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Air pollutant emissions and acoustic performance of hot mix asphalts

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HIGHLIGHTS

- Temperature has a great effect on gaseous and particulate emissions.
- Total PAHs observed is still far below the specified limitation.
- The PM2.5 variations on the construction site can be significant.
- VOC concentrations are in general extremely low from the laboratory and the filed.
- The PMSMA6 shows the best low noise performance among the other tested surface types.

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ABSTRACT

This paper presents a study aiming at assessing the air pollutant and noise emissions of asphalt pavements. Four types of asphalt mixtures commonly used in Hong Kong were studied in the laboratory and field. Temperature was found to be the most critical factor affecting pollutant emissions. The volatile organic compounds (VOCs), particulate matter 2.5 μm (PM2.5) and polycyclic aromatic hydrocarbons (PAHs) concentrations varied in accordance with the types of mixtures. The stone mastic asphalt with a nominal aggregate size of 10 mm (SMA10) produced the highest total VOCs, while the polymer modified friction course (PMFC) had the lowest. The polymer modified stone mastic asphalt with a nominal aggregate size of 6 mm (PMSMA6) emitted the most PM2.5 of 114.2 μg/m^3. PAHs were well below the health warning level of 200,000 ng/m^3. The PMSMA6 was the quietest road surface.

1. Introduction

Asphalt pavements are widely constructed all over the world because of their various advantages, such as superior engineering performance, comfortable riding surface, and short maintenance time. However, the necessary high temperature during the asphalt production and construction processes produces fume and odor emissions which not only pollute the environment, but also pose health risks to the workers and others in the nearby micro-environment. In addition, the increasing volume of vehicular traffic on the roads also aggravate concerns of road pavement noise.

The carcinogenic effect of bitumen fumes on human health, in particular lung function, has been reported in the epidemiological studies [1]. These emissions might also have atmospheric reactions with ozone and oxides of nitrogen, in turn producing fumes that can lead to photochemical smog and visibility degradation, which could be more toxic than the original compounds [2,3]. The primary air emissions from the hot mix asphalt (HMA) production most noticeably include particulate matter (PM), volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs) [2]. Most of the PM produced from HMA are within a fine and respirable size range, hence leading to damages to the respiratory system and thus adversely affecting human health. VOCs have been shown to have toxicological effects on the central nervous system, liver, kidneys and blood of the human body [2]. Exposure to VOCs compounds, such as benzene, at high levels over long periods may increase the risk of cancer [4]. Over 50 species of VOCs have been detected in asphalt, some of these species are recognized as toxic and have been regulated by the environmental protection agencies [4]. PAHs, which are carcinogenic, present in the atmosphere in a particulate form. Animal studies have reported respiratory tract tumors due to exposure to PAHs [5]. Despite the development of toxicological profiles of some compounds, the collective health effects of the fumes remain unknown and may present an issue [6]. Symptoms have been reported by the workers include irritation of the upper respiratory tract, headaches, fatigue, shortness

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of breath, dizziness, and nausea [7]. Traffic noise is another concern that affects a large number of residents and pedestrians, especially in urban areas with heavy traffic such as Hong Kong [8]. This environmental pollution does affect the public's comfort, health, and general standard of living [9]. Low noise road surfaces (LNRS), in particular those constructed with asphaltic concretes, have been considered as an effective mitigation measure to tackle traffic noise on roads [8–10].

Various efforts have been made to study the air emissions and the acoustic performance of HMA separately, but little research has been conducted on these aspects combined. This study aims to investigate the air emissions and acoustic level of different HMAs collectively so as to enable a better understanding of the inter-relationship between these two environmental factors. To help develop better sustainable pavements, the physical performances of different asphalt surfaces are also examined. Four widely used HMAs in Hong Kong, i.e., stone mastic asphalt (SMA), polymer modified stone mastic asphalt (PMSMA), open-graded friction course (OGFC), and dense-graded wearing course (WC) are studied in the laboratory and in the field to identify a better road surface for noise mitigation, without compromising the air pollutant emissions and mechanical properties of the road pavement.

2. Air and noise emissions of HMA

PM2.5 is considered more damaging to human health than PM10 due to its fine size that could penetrate the lung [11]. Local authorities have controlled threshold values of PM2.5. Hong Kong Environmental Protection Department (EPD) implements a limitation of 75 $\mu g/m^3$ [12]. Canadian Ambient Air Quality Standards (CAAQS) specify 28 $\mu g/m^3$ [13]. A quantified evaluation of the PM emissions from HMA using laboratory asphalt fractionation analyses found that more than 75% by weight of the particles were in the respirable size range of 0.9–3.5 μm; some of which are capable of deep penetration into the respiratory system, causing health risks [2]. The predominant VOC emissions were reported to be mainly composed of benzene, toluene and ethylbenzene. When temperatures increased from 150 °C to 200 °C, the toluene and ethylbenzene emissions increased correspondingly and substantially [2]. The gaseous emissions of the mixtures with neat bitumen and polymer modified asphalt at the paver were studied and polymer modified asphalt was found to emit less total VOCs [14]. Others found that porous asphalt mixtures generated more VOCs than nonporous asphalt mixtures [6]. In addition to PM and VOCs, researchers from the National Institute for Occupational Safety and Health (NIOSH) believe that PAHs in 4–7 ring may be more carcinogenic, while ones in the 2–3 ring may be more likely to be irritative [15]. PAHs were found to undergo decomposition at high temperatures and react in the atmosphere simultaneously producing a number of derivatives, which could be more toxic [3]. PAH concentrations significantly escalated when the asphalt temperature increased from 150 °C to 200 °C [2]. The Occupational Safety and Health Administration (OSHA) has mandated a permissible exposure limit in the workplace of 0.2 mg/m^3 (8-h time-weighted average), or 200,000 ng/m^3 [16]. The PAH carcinogen of the conventional asphalt producer was detected in a very low concentration [17]. To evaluate the air emissions exposure of the occupants from paving activities, studies have been conducted in laboratories [18–20], and also on construction site [6,14]. It was found that compositions of the fume were affected by several materials specific such as mix designs, binder types, air temperatures, ambient environment [6,19]. For instance, on a construction site, emission measurements on a construction site might be affected by some other pollution sources, such as vehicle emissions and construction dusts. NIOSH in cooperation with the Federal Highway Administration (FHA) found that, in real construction conditions, the places suffering the highest exposure were near the paver or asphalt delivery trucks [15]. They also found that the screed operators and roller operators were exposed to more PM during the asphalt paving process [15]. Nevertheless, the bitumen type, content and composition were found to be the most relevant [19].

To reduce noise emissions from HMA, an OGFC, in the form of a Polymer Modified Friction Course (PMFC) has been used to create a LNRS material. In general, PMFC is quieter than SMA while both provide significantly better skid resistance surface than that of conventional wearing courses (WC). The high air void content (over 18%) of its porous structure allows the air to vibrate internally, instead of being pumped strongly and noisily within the tyre/pavement interface, thereby reducing the traffic noise level. The OGFC was found 3–5 dB(A) quieter than conventional dense asphalt [9]. OGFC had the advantage of a significant noise reduction of up to 4 dB(A) when newly laid [21]. However, the accumulation of dust and debris generated mostly by vehicle tyres and road surface wear easily clogs the OGFC voids. Consequently, the noise reduction property is reduced. To maintain the low noise performance, extra road maintenance is essential, resulting in additional costs. SMA, a gap-graded asphalt mixture is known to have a better mechanical performance than OGFC, and the usage of the smaller normal aggregate sizes has indicated a potential for providing a low-noise surface. It has been reported that an SMA surface with a 9 mm nominal aggregate size (SMA9) is 3 dB (A) quieter than the SMA16 with a driving speed of 88 km/h [22]. A study conducted in Germany between 1991 and 1998 found a SMA surface 2–2.5 dB(A) quieter than the conventional HMA [9]. Research in Italy indicated that, by using SMA, as much as a 7.0 dB(A) reduction in noise levels at 110 km/h can be achieved [9]. With this background knowledge, this study is designed, as described below, to validate these observations in the hope to identify the well performed HMA in terms of air and noise emissions.

3. Study design

To achieve the objectives of this study, evaluations were conducted in both the laboratory and the field on four types of HMA: the PMFC10, WC10, SMA10 and the PMSMA6. The modifier used was styrene-butadienestyrene (SBS).

3.1. Mechanical property tests

The physical properties of pavements were first evaluated by laboratory tests. Four commonly used local road asphalt mixes, i.e., SMA10, PMFC10, PMSMA6 and WC10 were prepared and tested. Mix designs were based on the approved recipes by the local authority, i.e., Highways Department (HyD). Granite from a local quarry was used as the aggregate for all mixtures. Conventional bitumen (Pen 60/70) was used for the SMA and WC with an average mixing temperature of 155 °C, while the SBS modified bitumen, PG76 from Shell, was adopted for the PMFC and PMSMA. The average mixing temperature was 175 °C. The aggregate gradations of these mixes are shown in Fig. 1. The PMSMA10 has the binder content of 6.5% by weight of the asphalt mixtures; while the SMA10, PMSMA6, and WC10 have 6%; the PMFC10 has 5.5%; and the WC20 has 5%. The mixing procedures were complied with the Guidance Notes Mix Design of Bituminous Materials (RD/GN/022G) [23]. Preheated aggregates were first placed in a mixing bowl, the binder for the required mass was then poured into the bowl. They were quickly and thoroughly mixed by a trowel. Three