4th Construction Specialty Conference
4e Conférence spécialisée sur la construction

Montréal, Québec
May 29 to June 1, 2013 / *29 mai au 1 juin 2013*

Pollutants generated in asphalt resurfacing construction and their effects on workers' health

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Abstract: Asphalt pavement resurfacing is a common type of road construction project. During the construction process, a large quantity of pollutants is generated, including volatile organic components (VOCs), particulate matters (PM), and noise. These pollutants pose health risks to road workers. With increasing alertness of the potential negative impacts of pollution on health, stakeholders of paving industry have become more concerned about the pollutants generated in asphalt pavement construction than ever before. In some places, environmental concerns have affected the industry in recruiting and retaining young workers. This paper aims to identify the types of pollutants generated in asphalt resurfacing projects and the levels of pollution exposed by workers. Three types of pollutants (VOCs, PM, and noise) were measured and analyzed. The measurements, mostly taken at the workers' breathing and hearing zones, were also analyzed for potential health effects based on existing literature. The research results indicate that some pollution levels are quite high; however, there are great variations in the exposure levels experienced by workers. It is expected that this paper can assist the paving industry better understanding the health risks faced by workers, taking effective measures to reduce such risks, and improving self-protection awareness of the workers.

1 Introduction

Asphalt resurfacing is a common type of construction project to maintain and restore the conditions of road infrastructures. In Hong Kong, the asphalt paving industry places nearly 600 thousand tons of hot-mix asphalt (HMA) materials annually, and the industry directly employs a great number of workers. However, as a petroleum-derived product, hot asphalt mixed with aggregates can release harmful chemicals and particulate matters into air during construction. Meanwhile, excessive noise and dust can also be generated. Volatile organic components (VOCs), particulate matters (PM), and excessive noise are three forms of noticeable pollutants generated in asphalt pavement construction (Mcclean 2006, Mickelsen et al. 2006, Suter 2002). Although these pollutants are commonly encountered, they are rarely discussed together in previous studies. Particularly missing are their effects on the health of road workers, the mostly vulnerable groups who are exposed to these pollutants (Burstyn et al. 2002).

Safety and health related issues have been of a long and increasing concern in the construction industry. Adverse working conditions, hazardous materials emitted from HMA materials, and noise generated by construction equipment may potentially affect road workers' health. Although the health risks of these pollutants have not been fully defined, existing studies suggest that the principal adverse health effects are irritation of the mucous membranes, upper respiratory tracts, and eardrums (Mickelsen et al. 2006).

The goal of the research, as presented in this paper, is to characterize the workers' occupational exposure to various pollutants generated during asphalt resurfacing construction. It is expected that the research results help the paving industry understand the health risks faced by road pavement workers, take effective measures to reduce such risks, and provide information to the current and future concerned workers and improve their self-protection awareness.

2 Measurements of Major Pollutants Generated in Asphalt Resurfacing Construction

2.1 The Typical Process of Asphalt Resurfacing Construction

Because the road networks in many developed regions and countries have been well established, the major form of asphalt pavement construction in these places is resurfacing instead of new construction. In Hong Kong, there are more than 2,000 km of road pavement, and 75 percent of them are asphalt. Hundreds of resurfacing projects are carried out each year, consuming a large amount of HMA materials. To assess the pollutants generated in an asphalt resurfacing project, the typical construction process was analyzed and shown in Fig.1

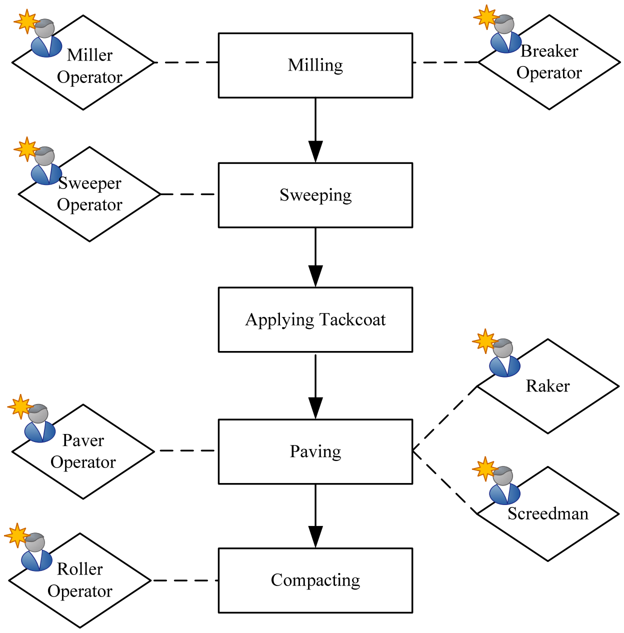

Figure 1: Typical working process of asphalt pavement resurfacing project

2.2 Identification of the Major Pollutants

Existing literature and onsite observations suggest that three major types of pollutants are generated during the resurfacing process as shown in Fig. 1, including asphalt fumes, dust (particulate matter), and noise. Asphalt fumes are made of volatile organic components (VOCs), polycyclic aromatic hydrocarbons (PAHs), particulates, sulfur, nitrogen oxides, and carbon monoxide (EPA 2011). In this study, the VOCs in asphalt fumes, particulate matter of small size (PM_{10} and $PM_{2.5}$), and noise were selected for detailed analysis.

VOCs, belonging to a special category of atmospheric pollutants, can adversely affect human health in both acute and chronic ways through inhalation and skin contamination (Celebi and Vardar 2008). VOCs are encountered in other type of construction as well, such as interior finish of a building (Malherbe and Mandin 2007). In asphalt pavement construction, because HMA materials have to be heated to an elevated temperature of more than 140 ^{o}C and then be placed and compacted at similar temperature level, massive amount of VOCs are generated and emitted during this process (Gudimettla et al. 2004, Mcclean 2004, Linch 2002). There are increasingly reported cases of occupational diseases among asphalt paving workers (Heikkil et al. 2002). Therefore, the VOCs in the paving process needs to be examined.

Resurfacing construction is a dusty process, too. Particularly, the milling of existing pavements and sweeping afterward generate a large amount of dust. A growing body of epidemiological research has consistently demonstrated that there is a relationship between particulate matter and excessive mortality and morbidity (Guo et al. 2010). The concentration of total particulate matters (PM) in the air inhaled by road workers has been reported by other researchers (e.g., Mickelsen et al. 2006). This study mainly focuses on $PM_{2.5}$ (particles with aerodynamic diameter≤ 2.5μm) and PM_{10} (particles with aerodynamic diameter≤ 10μm), because they are the most harmful to human health (Hueglin et al. 2005).

Apart from the atmospherical pollutants, excessive noise is another characteristic of asphalt resurfacing construction. Particularly, as existing pavements are demolished by pavement breakers, a high level of noise is generated. The accumulated noise produced by the construction activities may lead to physical and psychic deterioration of workers; therefore, it is necessary to assess the construction noise exposure and adopt preventive solutions accordingly (Fernández et al. 2009).

2.3 Experiment Design for Measuring Major Pollutants

Onsite measurements of VOCs, PM and noise need to be based on the construction tasks in Fig. 1. Those tasks involve various construction workers, including miller operators, pavement breaker operators, sweeper operators, rakers, screedmen, paver operators and roller operators. The involvement of these workers in the construction process is also shown in Fig. 1. The workers' exposure to the types of pollutants is dependent on the construction activities in which they are involved. An evaluation matrix was prepared and presented in Table 1, based on which on-site samples were collected at the personal breathing and hearing zones.

Table 1: The detailed description of worker monitor plan

Construction Stage	Worker	Duty	Monitor or not		
			VOCs	PM	Noise
Milling	Miller operator	The worker who is responsible for maneuvering the miller while milling the old overlay pavement.		√	√
	Breaker operator	The worker who is responsible for operating the hand-held breaker while demolish the old overlay pavement.		√	√
Sweeping	Sweeper operator	The worker who is responsible for operating the sweeper to clean up the demolished debris.		√	√
Paving	Raker	The worker who is responsible for ranking the hot mix asphalt to the correct thickness to reduce high and low area in the pavement.	√		√
	Screedman	The worker who is responsible for raising and lowering the paver screed to the proper depth and width for the application.	√		√

	Paver operator	The worker who is responsible for maneuvering the paver while laying down hot mix asphalt.	√	√
Compacting	Roller operator	The worker who is responsible for maneuvering the roller while compacting the pavement.	√	√

2.4 Collection and Analysis Methods for the Major Pollutants

The methods used to collect and analyze the different types of pollution samples are shown as follows. These methods have been widely used for the quantification of VOCs, PM and noise exposures.

At the paving site, VOCs emitted from asphalt is collected using metal cans, and then the concentration and chemical composition of VOCs are computed through gas chromatography-flame ionization detector (GC-FID) in laboratory.

The concentrations of $PM_{2.5}$ and PM_{10} are commonly used as the measurement parameters for outdoor air quality. In this study, the real time concentrations of $PM_{2.5}$ and PM_{10} were measured using a TSI dust monitor, DustTraks (model 8520). The readings from the DustTraks were calibrated by a tapered element oscillating microbalance (TEOM, model 1400A).

The most frequently used parameter to characterize construction noise is sound pressure level measured in decibels, although there are also some other important parameters such as exposure duration, impulsivity, frequency and spectrum, incidence and distribution along the working day (Fernández et al. 2009). In this study, the indices used for assessing the noise level exposed by road workers are L_{Aeq}, Peak, Max, Min, SPL, SEL, L_{tm3} and L_{tm5} in dBA unit. To measure the noise level, a sound level meter (SVAN 948) was used, as well as SVANPC++ software and a sound calibrator.

3 Case Study

Because all resurfacing projects are similar in terms of construction process and materials, a detailed case study was used to shed light on the pollution generated during each stage of asphalt resurfacing construction. It is noted that pollution measurements in an outdoor environment are influenced by various meteorological conditions. Therefore, based on weather forecasts, this study selected a project that took place in a typical weather condition in the summer with clear sky and low wind speed. In addition, continuous and multiple measurements were taken during the construction process to capture variations. It is anticipated that the measurements are representative of the typical situations encountered in a pavement resurfacing project.

3.1 Project Description

The selected road resurfacing project was located at Pokfulam Road in Hong Kong Island, Hong Kong. The resurfaced pavement sections are highlighted in yellow in Fig. 2. The section length was about 120 m and it was completed in one day. Hourly data on air temperature, freshly placed HMA temperature, wind speed, wind direction, humidity and atmospheric pressure were recorded. The meteorological data are summarized in Table 2.

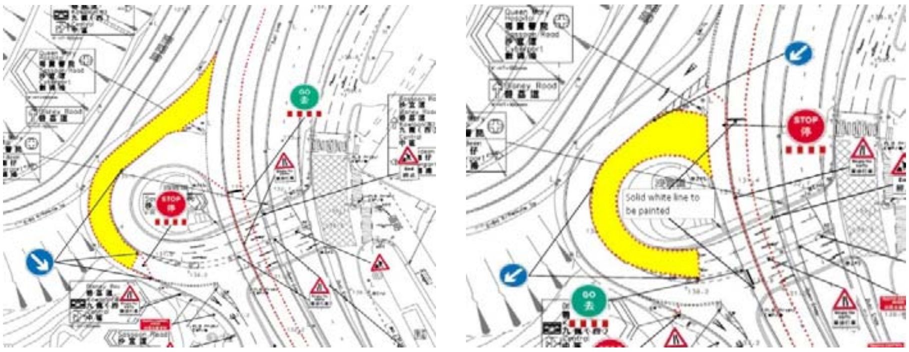

Figure 2: Stage 1 and stage 2 of HMA pavement resurfacing project at Pokfulam Road in Hong Kong

Table 2: Meteorology description of the selected case

	Temperature (°C)(air)	Pavement laydown temperature (°C)	Wind Speed (m/s)	Wind direction	Humidity (%)	Atmospheric pressure (mb)
Peak	30.4	143	2.7	Southeast wind	74.25	1004.75
Average	28	141	0.7			

3.2 Worker Exposure Level to VOCs

VOCs were measured during both the paving and compaction stages, as shown in Fig. 3. VOCs emissions exposed by the workers largely depend on the workers' locations: the closer they are to the hot-mixed materials, the higher level of VOCs they will be exposed to. In this study, the VOCs concentrations at multiple locations at the worker breathing zones were sampled. It was expected that the samples represent the exposure levels encountered by rakers, screedman, paver operator, and roller operators. Each sampling process took about five minutes. After the project, all the samplers were delivered to the Air Laboratory at the Hong Kong Polytechnic University to identify the chemical composition and concentration of VOCs emissions using GC-FID.

Figure 3: Measurements of VOCs during the paving stage

A total of forty-two different types of chemical compounds were identified and quantified. The data indicates that the VOCs concentrations near the paver were higher than those near the roller, and at each location, the VOCs concentrations decrease over time. The top five chemical components in different samples are summarized in Table 3.

Table 3: Top five chemical components and their concentration (in parenthesis) of VOC exposed to road workers (unit: ppb)

	Paving stage: sample 1	Paving stage: sample2	Compaction stage: sample 1	Compaction stage: sample 2
Five top compounds	1.2-Dibromoethane (5.77)	4-Ethyltoluene (7.95)	Freon-12 (0.67)	1.2-Dibromoethane (3.22)
	1,2,4-Trichlorobenzene (0.88)	p-Xylene (4.58)	Toluene (0.57)	1,2-Dichloroethane (1.99)
	1,1,2-Trichloroethane (0.68)	1.2-Dibromoethane (3.12)	Benzene (0.36)	4-Ethyltoluene (0.73)
	3-Chloropropene (0.43)	Toluene (2.11)	Freon-11 (0.33)	p-Xylene (0.72)
	1,3-Butadiene (0.20)	1,3,5-Trimethylbenzene (1.35)	1,2-Dichloroethane (0.28)	Toluene (0.71)

Most of the chemicals in Table 3 are harmful to human health at an elevated concentration level. A health risk assessment was carried out based on toxicological reference value (TRV) published by government organizations such as the Occupational Safety and Health Administration (OSHA), National Institute for Occupational Safety and Health (NIOSH), Agency for Toxic Substances and Disease Registry (ATSDR) etc. It was found that during the construction, the concentrations of individual chemicals in Table 3 are below TRV. Therefore, individually, these chemicals appear not posing a threat to the paving workers; however, collectively, their effects are unknown.

3.3 Worker Exposure Level to PM

It was found that, in this case study, the workers were exposed to a high level of particulate matter (PM). The $PM_{2.5}$ and PM_{10} concentrations were measured by the dust monitor (DustTrak, TSI Model 8520) at the workers' breathing zone in the milling, sweeping and paving stages, as shown in Fig. 4. The monitored road workers included operators of miller, operators of hand-held breakers and operators of sweeping machine. To take existing PM level in the air at the jobsite into consideration, the background $PM_{2.5}$ and PM_{10} concentrations were measured before construction started. The monitoring time covered the whole process of each stage, and DustTrak monitor logging interval was set to 10 seconds and the time constant to 1 second for all measurements. The instrument was calibrated according to the manufacturer's manual before conducting experiment. The measured average $PM_{2.5}$ and PM_{10} concentrations, along with the maximum and minimum values and 95% confidence limits are shown in Table 4.

Figure 4: Measurement of $PM_{2.5}$ and PM_{10}

Table 4: Summary of the measured data for $PM_{2.5}$ and PM_{10} (unit: mg/m^3)

Stage	$PM_{2.5}$		PM_{10}	
	Average (95% confidence limits)	Maximum (Minimum)	Average (95% confidence limits)	Maximum (Minimum)
Background	0.064 (0.063, 0.065)	0.076 (0.059)	0.060 (0.058, 0.062)	0.030 (0.108)
Milling	1.529 (0.927, 2.130)	13.894 (0.048)	0.082 (0.077, 0.086)	0.468 (0.053)
Sweeping	0.162 (0.068, 0.257)	1.203 (0.058)	0.098 (0.065, 0.130)	0.818 (0.056)
Paving	0.173 (0.128, 0.218)	1.673 (0.056)	0.423 (0.190, 0.655)	10.419 (0.051)
Whole Process	0.673 (0.433, 0.912)	13.894 (0.048)	0.180 (0.113, 0.246)	10.419 (0.051)

The monitored data indicate that the PM level in background air was relatively low, with an average concentration of 0.064 mg/m^3 for $PM_{2.5}$ and 0.060 mg/m^3 for PM_{10}. During the entire process of resurfacing, the average $PM_{2.5}$ was 0.673 mg/m^3 with 95% confidence limit between 0.433 and 0.912 mg/m^3, while the 95% confidence limit for PM_{10} was 0.180 ± 0.066 mg/m^3. By comparing the PM levels of the three construction stages, it can be seen that milling is the most hazardous period for road workers in terms of exposure to $PM_{2.5}$.

Several epidemiological studies have linked both $PM_{2.5}$ and PM_{10} with significant health problems, because the particles that are 10 micrometers in diameter or smaller could generally pass through the throat and nose and enter the lungs (EPA 2010). The current National Ambient Air Quality Standards (NAAQS) by U.S. Environment Protection Agency (EPA) for PM include a suite of standards to provide protection for exposures to both $PM_{2.5}$ and PM_{10}. EPA regulated the level for 24-hour $PM_{2.5}$ standard to be 0.035 mg/m^3 and 24-hour PM_{10} standard to be 0.15 mg/m^3 (EPA, 2010).The measured average concentration in the entire construction process for both $PM_{2.5}$ and PM_{10} exceed the above limits. With regard to $PM_{2.5}$, even the minimum concentration (0.048 mg/m^3) surpassed the EPA standard (0.035

mg/m^3), and milling can be regarded as the most hazardous activity with the highest $PM_{2.5}$ concentration (1.529 mg/m^3).

3.4 Worker Exposure Level to Noise

There are several noise sources at the construction site throughout almost all the stages of construction work. According to the current regulations, measurements must be conducted by placing the microphone in front of the affected workers' ears at the approximate distance of 10 centimeters (Fernández et al. 2009). In this study, measurement was performed according to the ISO 9612:1997 "Acoustics- Guidelines for the measurement and assessment of exposure to noise in a working environment", as shown in Fig. 5. The registered parameters with the sound level meter are shown in Table 5.

Figure 5: Measurement of Noise

Table 5: The registered parameters with the sound level meter (unit: dBA)

Parameter	Description
L_{Aeq}	Equivalent continuous A-weighted sound pressure level
Peak	Peak level for A-weighted sound pressure level
Max	Maximum sound pressure level registered with fast time weighting
Min	Minimum sound pressure level registered with fast time weighting
SPL	A-weighted sound pressure level
SEL	A-weighted sound exposure level
L_{tm3}	Takt-max A-weighted sound pressure level occurring in successive intervals of 3 s
L_{tm5}	Takt-max A-weighted sound pressure level occurring in successive intervals of 5 s

Summarized results of the measurements are presented in Table 6. In this study, the exposure levels of 7 types of road workers were measured. L_{Aeq} clearly shows that all the workers experienced an exposure that exceeds 80 dBA, which is the lower exposure limit by the existing regulations (Fernández et al. 2009). Moreover, the exposure levels of 3 out of 7 workers exceed 87 dBA, which is the top limit (reference). This indicates that the noise level that the road workers are exposed to was very high. The milling stage was the nosiest stage. Both the milling machine and hand-held breakers generated high noises, and miller and breaker operator who operated these machines were subject to high risk.

Table 6: Measured and calculated parameters (unit: dBA)

Worker	Stage	L_{Aeq}	Peak	Max	Min	SPL	SEL	L_{tm3}	L_{tm5}
Miller operator	Milling	94.9	130.6	107.3	67.4	90.4	124.5	98.4	99.3
Breaker operator	Milling	92.3	130.4	102.6	33.4	95.1	121.8	96.1	96.7
Sweeper operator	Sweeping	84.3	109.5	93.4	69.7	72.5	113.8	85.7	86.1
Paver operator	Paving	82.8	114.4	97.5	63.4	86.9	112.3	86.6	87.3
Screedman	Paving	84.9	118.4	102.9	66.9	71.7	114.4	88.1	88.7
Raker	Paving	86.2	131.8	105.3	56.0	76.3	115.7	90.3	91.3
Roller operator	Compacting	90.8	132.4	107.4	63.5	99.9	120.3	94.0	94.9

In summary, noise at the jobsite imposes potential health harm to road workers. Hearing protection devices should be provided for the road workers, especially for the milling workers. In addition, mitigation methods may be considered, including controlling the noise at source, reducing exposure time, and redesigning the workplace and reorganizing working patterns (Fernández et al. 2009).

4 Conclusions

With growing attention to sustainable development in construction, the potential impacts of construction projects on environment and health are increasingly emphasized by construction participants and adjacent communities (Gangollells et al. 2009). The exposure of road workers to VOCs, particular matters and noise is of concern to the asphalt paving industry. This paper presents a pilot study to investigate the impacts of three types of pollutants (i.e., VOCs, PM and noise) generated from asphalt resurfacing construction on road workers.

It is revealed in this study that asphalt resurfacing construction may make workers subject to high levels of exposures to particulate matters and noise, while the exposure level of VOCs is relatively low. Both the ambient $PM_{2.5}$ and PM_{10} concentrations during asphalt resurfacing construction exceeded the limits posed by U.S. EPA. There are also high levels of noise generated in different construction activities. The results from this study indicate that there is a need to improve working conditions and provide adequate protection to workers. These findings could help the construction industry understand the road workers' potential health risks, establish effective measures to reduce such risks, and develop guidelines to improve health-protection practices at construction sites.

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