damping performance of four types of asphalts (base, non-polymer modified, polymer modified, and stress-absorbing modified) was evaluated.

2.1. Materials

2.1.1. Base asphalts

Five base asphalts were used (FZ70, GF70, GF90, SK70, and SK90). The physical properties of these base asphalts before and after aging are shown in Table 1. The first two letters in these asphalt types refer to different companies from which the asphalt was taken and the last two digits refer to the penetration grade.

2.1.2. Polymers

Five polymers were used in this study: SBS1301, styrene–isoprene-styrene (SIS1209), styrene-ethylene/butylene-styrene (SEBS501), ethylene–vinyl-acetate (EVA560), and crumb rubber (CR). The technical characteristics of these polymers are presented in Table 2.

2.1.3. Additives

The following six additives were used in this study (Table 2):

- Sulfur is a commercial product (industrial grade) of the Wenhe Chemical Co., Ltd., China.
- Poly phosphoric acid (PPA) is a product of Sinopharm Chemical Reagent Co. Ltd., China.
- Plasticizer is furfural extract oil, which is chemically pure reagents produced by Huabao development of new petrochemical material Co., Ltd., Wuhan, China.

Table 1
Main technical characteristics of base asphalts.

	FZ70	GF70	GF90	SK70	SK90
Before Aging					
Softening (°C)	48.9	49.0	46.9	48.0	46.3
Penetration (25 °C/0.1 mm)	56.8	71.6	92.7	72.0	87.1
Ductility (15 °C, cm)	>150	>150	>150	>150	>150
After Ageing					
Softening (°C)	54.1	53.0	52.4	51.2	50.2
Penetration (25 °C/0.1 mm)	42.7	52.5	58.3	48.5	54.0
Ductility (15 °C, cm)	63.7	60.1	78.5	63.3	75.0

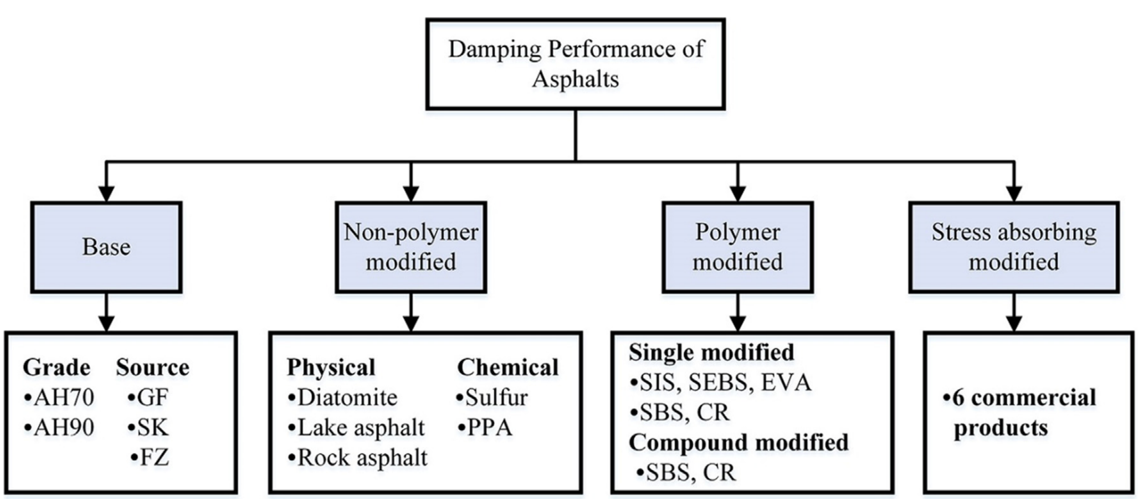

Fig. 1. Experimental design.

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