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Ambient exposure to coarse and fine particle emissions from building demolition

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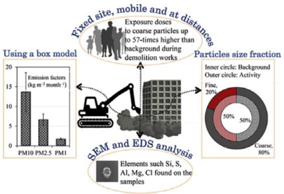
HIGHLIGHTS

- PM_{10}, $PM_{2.5}$ and PM_1 concentrations from a building demolition are assessed.
- Physicochemical properties of particles using SEM and EDS are investigated.
- Average exposure doses increased by up to 57-times during the demolition activities.
- PM profiles showed a logarithmic decay with increasing distance from demolition site.
- Chemical analysis showed dominant concentrations of silicon and aluminium.

GRAPHICAL ABSTRACT



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ABSTRACT

Demolition of buildings produce large quantities of particulate matter (PM) that could be inhaled by on-site workers and people living in the neighbourhood, but studies assessing ambient exposure at the real-world demolition sites are limited. We measured concentrations of PM_{10} ($\leq$10 μm), $PM_{2.5}$ ($\leq$2.5 μm) and PM_1 ($\leq$1 μm) along with local meteorology for 54 working hours over the demolition period. The measurements were carried out at (i) a fixed-site in the downwind of demolished building, (ii) around the site during demolition operation through mobile monitoring, (iii) different distances away from the demolition site through sequential monitoring, and (iv) inside an excavator vehicle cabin and on-site temporary office for engineers. Position of the PM instrument was continuously recorded using a Global Positioning System on a second basis during mobile measurements. Fraction of coarse particles ($PM_{2.5-10}$) contributed 89 (with mean particle mass concentration, PMC $\approx$ 133 ± 17 μg m^{-3}), 83 (100 ± 29 μg m^{-3}), and 70% (59 ± 12 μg m^{-3}) of total PMC during the fixed-site, mobile monitoring and sequential measurements, respectively, compared with only 50% (mean 12 ± 6 μg m^{-3}) during the background measurements. The corresponding values for fine particles ($PM_{2.5}$) were 11, 17 and 30% compared with 50% during background, showing a much greater release of coarse particles during demolition. The openair package in R and map source software (ArcGIS) were used to assess spatial variation of PMCs in downwind and upwind of the demolition site. A modified box model was developed to determine the emission factors, which were 210, 73 and 24 μg m^{-2} s^{-1} for PM_{10}, $PM_{2.5}$ and PM_1,

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respectively. The average respiratory deposited doses to coarse (and fine) particles inside the excavator cabin and on-site temporary office increased by 57- (and 5-) and 13- (and 2-) times compared with the local background level, respectively. The monitoring stations in downwind direction illustrated a logarithmic decrease of PM with distance. Energy-dispersive X-ray spectroscopy and scanning electron microscopy were used to assess physicochemical features of particles. The minerals such as silica were found as a marker of demolition dust and elements such as sulphur coming from construction machinery emissions. Findings of this study highlight a need to limit occupational exposure of individuals to coarse and fine particles by enforcing effective engineering controls.

1. Introduction

Exposure to particulate matter (PM), including PM_{10} ($\leq$10 μm), $PM_{2.5}$ ($\leq$2.5 μm) and PM_1 ($\leq$1 μm), is known to have adverse impacts on the human health (Heal et al., 2012). A number of epidemiological studies have shown excess mortality due to PM exposure from sources such as road traffic and industries (Janssen et al., 2013; Kan et al., 2007; Namdeo and Bell, 2005). Furthermore, excessive inhalation of PM_{10} and $PM_{2.5}$ has been linked to a variety of respiratory diseases, such as lung cancer (Turner et al., 2011; Vineis et al., 2004), asthma (Dorevitch et al., 2006; Eggleston et al., 1999), renal (Spencer-Hwang et al., 2011; Weng et al., 2015) and cardiovascular diseases (Brook et al., 2010; Peng et al., 2008), besides depression problems among construction workers (Haynes and Savage, 2007). Numerous studies have reported increased risk of death due to ischemic heart disease among construction plasterers, masons and welders (Cavallari et al., 2007; Sjogren et al., 2002; Stern et al., 2001). Similar adverse health effects have also been observed among *non-smoking* workers at construction sites (Bergdahl et al., 2004; Verma et al., 2003).

There is a reasonable amount of literature on emissions of coarse (hereafter referred to as PM_{2-5-10} fraction), fine ($PM_{2.5}$) and ultrafine ($PM_{0.1}$) particles from sources such as industrial works (Diapouli et al., 2013; Jaecker-Voirol and Pelt, 2000; Rodriguez et al., 2004; Toledo et al., 2008), road works (Fuller and Green, 2004; Ho et al., 2003; Tian et al., 2007; Woskie et al., 2002), road vehicles (Goel and Kumar, 2015; Kean et al., 2000; Kumar et al., 2011a, 2014) and non-vehicular activities (Kumar et al., 2013b, 2014; Saliba et al., 2010). However, there are limited studies that have measured emissions and exposure to PM around operational building demolition sites, which is the focus of this article.

Construction and demolition waste contribute up to about 33% of the total waste from all the streams; about half of which is demolition waste (Balaras et al., 2007). Construction and demolition of structures generate in excess of 450 million tonnes of waste each year in Europe, with about 53 million tonnes per year in the UK alone (Lawson et al., 2001; Rao et al., 2007). However, the number of buildings demolished each year is expected to increase by 4-fold by 2016 in the UK from the levels of about 20,000 per year in 2008 (ECI, 2005; Roberts, 2008). This increased rate of building demolition could be linked to growing population of the urban areas and the need for improvements to meet new urban design guidelines and adopt building technologies (Balaras et al., 2007; Kumar et al., 2016a, 2016b). For example, the global urban population is expected to increase by about 60% in 2035 from the 2013 levels (GroBmann et al., 2013; Kumar et al., 2013a).

Building demolition can be accomplished through either implosion or mechanical means (e.g. excavator and wrecking ball). Demolition by both mechanical disruption (Dorevitch et al., 2006) and implosion (Beck et al., 2003) produce significant amount of PM, but the impact of implosion demolition on surrounding areas air quality is generally short-lived and severe (Beck et al., 2003).

Recent studies have shown that workers in construction industry dealing directly with concrete and cement products are exposed to notable PM emissions (Azarmi et al., 2014; Croteau et al., 2002; Flanagan et al., 2006; Kumar et al., 2012b) compared with those working in metal and wood industries (Fischer et al., 2005; Lim et al., 2010). There are sufficient evidences that activities such as demolition, earthmoving and building renovation are important sources of PM and degrade the surrounding air quality (Azarmi et al., 2015a; Beck et al., 2003; Font et al., 2014; Hansen et al., 2008; Joseph et al., 2009; Muleski et al., 2005). In addition, PM pollution from demolition activity can adversely impact the health of people living close to demolition sites, especially when the measures to restrict particles released from sites are inadequate (Kumar et al., 2012a). Therefore, assessment of PM exposure becomes even more important when such sites are situated within the densely built residential areas or sensitive areas such as schools and hospitals.

Understanding the chemical constituents, morphology (i.e. size, shape) and surface properties of particles released from building demolition are important for determining their toxicity and health effects (Lo et al., 2000; Senlin et al., 2008). There are techniques such as scanning electron microscopy (SEM) for analysing morphology and energy dispersive X-ray spectroscopy technique (EDS) to find elemental composition, which are used by numerous environmental studies (Kupiainen et al., 2003; Mouzourides et al., 2015; Paoletti et al., 2002). For example, Mouzourides et al. (2015) assessed the characteristics of bulk PM samples collected on Polytetrafluoroethylene (PTFE) filters at an urban air pollution monitoring station in Nicosia (Cyprus) using SEM and EDS techniques. The results showed presence of elements such as calcium (Ca), nitrogen (N) and lead (Pb) on the samples. Likewise, Paoletti et al. (2002) studied the physicochemical characteristics and composition of particles in an urban area of Rome (Italy). They observed elements such as carbon (C) and N, mainly originated from vehicular sources. Currently, limited studies have reported physicochemical properties of particles released from the building demolition and therefore this is taken up for investigation in this study.

Health concerns related to dust inhalation have led to a number of dust control and reduction initiatives in demolition industry. The United States Environmental Protection Agency (US EPA) have provided specific emission factors for different operations such as demolition, construction and mineral operations to control PM emissions (EPA, 2011). In addition, the UK Health and Safety Executive (HSE) developed a good practice guideline to limit exposure to hazardous substances at the demolition sites (HSE, 2006, 2011). Furthermore, at local level, “Best Practice Guidance” is produced by London Councils in partnership with the Greater London Authority in the UK, which contains a number of practical methods to control dust and emissions from