Airborne Levels of Lung Carcinogens at an Ascon Manufacturing Site

Kyeongmin Lee[1], Sungwon Choi[1], Miyeon Kim[1], Dongwoo Song[2], Ki-Youn Kim[2*]

[1] *Institute of Occupation and Environment, Korea Workers' Compensation and Welfare Service*

[2] *Department of Safety Engineering, Seoul National University of Science and Technology*

Corresponding author

email: kky5@seoultech.ac.kr, department: Department of Safety Engineering, Seoul National University of Science and Technology

Abstract

Airborne levels of total and respirable dust, quartz, polycyclic aromatic hydrocarbons, and elemental carbon in an ascon manufacturing environment were assessed to determine operators' exposure and the likelihood of developing occupational respiratory diseases.

The ascon production process is divided into four steps, namely feeding, drying, mixing and loading. The feeding process is to transfer aggregate to conveyors underground via. The drying process is intended to remove moisture from the aggregate and maintain the temperature required for mixing the aggregate, asphalt and additives. The mixing process blend with the aggregate, asphalt and additives to make ascon. The loading process involves loading dump trucks with ascon, which is disgorged from an outlet on the mixing machine.

The airborne levels of total and respirable dust and quartz at hopper 1 were 8.540, 1.536, 0.125 mg m^{-3}. The airborne levels of total and respirable dust and quartz at hopper 6 were 10.092, 3.989, and 0.331 mg m^{-3}. At the vibrating screen, the airborne levels of respirable dust and quartz were 12.362 and 1.645 mg m^{-3}. The level of airborne elemental carbon from a burner of a dryer was 0.001 mg m^{-3}. The levels of total and respirable dust and quartz at the mixer outlet were 0.685, 0.265, and 0.011 mg m^{-3}. The levels of total and respirable dust and quartz in the dump truck zone were 0.419, 0.036, and 0.011 mg m^{-3}. Only naphthalene was

much lower than 10 ppm PEL of naphthalene. The naphthalene levels measured in the dryer burner, dump truck zone, dump truck waiting zone, and operation room were 0.274, 0.138, 0.192, and 0.237 ppm. The naphthalene levels measured in the conveyors on the ground, vibratory sieve, bunker C oil tank, and mixer outlet which were 0.074, 0.088, 0.080, and 0.074 ppm were generally very low. During the operation tasks, the personal exposure levels of total and respirable dust were relatively low, at 0.027 and 0.013 mg m^{-3}. Respirable dust and quartz levels of the operator were 4.260 and 0.548 mg m^{-3} when cleaning the conveyors underground.

Based on this study, we can conclude that concentrations of PAHs are hardly emitted at the ascon mixing plant, during ascon production. On the contrary, the aggregate dust highly containing quartz is significantly released during ascon production. In terms of ascon manufacturing environment management, this study means an environmental evaluation is the first time for those substances developed with lung cancer at ascon manufacturing site.

INTRODUCTION

Ascon, which is an abbreviation for asphalt concrete, is composed of asphalt, aggregates, and mineral fillers such as limestone and steel slag. Asphalt, asphalt mixture and hot mix asphalt are commonly used as alternative terms to ascon. Ascon is used in many construction fields, generally to pave roads. The annual productivity of ascon increases gradually every year, and recently reached approximately 23 million tons. In South Korea, there are approximately 341 asphalt concrete manufacturing workplaces (NIER, 2012).

Asphalt is the final remaining substance left after refining crude oil. Asphalt may also be called “bitumen” and is a component of pitch, which is derived from crude oil and is a semisolid or semiliquid resin with high viscosity. Polycyclic aromatic hydrocarbons (PAHs) are found in asphalt, which is an organic compound (Partanen and Boffetta, 1994). The International Agency for Research on Cancer (IARC) reported that PAHs are carcinogenic substances that contribute to the development of lung and bladder cancer (IARC, 2013).

The ascon manufacturing process involves not only asphalt, but also several other raw materials that are known lung carcinogens. Aggregate obtained from quarries is one of the raw materials used in ascon production. Aggregate is partially composed of quartz, which is a lung carcinogen, as crystalline silica (Marinoni and Broekmans, 2013). Furthermore, diesel engine exhaust (DEE), which is a known carcinogen and causes lung and bladder cancers, is emitted by many massive dump trucks while they wait for ascon to be loaded from ascon manufacturing facilities (IARC, 2014). DEE is also emitted during the drying process, which uses bunker C oil as a burning source. Hence, there is a risk of exposure to PAHs, quartz and DEE during the ascon manufacturing process. It is therefore necessary to confirm the airborne concentrations of these materials and assess workers' exposure at ascon manufacturing sites. Unfortunately, it is difficult to find relevant references on this topic.

Ascon mixing plants are commonly situated close to residential areas so that just manufactured ascon can be moved quickly to road construction sites. The PAHs found in asphalt can be dispersed into the atmosphere while ascon is being manufactured. Local residents who live close to ascon mixing plants are likely to be exposed to PAHs. In South Korea, a relatively high incidence of diverse cancers, including lung cancer, is an issue for local residents, particularly in areas near ascon mixing plants. It is controversial to state that local residents are exposed to PAHs during ascon production and that such production affects the atmospheric PAH levels in residential areas although it is suspected that PAHs contribute to cancer. The levels of exposure to PAHs have never been assessed from atmosphere of an ascon manufacturing plant while the levels of exposure to PAHs were discovered in a work site handling ascon (Randem et al., 2003).

The Institute of Occupation and Environment (IOE), which is administrated by the Korean Worker's Compensation and Welfare Service, carried out an occupational environment assessment on the ascon manufacturing process to demonstrate its impact on the development of occupational respiratory disease in an which we assessed exposure levels of the operator by measuring toxic substances.

In this study, we focused whether several carcinogens can be emitted into the atmosphere during ascon producting and actual information of the carcinogen concentration acquired from the field is used to evaluate environment risk in ascon manufacturing site.

METHOD

A brief description of the process and task

The ascon manufacturing process

Ascon is produced by mixing appropriate amounts of asphalt, aggregate, filler and additives at a temperature of approximately 180°C at an automated manufacturing facility. The ascon production process is divided into four steps, namely feeding, drying, mixing and loading. During the feeding process, the aggregate, which is stored in an open-air storage yard and has a standardized size, is transferred to conveyors underground via hoppers (Fig. 1). The aggregate is sieved in a vibrating screen before being placed in a dry drum (Fig. 2(a)). The drying process is intended to remove moisture from the aggregate and maintain the temperature required for mixing the aggregate, asphalt and additives (Fig. 2(b)). In the mixing process, the asphalt is blended with the aggregate and additives to make ascon. The loading process involves loading dump trucks with ascon, which is disgorged from an outlet on the mixing machine (Fig. 3).

The tasks of the operator working

The job of an operator who runs an ascon mixing plant can be divided into common subtasks. The primary task of the operator is to monitor the conditions of the plant from an operation room (Fig. 4(a)). The operator is hardly exposed to any chemicals during this task. A subsidiary task of the operator is to fix the plant apparatus when necessary, carry out walk-around inspections, and clean aggregate that has settled around the conveyor belts in the basement (Fig. 4(a)).

Measurement and analysis of lung carcinogens

To evaluate the hazards associated with exposure to lung carcinogens, we assessed the levels of dust, quartz, elemental carbon and PAHs at an ascon manufacturing site. To assess the exposure to dust and quartz, we measured the total and respirable dust and respirable-sized quartz in the air to determine their airborne levels. The total and respirable dust levels were measured side by side at the same time, in accordance with National Institute for Occupational Safety and Health(NIOSH) Manual of Analytical Method (NMAM) #0500 and #0600. Respirable dust was analyzed to determine the concentration of respirable-sized quartz, in accordance with NMAM #7500. To identify the source of the quartz, we randomly collected bulk samples of aggregate and ascon during the feeding and loading processes and evaluated the quartz content. The aggregate and ascon were composed of respirable-sized powder due to pretreatment in a small milling machine. The quartz contents of the aggregate and ascon powders were determined by X-ray diffraction (XRD, D8 Advance; Bruker Inc., Karlsruhe, Germany). Furthermore, the DEE levels were measured at the drying machine, which uses bunker C oil as fuel, and during the loading process, in which numerous dump trucks are resting or moving while the engine is turned on. The samples were analyzed in accordance with NMAM #5040. We measured the total and respirable dust, PAHs, quartz and DEE, which are related to the incidence of lung cancer close to ascon mixing plants, in accordance with the official methods recommended by NIOSH. In our assessment of PAH levels, we designated 16 types of PAHs, which were formally classified by the Environmental Protection Agency (EPA). These are naphthalene (NAP), acenaphthylene (ACY), acenaphthene (ACN), fluorene (FLN), phenanthrene (PHE), anthracene (ANT), fluoranthene (FLU), pyrene (PYE), benzo(a)anthracene (BAA), chrysene (CHR), benzo(b)fluoranthene (BBF), benzo(k)fluoranthene (BKF), benzo(a)pyrene (BAP), benzo(g,h,i)perylene (BGP), dibenz(a,h)anthracene (DBA), and indeno(1,2,3-cd)pyrene (IND). In accordance with NMAM #5515, these gas and particulate substrates of PAHs were measured in an XAD-2 sorbent tube (SKC Inc., Valley View Road, PA, USA) and a PTFE filter (SKC Inc.), after extraction for 30 minutes in a sonicator and the addition of 2 and 5 ml dichloromethane, respectively. The particulate PAHs were concentrated using a nitrogen evaporator. Finally, the PAHs were characterized using a gas chromatography-mass spectrometer. The calibration curves of the PAHs were plotted using the EPA 610 mixture standard solvent (SUPELCO Inc., Bellefonte, PA, USA).

RESULT

Quartz content analyzed in bulk samples of aggregate and ascon

Ascon and aggregate were analyzed for quartz contents by using XRD. The results of the quantitative analysis showed that the average quartz content of the bulk samples of aggregate and ascon was approximately 36.1% (n=5) and 26.7% (n=3), respectively. Quartz contained in ascon is from aggregate because ascon is a mixture of aggregate and asphalt.

Airborne levels of total and respirable dust, quartz and elemental carbon detected during each process

The samples collected from hopper 1 during the feeding process contained airborne levels of total and respirable dust of 8.540 and 1.536 mg m^{-3}, respectively, which are high. There was 0.125 mg m^{-3} of quartz at hopper 1. The time-weighted average (TWA) over 8 hours of airborne quartz measurements was calculated as 0.124 mg m^{-3}, which was over twice the permissible exposure limit (PEL, 0.05 mg m^{-3}) for quartz according to the regulations of the Ministry of Employment and Labor (MOEL). At hopper 6, the airborne levels of total and respirable dust were 10.092 and 3.989 mg m^{-3}, respectively, which are also high. The level of quartz detected at hopper 6 was 0.331 mg m^{-3}. The TWA of the level of airborne quartz was 0.288 mg m^{-3}, which is approximately six times higher than the PEL of quartz. At the vibratory sieve, the levels of airborne respirable dust and quartz were, respectively, 12.362 and 1.645 mg m^{-3}, which are also significant. The TWA of the airborne level of quartz was calculated as 2.046 mg m^{-3}, which is about 40 times higher than the PEL. High levels of total and respirable dust are due to conveyors and vibrating screen machine in the moving process. In addition, quartz is also high owing to resprable dust.

In the cases of the samples collected during the drying process, the airborne level of elemental carbon at one of the burners of a dryer was 0.001 mg m^{-3}, which is low. Although bunker C oil is used for fuel of the drying process, combusted substances are not emitted into the atmosphere. In the samples collected during the mixing process, the airborne levels of total and respirable dust and quartz at the mixer outlet were 0.685, 0.265, and 0.011 mg m^{-3}, respectively. The TWA of the airborne level of quartz was calculated as 0.012 mg m^{-3}, which is lower than the PEL of quartz. During the loading process, the airborne levels of total and respirable dust and quartz in the dump truck zone were, respectively, 0.419, 0.036, and 0.011 mg m^{-3}. The TWA of the airborne level of quartz was 0.01 mg m^{-3}, which is lower than the PEL. Total and respirable dust are not relatively high because ascon mixed into the mixing machine has viscosity.

Meanwhile, the airborne levels of elemental carbon measured during the feeding, drying and loading processes were 0.001–0.002 mg m^{-3}, which are very low.

Airborne levels of gas and particulate PAHs detected during each process

The airborne levels of PAHs measured in this study were almost undetectable or under the limit of detection (LOD, 0.3–0.5 μg/samples). Only NAP was detected in the gas substrates of the PAHs, and the levels were much lower than the PEL (10 ppm) of NAP according to MOEL (Table 3). These results measured in the processes were higher than that obtained from the entrance of the ascon manufacturing site, which we measured as a control (Table 3). The levels of NAP detected in the dryer burner, dump truck zone, dump truck waiting zone, and operation room, which were 0.274, 0.138, 0.192, and 0.237 ppm, respectively, were relatively high in comparison to the levels of NAP detected at other sampling points. The levels of NAP measured at the conveyor belts on the ground, vibratory sieve, bunker C oil tank, and mixer outlet were 0.074, 0.088, 0.080, and 0.074 ppm, respectively. All of these values are very low. Asphalt automatically is transferred in sealing when ascon is mixed into the mixing machine.

Personal exposure levels to total and respirable dust, and quartz, according to subtasks carried out by the operator

We assessed the variation in personal exposure levels with respect to the different subtasks carried out by the operator. The subtasks include an operation task, for which the operator works in the operation room of the ascon mixing plant; and a cleaning task, in which the operator cleans aggregate dust that has settled around the underground hopper and conveyor belts in the basement. During the operation task, the personal exposure levels of total and respirable dust were measured to be 0.027 and 0.013 mg m^{-3}, respectively, which are very low (Table 3). Quartz was not detected in the operation room. During the cleaning task, the personal exposure levels of respirable dust and quartz were 4.260 and 0.548 mg m^{-3} (Table 3), respectively. The TWA of the personal exposure level to quartz was 0.018 mg m^{-3}, which is lower than the PEL (Table 3).

DISCUSSION

Various types of aggregate are used as raw materials for the ascon manufacturing process (Ahmedzade and Sengoz, 2009). Mineral aggregate is made of granite stone, and sand is used as filler in the asphalt industry (Parks et al. 1999, Healy et al. 2013). In other studies, it has been reported that the aggregate used in ascon contains quartz (Marinoni and Broekmans. 2013, Cho et al. 2016). In our study, we analyzed bulk samples and confirmed that the aggregate contained some quartz. This suggests that the main source of quartz in ascon is the mineral aggregate, which is obtained from quarries. However, there were differences between the quartz contents of aggregate and ascon. These differences may have been caused by the heating treatment used during the drying process, in which the crystal structure of quartz was transformed into a non-crystalline structure, despite the fact that the temperature was not particularly high.

The Ministry of Environment classifies an ascon manufacturing facility as a workplace that emits air pollutants, according to the information on particulate matter emission published by the US Environment Protection Agency (Jang et al., 2014). In our study, Table 1 shows that the high concentration of dust is caused by transferring material, such as moving it between conveyor belts during the feeding process. This suggests that an aggregate consisting of fine particles that is very dry can easily be dispersed when transferred to the vibratory sieve and conveyor belts. This dust, which is released into the air, was confirmed to be respirable-size, and thus very hazardous. This also demonstrates that ascon manufacturing facilities release considerable quantities of dust into the air. Furthermore, our study also shows that respirable-size quartz particles are airborne during the ascon manufacturing process. Airborne quartz was detected in the respirable dust collected during most stages of the process (Table 1). During the feeding process, airborne quartz was released while the aggregate was transferred. During the mixing and loading processes, airborne quartz was released from the mixer, which mixes aggregate, asphalt and additives. These results suggest that the airborne quartz particles are released from the aggregate. These particles contribute to the air pollution detected near ascon manufacturing facilities. Ascon manufacturing facilities should be monitored closely because respirable-size quartz is classified as a lung carcinogen.

In Germany, the IFA (Institutes for Occupational Safety and Health of the German Social Accident Insurance) reported that asphalt mixing plants are workplaces where operators are exposed to quartz (IFA, 2008). According to the IFA report, workers are exposed to high levels of quartz during production due to various sources of dust, including screening machines and transfer points. The authors presented the quartz concentrations at the workplace measured during an investigation. The quartz concentrations detected at the mixing plant from 1972 to 1984, 1985 to 1994, and 1995 to 2004 were 0.27, 0.09, and 0.03 mg m^{-3}, respectively, so the levels decreased over the years. In our study, the quartz levels measured in 2017 were lower than the average concentrations detected between 1995 and 2004 (Table 1). Given this trend, our results are consistent with those reported previously. Furthermore, the report states that the quartz concentration at locations where materials are transported externally, such as conveyors, is 0.04 mg m^{-3}, which is lower than the concentrations that we measured at the hoppers in the basement (Table 1). Therefore, it is important to note whether a sample is collected from an external site or the basement. As described above, we found that vibratory sieves and conveyor belts are dust sources, from which most dust is released, and the quartz concentrations at these points are significantly higher than elsewhere. This may be why the previously measured quartz concentrations are higher than in recent measurements.

Darby et al. (1986) reported that road workers who work at a road construction site were exposed to quartz, PAHs and burnt diesel fuel to varying degrees, depending on their tasks. A fantail operator who controls the aggregate deposition, and a sweeper, who sweeps the road, are exposed to respirable dust that consists of 0.2–24% quartz. The aggregate used at the road construction site contained 19–43% quartz, as determined by XRD analysis of five bulk aggregate samples. According to our study, an operator who runs an ascon manufacturing facility carries out several tasks, including cleaning the conveyer and the hopper during the feeding process and undertaking walk-around inspections, as well as operating the plant. Table 2 shows that the operator is exposed to respirable-size quartz when cleaning aggregate from around the underground conveyers and hoppers. This demonstrates that respirable dust containing quartz can be released at transfer points during the feeding process. Our results also indicate that the quartz content of aggregate bulk samples is 36.1%. This provides convincing evidence that workers who handle the aggregate directly have no choice but to be exposed to quartz, which is a carcinogen. Therefore, asphalt industry workers should manage their exposure to quartz.

In the asphalt industry, workers who handle bitumen or tar directly when constructing pavements are exposed to PAHs and can develop cancer due to exposure to carcinogens (Sawicki et al., 1962, Partanen and Boffetta, 1994, Boffetta et al., 2003). Darby et al. (1986) reported the airborne concentrations of PAHs while spraying coal tar or bitumen at a construction site. The results of this study indicate that most PAHs primarily consist of particulate PAHs containing benzo(a)pyrene. Watts et al. (1998) reported that asphalt workers are generally exposed to PAHs, depending on their job categories. The results of this study also showed that high-molecular-weight PAHs, such as benzo(a)pyrene, were the dominant species, whereas we did not detect high-molecular-weight PAHs in our study (Table 2). At the ascon manufacturing site tested, it is unlikely that asphalt is released directly into the atmosphere during ascon production because asphalt is automatically transferred to a mixer through a sealed pipe. Our operator does not handle asphalt directly due to the automatic asphalt input system. Although our operator carries out work related to asphalt, they are rarely exposed to high-molecular-weight PAHs. Furthermore, we only detected NAP from gaseous PAHs, and the levels detected were lower than the PEL of NAP. This suggests that the airborne NAP detected at the ascon manufacturing site is released by dump trucks waiting to transport the produced ascon to construction sites. Hence, DEEs from diesel trucks may affect the levels of NAP released into the atmosphere at the ascon manufacturing site.

The airborne levels of total PAHs in heavy traffic areas of Seoul were measured as 16.52 ng m^{-3} (n=13, 5.52–38.89 ng m^{-3}) in Gwanak-gu, and 59.10 ng m^{-3} (n=8, 28.98–100.50 ng m^{-3}) in Seodaemun-gu (Park et al., 2010). Another study indicated that the airborne levels of total PAHs distributed in the atmosphere of Seoul were from 4.32–35.9 ng m^{-3} for PM_{10}, depending on the season (Lee et al., 2008). However, in our study, NAP was only detected in 16 species of PAHs, and the airborne concentration of NAP was 0.052–0.274 ppm at the ascon manufacturing site. Our measured levels were much higher than those obtained from the areas of heavy traffic around Seoul. However, it is not possible to simply compare these previous results with ours, given that they were obtained using different measurement and analysis methods. We followed the measurement and analysis methods recommended for PAHs in NIOSH, which are focused on assessing high PAH levels in occupational environments. Therefore, we were not able to identify a nanogram level of PAHs in this study, given the detection limit which was a microgram level in our method. We can therefore only confirm that the airborne levels of PAHs at the ascon manufacturing site detected in this study are lower than the PEL reported by NIOSH.

DEE, which has been classified as a carcinogen since 2012, is known to be a primary component of air pollution (Schauer et al., 1999; IARC, 2014). DEE is composed of a range of hazardous substances and is mainly emitted by diesel motor vehicles (Kagawa, 2002). Diesel engine technology has been improved to decrease DEEs from diesel motor vehicles since the late 1990s, in accordance with worldwide environmental regulations (Tzamkiozis et al., 2010). The airborne levels of elemental carbon are generally believed to be related to DEEs in occupational environments. The results of our study indicate that the airborne levels of elemental carbon were low, despite the fact that there are often several diesel dump trucks idling at ascon manufacturing sites. However, historic DEEs from diesel vehicles would be higher than DEEs from current vehicles. It appears that the operator was exposed to DEEs at ascon manufacturing sites in the past.

CONCLUSION

We assessed airborne concentrations of quartz, PAHs and elemental carbon, which are associated with lung cancer, at an ascon manufacturing site, and the personal exposure levels of quartz for an operator carrying out their regular subtasks. The quartz content of the raw aggregate material and newly produced ascon was evaluated to confirm the quartz source, based on our analysis of the aggregate and ascon bulk samples. Quartz was released during ascon production.

Based on this study, we can conclude that concentrations of PAHs are hardly emitted at the ascon mixing plant, during ascon production. On the contrary, the aggregate dust highly containing quartz is significantly released during ascon production. In terms of ascon manufacturing environment management, this study means an environmental evaluation is the first time for those substances developed with lung cancer at ascon manufacturing site although this study simply evaluates emission of carcinogens during ascon production.

This study has limitation that is few sample, which could not be detailed or statistical evaluation for big meanings. Nevertheless, a high level of quartz emission during the ascon process is meaningful. For prevention of exposure to quartz among workers, this aggregate dust should be under continuous surveillance and equipment to hold during the aggregate transfer should be installed on the conveyor belt and vibratory sieve.

REFERENCES

Ahmedzade P and Sengoz B. (2009). Evaluation of steel slag coarse aggregate in hot mix asphalt concrete. *J Hazard Mater*. 165: 300-305.

Boffetta P, Burstyn I, Partanen T, Kromhout H, Svane O, Langard S, Jarvholm B, Frenzel-Beyme R, Kauppinen T, Stucker I, Shaham J, Heederik D, Ahrens W, Bergdahl I, Cenee S, Ferro G, Heikkila P, Hooveld M, Johansen C, Randem B, and Schill W. (2003). Cancer mortality among European asphalt workers: An international epidemiological study: I. Results of the analysis based on job titles. *Am J Ind Med*. 43(1): 18-27.

Cho KS, Kim SH, and Seo CH. (2016). An experimental study on thermal properties according to rock type of the crushed aggregates for concrete. *JAIK_SC*. 32(4): 31-35.

Darby FW, Willis AF, and Winchester RV. (1986). Occupational health hazards from construction and sealing work. *Ann Occup Hyg*. 30(4): 445-454.

Healy CB, Coggins MA, Van Tongeren M, MacCalman L, and McGowan P. (2014). Determinants of respirable crystalline silica exposure among stoneworkers involved in stone restoration work. *Ann Occup Hyg*. 58(1): 6-18.

International Agency for Research on Cancer (IARC) (2013). *Monographs on the evaluation of carcinogenic risks to humans Volume 103 Bitumens and bitumen emissions, and some N-and S-Heterocyclic polycyclic aromatic hydrocarbons*, IARC, Lyon.

International Agency for Research on Cancer (IARC) (2014). *Monographs on the evaluation of carcinogenic risks to humans Volume 105 Diesel and gasoline engine exhausts and some nitroarenes*, IARC, Lyon.

Institutes for Occupational Safety and Health of the German Social Accident Insurance (IFA) (2008). *BGIA-Report 8/2006e: Exposure to quartz at the workplace*, German Social Accident Insurance (DGUV), Berlin.

Jang KW, Lee SB, Kim JH, Kim HC, Hong JH, and Kim SK. (2014). A study on estimating

PM emission from asphalt-concrete manufacturing facilities. *J. Korean Soc. Atmos. Environ*, 30(1): 37-47.

Kagawa J. (2002). Health effects of diesel exhaust emissions-a mixture of air pollutants of worldwide concern. *Toxicology*. 181-182: 349-353.

Lee JY, Shin HJ, Bae SY, Kim YP, and Kang CH. (2008). Seasonal variation of particle size distributions of PAHs at Seoul, Korea. *Air Qual Atmos Health*. 1(1): 57-68.

Marinoni N and Broekmans M A.T.M. (2013). Microstructure of selected aggregate quartz by XRD, and a critical review of the crystallnity index. *Cem Concr Res*. 54: 215-225.

National Institute of Environmental Research (NIER) (2012). *A study in the licensing and certification system to improve asphalt manufacturing facility*, NIER, Incheon.

Parks CG, Conrad K, and Cooper GS. (1999). Occupational exposure to crystalline silica and autoimmune disease. *Environ Health Perspect*. 107(5): 793-802.

Park JS, Yoon SK, and Bae KB. (2010). Distribution and emission source of PAHs in ambient air of Seoul. *J Anal Sci Technol*. 23(3): 269-277.

Partanen T and Boffetta P. (1994). Cancer risk in asphalt workers and roofers: review and meta-analysis of epidemiology studies. *Am J Ind Med*. 26: 721-740.

Randem BG, Langard S, Dale I, Kongerud J, Martinsen JI, and Andersen A. (2003). Cancer incidence among male Norwegian asphalt workers. *Am J Ind Med.* 43: 88-95.

Sawicki E, Fox FT, Elbert WC, Hauser TR and Meeker JE. (1962). Polynuclear aromatic hydrocarbon composition of air polluted by coal-tar pitch fumes. *Am ind Hyg Assoc J.* 23(6): 482-486.

Schauer JJ, Kleeman MJ, Cass GR, and Simoneit BRT. (1999). Measurement of emissions from air pollution sources. 2. C1 through C30 organic compounds from medium duty diesel trucks. *Environ Sci Technol*. 33(10): 1578-1587.

Tzamkiozis T, Ntziachristos L, and Samaras Z. (2010). Diesel passenger car PM emissions: From Euro 1 to Euro 4 with particle filter. *Atmos Environ*. 44: 909-916.

Watts RR, Wallingford KM, Williams RW, House DE, and Lewtas J. (1998). Airborne exposures to PAH and $PM_{2.5}$ particles for road paving workers applying conventional asphalt and crumbrubber modified asphalt. *J Expo Anal Environ Epidemiol*. 8(2): 213-229.

Table 1. Airborne levels of total and respirable dust, quartz and elemental carbon measured during the ascon manufacturing process.

Process	Sampling area	Sampling time (min)	Dust ($mg\ m^{-3}$)		Quartz ($mg\ m^{-3}$)	Elemental carbon ($mg\ m^{-3}$)
			Total	Respirable		
Feeding	Hopper 1 (Basement)	476	8.540	1.536	0.125	-
	Hopper 6 (Basement)	417	10.092	3.989	0.331	-
	Vibratory sieve (Ground)	597	-	12.362	1.645	0.002
Drying	Burner of dryer	551	-	-	-	0.001
Mixing	Mixer outlet	530	0.685	0.265	0.011	-
Loading	Dump truck zone	436	0.419	0.036	0.011	0.002

Table 2. Airborne levels of PAHs detected at the ascon manufacturing site.

Sampling area	Sampling time (min)	PAHs (ppm)															
		NAP	ACY	ACN	FLN	PHE	ANT	FLU	PYE	BAA	CHR	BBF	BKF	BAP	BGP	DBA	IND
Conveyor used in the feeding process	859	0.074	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
Vibratory sieve used in the feeding process	794	0.088	LOD	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
Dryer burner used in the drying process	380	0.274	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
Bunker C oil tank used in the drying process	567	0.080	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
Mixer outlet used in the mixing process	854	0.074	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
Dump truck zone used in the loading process	382	0.138	*ND*	LOD	LOD	LOD	LOD	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
Dump truck waiting zone	460	0.192	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
Operation room	333	0.237	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
Entrance to the ascon manufacturing site	879	0.052	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*

[a] LOD: limit of detection (0.3–0.5 μg/samples)

[b] ND: not detected

Table 3. Personal exposure levels of total and respirable dust and quartz while the operator works subtasks.

Subtask	Sampling time (min)	Total dust (mg m^{-3})		Respirable dust (mg m^{-3})		Quartz
		Crude	TWA	Crude	TWA	Crude
Operating	536	0.027	0.030	0.013	-	*ND*
Cleaning	16	-	-	4.260	0.142	0.548

[a] TWA: time-weighted average (8 h)

[b] ND: not detected

Figure Captions

Fig. 1. Steps of the ascon manufacturing process.

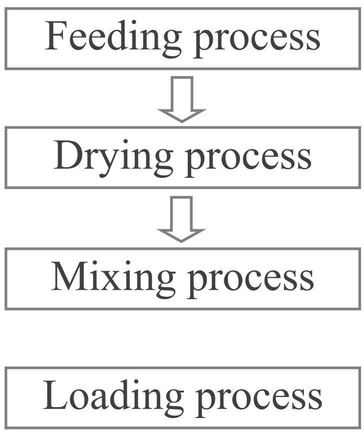
Feeding process
Drying process
Mixing process
Loading process

Fig. 1

Appendix.

<An open-air storage yard>

<Underground conveyor>

<Vibrating screen>

<Drying process>

<Ascon mixing machine>

<Dump truck>

<The operation task>

<The cleaning task>