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Title: Air pollutant emissions and acoustic performance of hot mix asphalts

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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 2.5μm (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 10mm (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 6mm (PMSMA6) emitted the most PM2.5 of 114.2μg/m^3. PAHs were well below the health

warning level of 200,000ng/m^3. The PMSMA6 was the quietest road surface.

Keywords: Gaseous emissions, PM2.5, VOCs, PAHs, road noise, asphalt pavement

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 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 75μg/m^3 [12]. Canadian Ambient Air Quality Standards (CAAQS) specify 28μg/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 0.9~3.5μm; 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^{o}C to 200^{o}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-hour 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 3-5dB(A) quieter than conventional dense asphalt [9]. OGFC had the advantage of a significant noise reduction of up to 4dB(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 9mm nominal aggregate size (SMA9) is 3dB(A) quieter than the SMA16 with a driving speed of 88km/h [22]. A study conducted in Germany between 1991 and 1998 found a SMA surface 2-2.5dB(A) quieter than the conventional HMA [9]. Research in Italy indicated that, by using SMA, as much as a 7.0dB(A) reduction in noise levels at 110km/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-butadiene-styrene (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^{o}C, while the SBS modified bitumen, PG76 from Shell, was adopted for the PMFC and PMSMA. The average mixing temperature was 175^{o}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 sample replicates were made for each type. The physical properties of these samples including air voids, bulk density, Marshall flow and stability were tested according to ASTM standards [24-28].

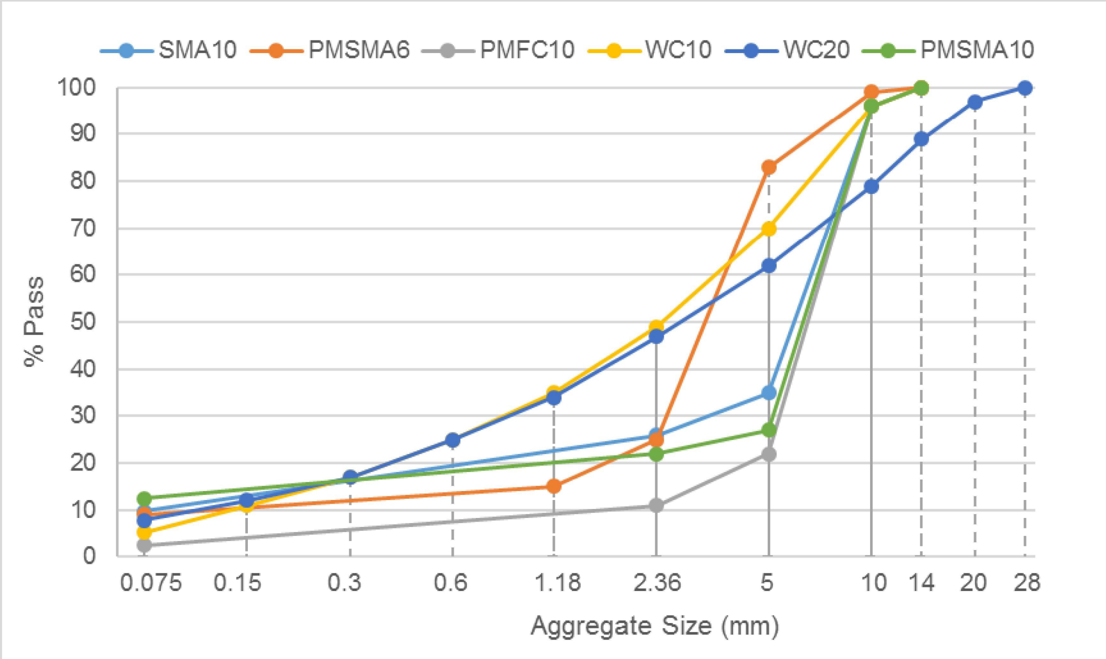

Fig. 1. Aggregate gradations of SMA10, PMSMA6, PMFC10, WC10, WC20 and PMSMA10

3.2 Laboratory air sampling

PM2.5, VOCs and PAHs were monitored in the laboratory controlled environment while the Marshall samples were being manufactured at their corresponding mixing temperatures. PM2.5 was monitored in real time using a PM monitor, DustTrack 8530. VOCs emissions were sampled by using vacuum canisters with a flow rate of approximately 200ml/min. Samples were analyzed by the HP6980 gas chromatograph (GC) coupled with HP5973 mass selective (MS) detector according to the International Organization for Standardization (ISO) standard TO14 Method [29]. The Photoelectric Aerosol Sensor (PAS) 2000 was used to measure the PAHs concentrations. During the five-minute mixing of the asphalt mixture, the PM monitor, canister, and the PAHs sensor were placed on a fixed platform at a height of the worker's breathing zone. The detected levels of VOCs were the average concentrations in the sampling period while the detected level of PM2.5 was the real-time records with an interval of 1 second. The number of sample tested for each asphalt mixture is shown in Table 1. The mixing temperature was around 155^{o}C for the SMA10, WC10 and WC20, and around 175^{o}C for the PMSMA6, PMSMA10 and PMFC10.

Table 1. Sample size of each HMA for laboratory tests

	SMA10	PMFC10	PMSMA6	WC10	WC20	PMSMA10
PM2.5	4	3	5	3	3	3
VOCs	3	3	4	3	3	3
PAHs	-	-	3	3	3	3

3.3 In-Situ air sampling

Construction sites of these HMAs are identified to compare with the laboratory tests. Within the study period, four types of pavements in a total 12 sites were identified and therefore monitored (Table 2). VOCs and PM2.5 were measured.

Table 2: In-situ sample sizes

	PMFC10	PMSMA6	PMSMA10	WC20

Number of pavement construction site	3	3	3	3

The process of PM2.5 and VOCs sampling on site was similar to that in the laboratory, a VOC canister was placed together with the PM monitor. The VOC samples were collected using a pre-vacuumed canister at a flow rate of around 200ml/min, and then analyzed by GCMS in the laboratory. Each canister collected air sample for about 15 minutes. Since pavement construction is a dynamic process that involves multiple working stages and lasts for a period of time, four canisters in total were used for each construction site air sampling. Of these four, one canister was used for the background ambient emissions before construction, while the other three were used to collect air samples during the paving process. Meanwhile, PM2.5 was measured in real time by the PM monitor, data was recorded every second. The background emission level before construction was measured. When the paver began to operate, the PM2.5 was monitored for a continuous period of 50mins. For each survey, the air monitors were set at a spot 15 meters away from the paving starting point, and 40cm away from the curb.

3.4 CPX survey

Among several noise measurement methods, the Close Proximity (CPX) method specified in the ISO11819-2 is the most commonly used method internationally, which allows valid comparisons between sites over time [21, 30]. In this study, the acoustic property of the pavements was evaluated by measuring the tyre/road noise level using the CPX trailer fabricated by the PolyU, as shown in Fig. 2. The trailer was designed according to the ISO DIS11819-2: Acoustics–Method for Measuring the Influence of Road Surfaces on Traffic Noise–Part 2: The Close Proximity Method [30]. The specific illustration of the microphones in the trailor is illustrated in Fig. 3.

Fig. 2. The CPX vehicle with trailer

A twin-wheeled CPX trailer was equipped with two mandatory microphones at each wheel, positioned 200mm from the tyre side walls and 100mm above the surface and pointing at an angle of 45^{o} between the tyre and the road contact interface [31]. The Standard Road Testing Tyre (SRTT) was fitted for performing the tyre/road noise measurements. Many carefully selected pavement surfaces of the PMFC10, SMA10, PMSMA6, and WC10 were surveyed at a reference driving speed of 50km/h. In addition to the results of our previous study, the sample numbers of the four pavement types are summarized in Table 3 [32, 33]. To ensure the reliability of data, at least three runs were applied for each tested section.

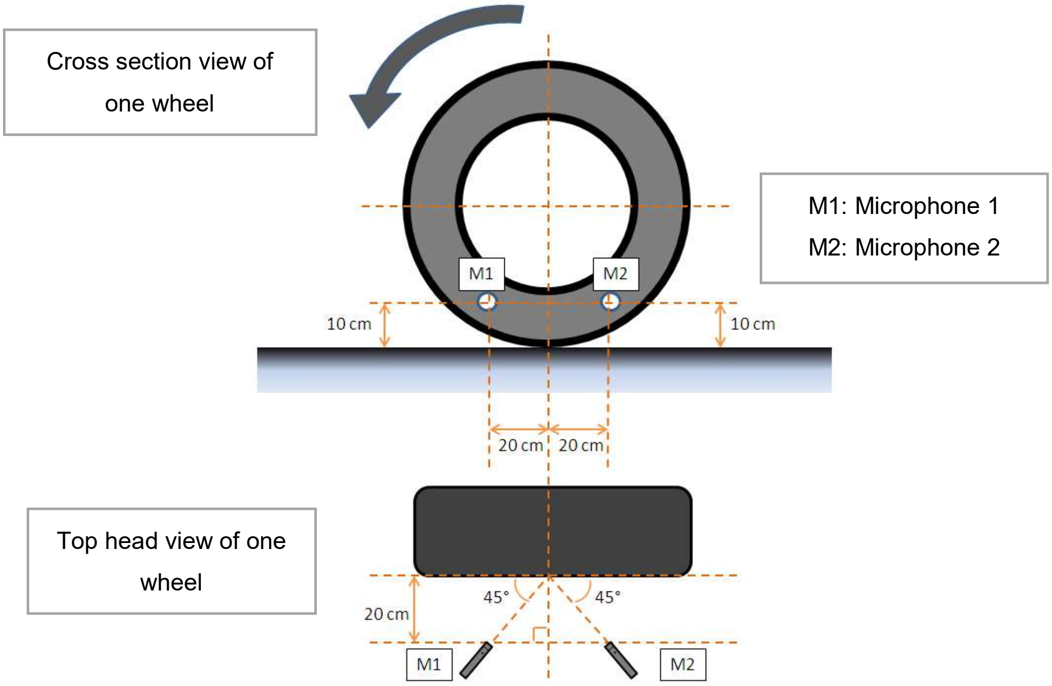

Fig. 3. Microphone positions of one-side wheel in the CPX trailer

Table 3. Sample numbers in the CPX survey for the four pavement surfaces

Sample numbers (sections)	PMFC10	PMSMA6	SMA10	WC10
SRTT	63	8	4	4

4. Results and discussions

4.1 Laboratory sample properties

Four kinds of asphalt mixtures, with three types of SMA, were fabricated in the laboratory. The physical properties of these samples were evaluated, including air voids, bulk density, Marshall flow and stability. Specific results are given in Table 4.

Table 4. Physical properties of laboratory samples

	PMFC10	PMSMA6	SMA10	WC10	PMSMA10	WC20
Air voids (%)	18.81 (18-25)	8.69 (7-10)	3.61 (3.5-4.5)	3.31 (3.0-5.0)	3.53 (3.5-4.5)	3.07 (3.0-5.0)
Bulk density (Specific gravity)	1.97	2.18	2.31	2.32	2.28	2.36
Marshall flow (mm)	2.34	2.82	2.39 (≤4)	2.02 (≤4)	3.77	2.38(≤4)
Marshall stability (KN)	7.74	12.49 (≥6)	10.49 (≥6)	14.18 (≥10)	14.83 (≥6)	17.6 (≥10)

The mix design was based on the available technical specifications from the Highways Department (HyD) of the Hong Kong government. The specifications are cited in the blankets in Table 4. These specifications are in line with the American standards [34, 35, 36]; for example, the air void of dense graded and the typical SMA are designed in a range of 3 to 5%; while the open-graded mixture is targeted in the range of 18 to 22% in US [34]. By comparing the test results to the specification, the samples were of acceptable quality.

As shown in Table 4, the dense-graded mixtures (WC10 and WC20) have the densest structure among the others, and have high Marshall Stability values. WC20 shows a higher density than WC10. The porous asphalt (PMFC10) has the highest air void content of over 18%, leading to a low stability value. For the SMA10, PMSMA10, the air void contents vary little around 3.5%. However, when the nominal aggregate size of SMA change from 10 to 6mm, PMSMA6 has a much higher air void of 8.69%. This is probably because with the same mixture volume and similar bitumen content, the one with more crushed aggregates has a greater surface area, and the interlock skeleton of these aggregates has formed more interspace. With the SBS polymer modification, the stability of PMSMA10 was greatly improved compared to SMA10 and PMSMA6 was also improved to have a higher stability value than SMA10. The Marshall Stability of polymer modified mixes was similar to that of the well-graded mix, WC10. As for SMA10, WC10 and PMFC10 with the same nominal aggregate size, the larger the air voids, the smaller is the Marshall Stability value.

4.2 Air emission results from laboratory experiments

4.2.1 PM2.5 results

The PM2.5 concentrations of the five types of mixtures are presented in Fig. 4.

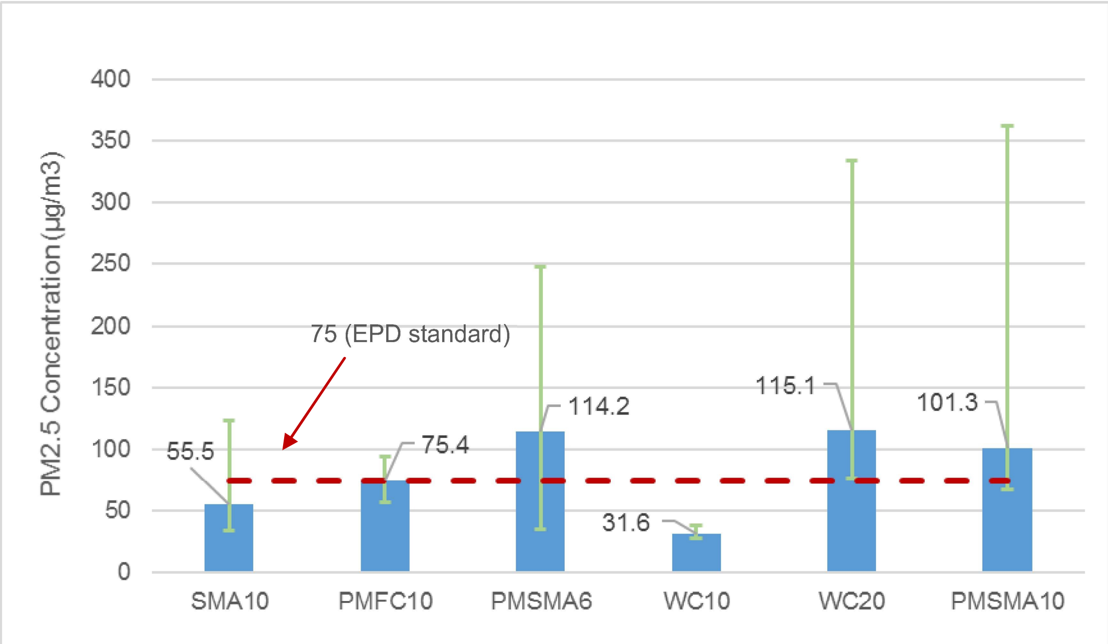

Fig. 4. PM2.5 results at laboratory mixing (temperature=155 – 185°C)

It can be seen from Fig. 4 that more PM2.5 was emitted by the PMSMA6, PMSMA10 and WC20 than the SMA10, and WC10 during the laboratory mixing process. Their detected concentrations exceeded the EPD specified standard of 75μg/m^3 [12]. This was probably caused by multi-factors especially the higher mixing temperature needed for the polymer modified asphalt. Additionally, the relatively high portion of the fillers in PMSMA and WC20 also contributed to the amount of particulate matters detected.

4.2.2 VOCs results

Air samples were collected and analyzed by GCMS according to the Compendium Method TO-14. In total, 41 VOCs compounds were collected and analyzed. Since 30 out of the 41 compounds were below the limit of detection, only 11 detectable VOC species were analyzed [37]. The concentrations of these 11 compounds and the total VOCs of the mixtures are illustrated in Fig. 5.

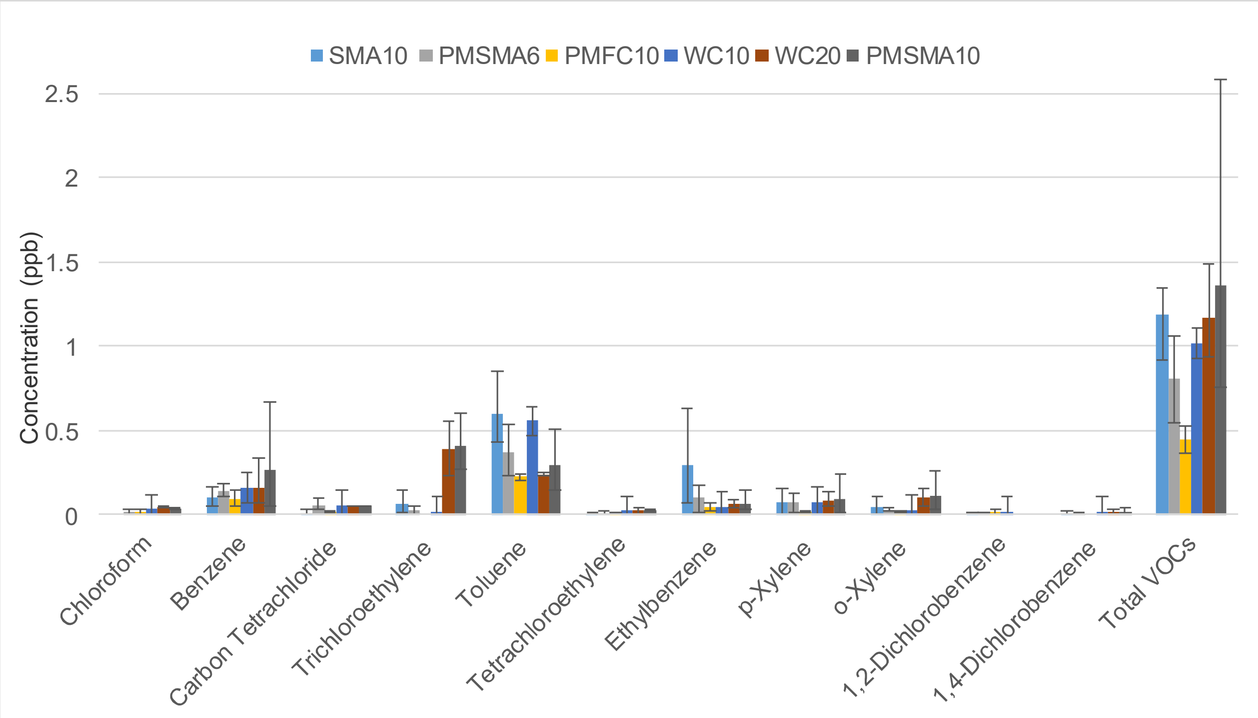

Fig. 5. VOCs from asphalt mixtures at laboratory mixing (temperature=155 – 185°C)

As shown in Fig. 5, benzene, toluene, trichloroethylene, and ethylbenzene, are the four dominant VOC species in all the mixtures. This finding is consistent with that of the previous study [2]. The SMA10 has the highest toluene and ethylbenzene emissions. In general, mixes using binder 60/70 emits more VOC compounds than using PG76. PMFC10 has the lowest total VOC emissions. This phenomenon is probably caused by the polymeric phase dispersed on the bitumen surface at a higher temperature. This could act as a protective layer and suppress the emissions from the bitumen. However, PMSMA10 has the highest total VOC emissions with a large variation. This indicates an uncontrollable VOC plume may have interfered one of the experiment. For the four dominated species, i.e., benzene, toluene, trichloroethylene and ethylbenzene, EPD specified levels for good air quality class are at 5, 290, 143 and 333 ppb respectively [4]. As illustrated in Fig. 5, the measured concentrations of these three emittants are respectively all below 0.2, 0.6, 0.5 and 0.3ppb, indicating that the VOCs concentrations measured in the laboratory are extremely low.

4.2.3 PAHs results

Total PAH values of PMSMA6 PMSMA10, WC10 and WC20 were measured in the laboratory; the results are shown in Table 5.

Table 5. Total PAHs from asphalt mixtures at laboratory mixing

	PMSMA6	PMSMA10	WC10	WC20
Mixing temperature	175 - 190°C	175 - 185°C	165 - 180°C	155 - 170°C

Mean value (ng/m^3)	26.3	18.8	54.7	20.9
Standard derivation	35.1	6.4	65.9	51.9
Maximum value	330.6	54.5	484.7	57.9

During the 10 minutes of mixing, great variations of total PAHs were observed for all asphalt mixtures. It is very likely caused by the temperatures. PAH concentrations were observed significantly increased when the temperature increased from 150 to 200°C [2]. It could possibly be explained by the fact that the PAHs with high vapor pressures volatilized at a lower temperature, whereas the ones with relatively low vapor pressures also volatized when temperature increased [2]. PMSMA6 was mixed at a higher temperature range of 175 - 190°C than that of the PMSMA10 of 175 - 185°C, and the maximum PAHs detected is considerably higher with a big standard derivation. The similar trend is found between the WC10 and the WC20. It could be concluded from Table 5 that with the same binder, the higher the temperature, the more PAHs were emitted; and the greater was the variation. Total PAHs emitted from PMSMA6 has the mean value of 26.3ng/m^3, peaking at about 330ng/m^3. For WC10, the total PAHs values fluctuated around 55ng/m^3, and peaking at approximately 484ng/m^3. Even with a lower mixing temperature, the use of conventional binders resulted in a higher emission of PAH. The difference may be caused by i) different binders, i.e., PG76 and conventional binder; ii) different mixing temperature; and the iii) different design mix. Nevertheless, these measured levels are far below the limiting value of 200,000ng/m^3 specified by the Occupational Safety and Health

Administration (OSHA) [17].

4.3 Air emissions from construction sites

4.3.1 PM2.5 results

The onsite PM2.5 results of WC20, PMSMA10, PMSMA6, and PMFC10 were measured. The results show that the onsite PM2.5 concentrations are significant higher than those in the laboratory, even within the same type of bituminous mixtures. This is because the real environment is affected by multiple factors, such as the daily air temperature, the traffic situation and wind speed and direction. The PM2.5 concentrations of different mixture types showed a similar trend as is shown in the Fig. 6. The results illustrate that PM2.5 concentrations vary in accordance with the construction phase. The peak PM2.5 concentrations generally appear as soon as the paver was passing the monitoring point. The pavement temperature was still at a high level and more volatile compounds and vapors evaporated. When the paver passed by, the emissions from the paver diesel engine also contributed to the PM2.5, as demonstrated by the episodes in Fig. 6. The PM2.5 increased upon commencement of compaction process because of the fume emissions caused by the compactor and the paver diesel engine. When the temperature dropped over time, the PM2.5 concentrations decreased. PM2.5 was considerably higher when the temperature difference between the heated asphalt mixtures and the air temperature was bigger (owing to lower air temperature).

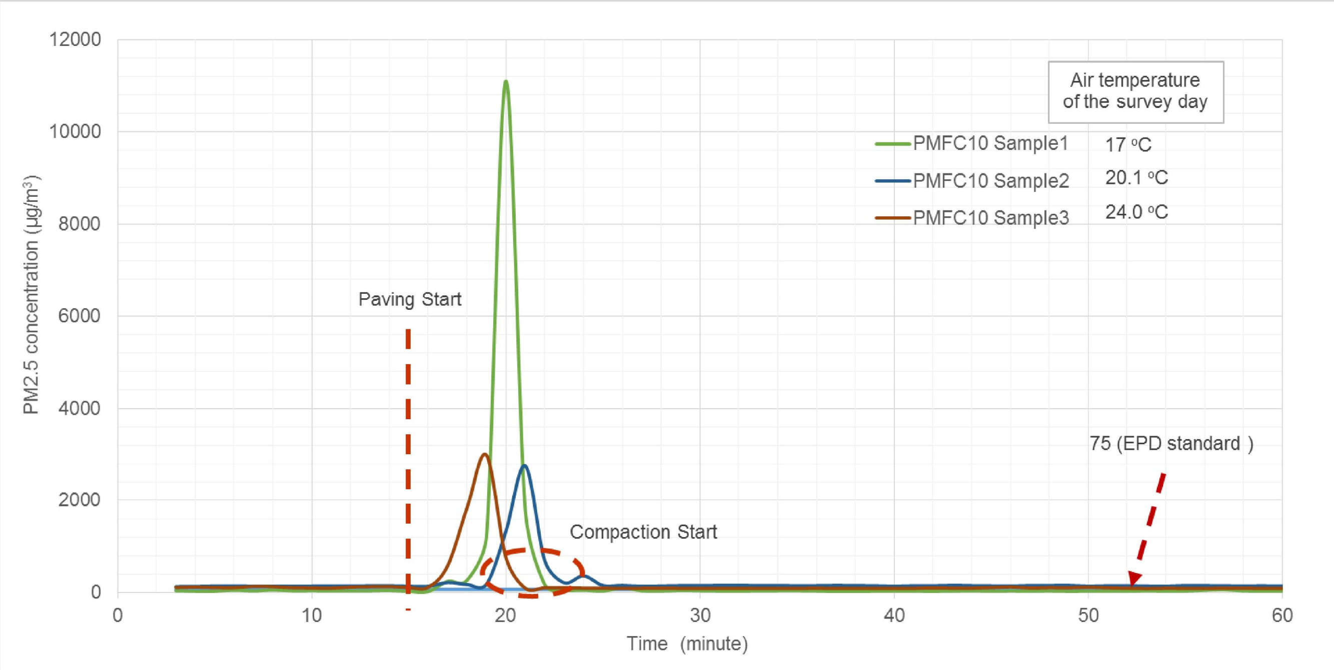

Fig. 6. Measured PM2.5 onsite for PMFC10

4.3.2 VOCs results

The measured VOC compounds onsite for WC20, PMSMA10, PMSMA6, and PMFC10 are shown in Fig. 7 to 9. Fig. 7 shows the concentrations VOC species for the first 15 minutes. During this period, the paver rolled passing the stationary monitor, with a temperature of approximately 135~200°C. Fig. 8 shows the VOC concentrations in the following 15 minutes, during which the compacting roller was working back and forth by the side of the VOC monitor. Another 15-minute sample was collected when the roller was in general working at a distance from the monitoring spot, and occasionally returning for compaction. The results are shown in Fig. 9.

Different from the laboratory sample tests, toluene, benzene and p-xylene are the dominant compounds for the onsite VOCs. This maybe owing to the paver engine exhaust, the cigarette smoke from the workers, as well as the gasoline vapored from the vehicles nearby; xylene however was mainly found in the workplace [38]. The laboratory experiment was under a controllable environment, while the in-situ assessments were exposed under the real emissions environment, which was uncontrollable. In a previous study, benzene concentration was found at 1.1 ppb during the laying of polymer modified asphalt at a temperature of 165°C [14]. In this study, as presented in Fig. 7, benzene concentration from polymer modified asphalt - PG76 is around 0.5 ppb. Both results indicate the low level of benzene emitted from the asphaltic concrete pavement laying process. The highest VOC concentrations are observed during the paving process. And, VOCs decreased with the lowering of temperatures.

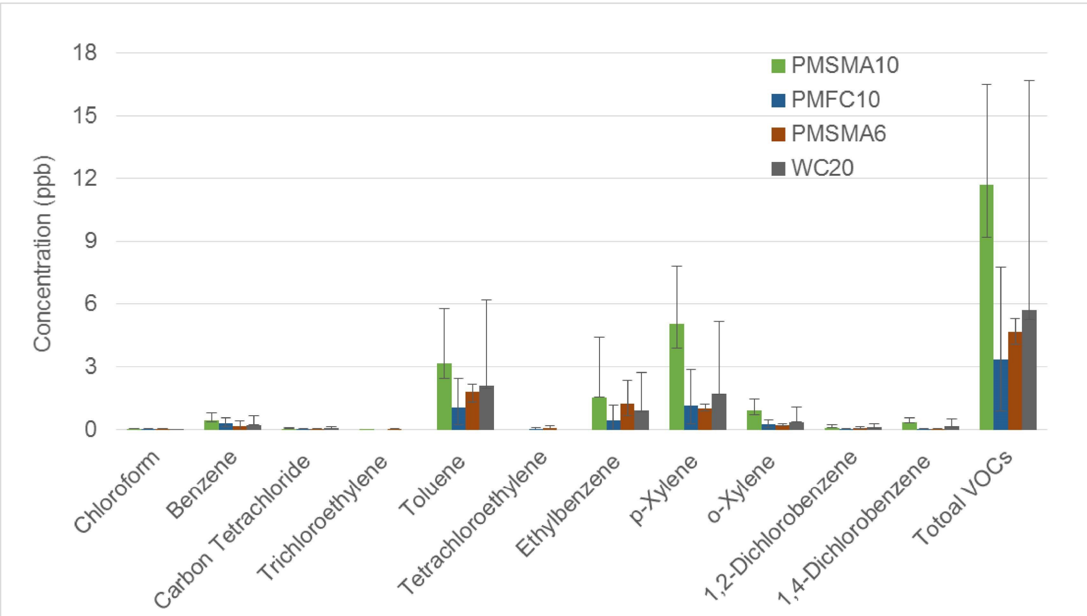

Fig. 7. VOCs from asphalt mixtures at the 0-15 minutes (temperature=135-200°C)

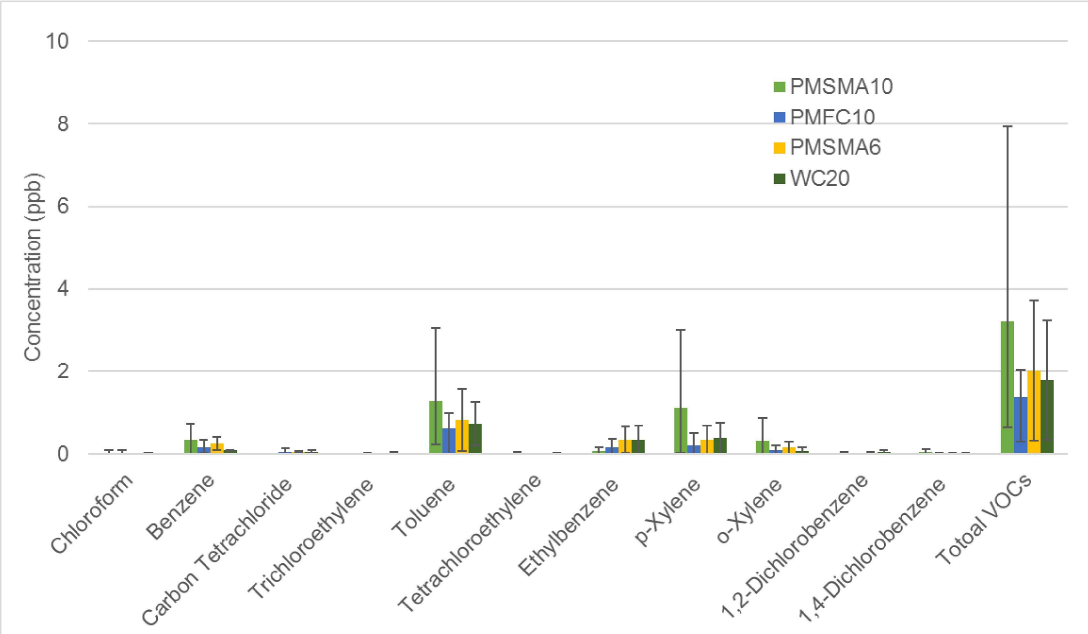

Fig. 8. VOCs from asphalt mixtures at the 16-30 minutes (temperature=70-140°C)

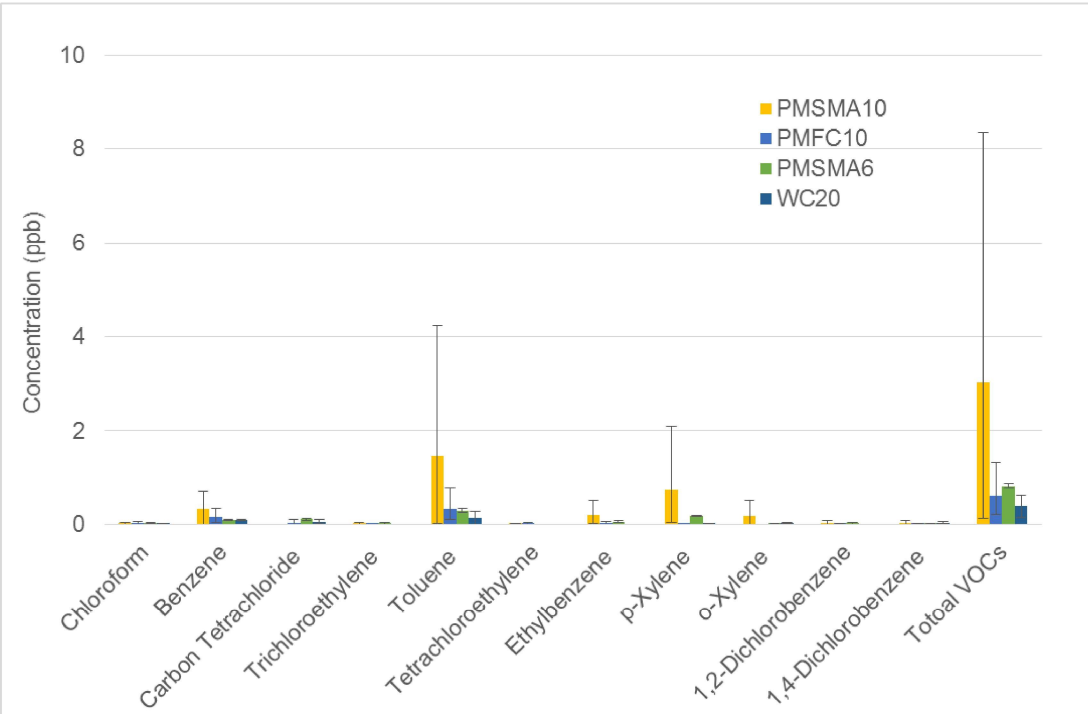

Fig. 9. VOCs from asphalt mixtures at the 31-45 minutes (temperature=60-80°C)

The onsite total VOC (TVOC) concentrations of PMSMA10, PMFC10, PMSMA6 and WC20 in average in different time periods are shown in Fig. 10. It indicates that the

TVOC concentrations decreased with time. For all kinds of surfaces, concentrations in the paving stage (at the first 15 minutes) are higher than those after. When the paving crew moved away, and the temperatures decreased with time, the VOC concentrations decreased in the meantime.

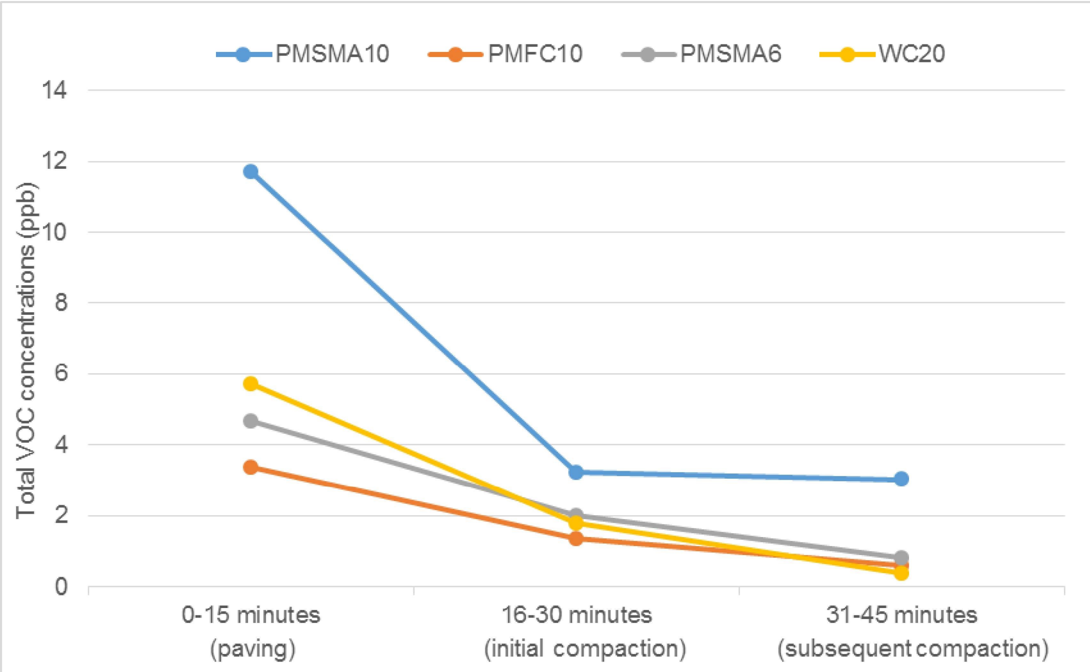

Fig. 10. Trends of total VOC concentrations of asphalt mixtures with time

The VOC concentrations of PMSMA10, PMFC10, PMSMA6 and WC20 in different paving stages were analyzed by Pearson Correlation two-tailed test. The analysis indicated that most of the VOC concentrations are positively correlated. It suggests that the linear correlation is present in the VOCs over time, the TVOC concentrations during the compaction process would get higher if the initial concentration when paving is higher.

4.4 Relationship between laboratory and in-situ air samples

To further explore the relationships between the laboratory and in-situ air samples, the Pearson correlation analysis was employed. By running the Pearson correlation, hardly any significant correlation was found between the PM2.5 samples from the laboratory and the construction sites for various types of road surfaces. It shows that uncontrollable factors might have great impacts on the PM levels.

The VOCs from both the construction sites and the laboratory were analyzed by surface type. In particular, there appears to be a very strong, positive correlation for PMSMA6 ($r=0.884$, $p=0.000$) and PMFC10 ($r=0.815$, $p=0.002$) between the laboratory and in-situ concentrations, while no significant correlation was observed for PMSMA10 ($r=0.223$, $p=0.510$) and WC20 ($r=0.236$, $p=0.485$). It suggests that the uncontrollable factors could have great impact on the VOC emissions of asphalt mixtures. Fig. 11 shows that the average TVOC concentrations in the field and in the laboratory have a similar trend for different road surface types. In particular, PMSMA10 was detected to have highest TVOC levels, while PMFC10 has the lowest.

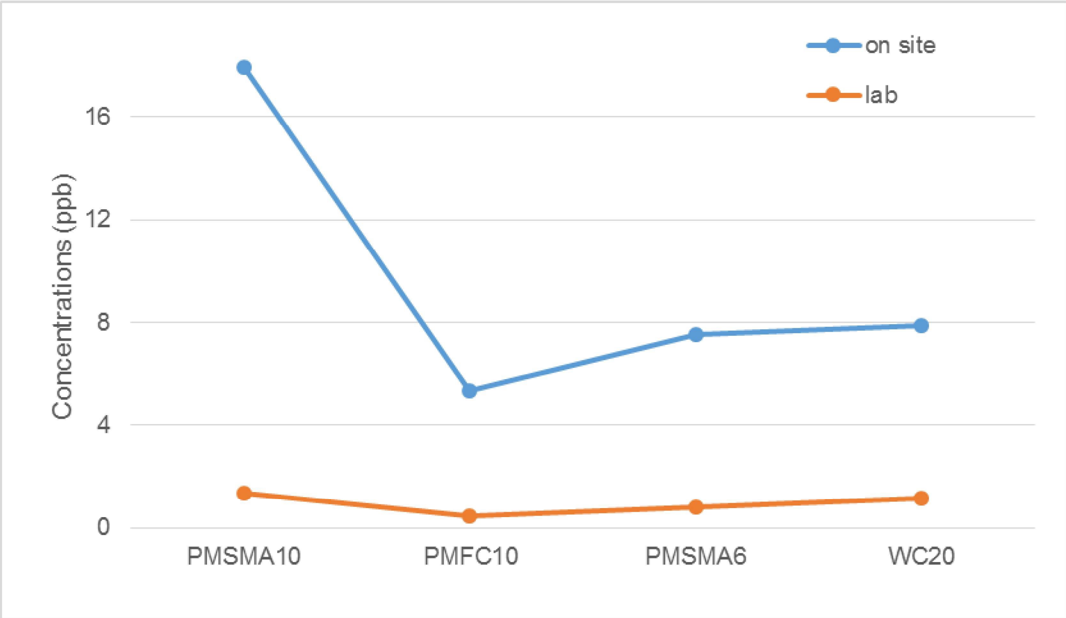

Fig. 11. Total VOC concentrations of asphalt mixtures in the laboratory and on site

4.5 CPX Survey Results

The tyre/road noises measured with the Standard Road Testing Tyre (SRTT) at 50km/h are given in Fig. 12. As illustrated, SMA10 is the nosiest pavement surface, while a smaller aggregate size, such as PMSMA6, is responsible for less noise. The noise performance with PMFC10 varies greatly, as there are new and old surfaces. Although in general a good performance is shown when it is newly laid, but deteriorates as the surface ages especially when the air pores are clogged. It is worth noting that there are about 60 PMFC10 surfaces while less than 10 of the other types of surfaces were surveyed. Overall, for the low noise performance, different pavement surfaces can be ranked from high to low as PMSMA6, PMFC10, WC10, and SMA10.

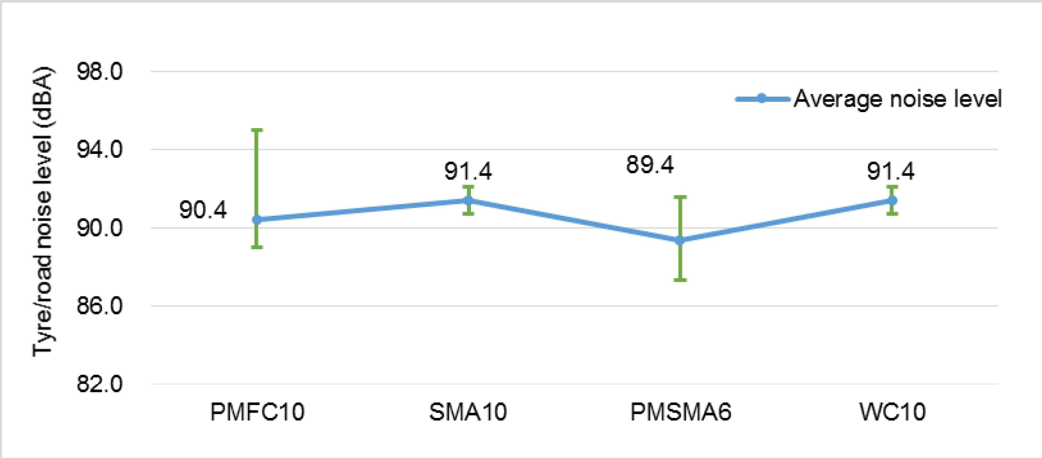

Fig. 12. The CPX tyre/road noise of PMFC10, WC10, SMA10 and PMSMA6 measured with SRTT at 50km/h

5. Conclusions

This study has investigated the gaseous and acoustic emissions of four different commonly used pavement surfaces in Hong Kong. The following conclusions are drawn:

1. The laboratory study revealed that temperature has a great effect on gaseous and particulate emissions. Under a constant air temperature of 25°C in the laboratory, higher mixing temperatures normally result in higher emissions of PM2.5. Comparing mixes using normal bitumen Pen 60/70 with the mixing temperature of 155°C, to the mixes with polymer modified bitumen PG76 with a mixing temperature above 175°C, the average PM2.5 concentrations were in general higher (PMFC and PMSMA had 75.4 and 114.2μg/m^3 respectively while WC and SMA had 55.5 and 31.6μg/m3 respectively).
2. An elevated exposure of total PAHs was observed. Nevertheless, even the peak detected concentration of 484 ng/m^3 was still far below that of the Occupational

Safety and Health Administration (OSHA) standard of 200,000ng/m^3.

3. As observed from the construction sites, PM2.5 concentrations of different types of asphaltic mixtures were detected to exceed the EPD regulated level. Furthermore, it is worth noting that when the air temperature fell, PM2.5 concentrations significantly increased owing to the greater temperature difference between the heated bitumen and the air temperature. This observation however, has to be carefully interpreted because the wind speed, wind direction as well as nearby activities were uncontrollable. The PM variations can be significant.
4. VOC concentrations were, in general, extremely low, when measured in both the laboratory and on the construction sites. The total VOC and the 11 detected VOC species by the GCMS barely exceeded 3ppbv, and hence compared with the specified excellent class IAQ air objectives of 87ppbv for public places (8-hour average). VOC concentration was shown to vary in accordance with the type of asphaltic mixtures and the temperatures.
5. Although it is hard to conclude the relationships of air emission concentrations in the laboratory and road construction sites, it is clear that emission concentrations for various HMAs are in the right order (i.e., PMSMA10, WC20, PMSMA6 and PMFC10) in both the laboratory and the sites.
6. The PMSMA6 showed the best low noise performance with an average tyre/road noise of 89.4 dB(A). The average tyre/road noise was 90.4 dB(A) for PMFC10, 91.4 dB(A) for SMA10 and 91.4 dB(A) for WC10.

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