Journal of Cleaner Production 112 (2016) 607–619

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Visualizing distribution of naturally discharged asbestos fibers in Korea through analysis of thickness changes in asbestos cement slates

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ARTICLE INFO

Article history:
Received 15 December 2014
Received in revised form
16 July 2015
Accepted 1 August 2015
Available online 8 August 2015

Keywords:
Asbestos
Asbestos cement slate
Thickness change
Distribution

ABSTRACT

Asbestos slates are harmful when asbestos fibers are lost and emitted into the surrounding areas through years of weathering. This study quantified the amount of asbestos discharged naturally from slates and visualized the amount of asbestos discharged naturally from slates in administrative districts in Korea. First, the researchers measured the thickness of slates and calculated the age of 193 slate-roofed buildings in three similar regions with average weather conditions in Korea. Then a regression analysis was conducted with SPSS 2.0 based on the results of the field survey, and this showed that the level of eroded slate by age is $(-0.015 + 0.034 \times n)$ mm/year. When applying the deduced formula for change in thickness, to slates with different specifications, the amount of asbestos discharged naturally per unit area of slate would be $(-2.5 + 5.67 \times n)$ g/m^2. The map visualized with the 'Natural Break' option of the ArcGIS program shows the amount of asbestos discharged naturally is relatively less in Gangwon-do (6903.36 kg/year), but greater in Gyeonggi-do (165,436.03 kg/year), Gyeongsangnam-do (108,375.41 kg/year) and Jeollanam-do (162,280.53 kg/year). The map visualized using the 'Equal Interval' option shows that the amount of asbestos discharged naturally from slates is overwhelmingly greater in Ulsan (64,704.24 kg/year) than in any other region. This study provides data that the government can utilize to establish a plan to remove and dispose of slates, and to select priority regions for slate removal to benefit public health and the environment. The results of this study also suggest methods that can be used to estimate the amount of asbestos discharged naturally from slates with different specifications in other countries.

1. Introduction

Asbestos is a group of silicate minerals occurring naturally as bundles of fiber, which has been used since ancient times due to its high affordability and desirable physical properties including resistance to heat and fire and antiseptic and insulating properties. Asbestos consumption increased rapidly with the introduction of steam engines during the Industrial Revolution (Becklake, 1976; Bourgault et al., 2014). Global consumption of asbestos rose exponentially between the 1940s and 1980s, when it reached its peak (Kim et al., 2015; Virta, 2006). Unfortunately, exposure to asbestos is now known to cause incurable diseases after a latent period of 20–50 years including pulmonary asbestosis, lung cancer with an unfavorable prognosis and malignant mesothelioma (Bahk et al., 2013; Doll et al., 1985). Because of this impact on health, asbestos use was gradually reduced from the 1970s onwards and by the early 1990s some countries started establishing laws and regulations to prohibit or limit the development of its use (Bahk et al., 2013; Kane, 1996; Nicholson, 2001). Despite its known ill effects, asbestos is still currently used in large quantities in many countries as a component of building materials, especially in the form of asbestos cement (Bhagia et al., 2010; Kazan-Allen, 2005; Le et al., 2010; Li et al., 2014). Korea, for instance, started importing asbestos in the 1960s. Peak use of about 95 thousand tons was recorded in 1992 but figures have consistently decreased since then (Kim et al., 2009). In 1990, when the Korean Occupational Safety and Health Act was revised, asbestos was added to the list of harmful substances for which permission must be sought before use. In 2009, Korea completely banned the use of asbestos with the revision of an enforcement decree of the Act (The Ministry of Environment of Korea Government, 2009). In addition, the country has established the Asbestos Injury Relief Act, and the Asbestos Safety

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http://dx.doi.org/10.1016/j.jclepro.2015.08.004
0959-6526/

Management Act, to regulate compensation for damage caused by asbestos and to control the safe handling of used asbestos (Kim et al., 2014).

Over 90% of the asbestos currently in use globally is used to manufacture asbestos cement sheets and pipes (Ramazzini, 2010). In Korea, about 96% of the imported asbestos in the 1970s was used in slates; in the 1990s this value dropped to 82% (Paek et al., 1998). In Korea, slates were manufactured using a mixture of about 90% cement and 10% chrysotile. All the slates produced were asbestos cement slates (Kim et al., 2010). Slate is generally not deemed harmful to health, since the asbestos fibers are strongly bound by the cement (U. S. Environmental Protection Agency, 1990). However, problems are caused when asbestos fibers are emitted into the environment through years of weathering (Bornemann and Hildebrandt, 1986). The levels of concentration of asbestos in the air around buildings with deteriorated slate roofs have been found to be very harmful to health (Spurny, 1989) Environmental or occupational exposure to asbestos increases the hazard of respiratory diseases, such as pulmonary asbestosis, lung cancer and malignant mesothelioma (Kamp, 2009; Mossman et al., 1996). In Korea, there has been at least one case of a resident of a slate building who was diagnosed with malignant mesothelioma and another of lung cancer occurring due to the emission of asbestos from slates (Jung et al., 2006). This is the reason why the Korean government is pushing for the removal and disposal of slates containing asbestos from buildings in Korea. The removal and disposal of such slates, however, will be a long-term project given that slate roofs are so common in buildings and that the cost of removing them is high. Considering the global trend of banning asbestos, its hazards and the difficulty of removing and disposing of slates, it is imperative to work out the rate of asbestos discharged naturally from slate in order to maintain and manage asbestos effectively. The amount of asbestos discharged naturally from slates indicates the amount of asbestos emitted from the surface of slates due to aging and influence of weather conditions. The researchers reviewed existing work to determine the amount of asbestos discharged naturally from slates. Bornemann and Hildebrandt (1986) reported that an older slate roof which has long been installed or a slate roof with a damaged surface emits asbestos fibers to the air at an annual average rate of 3 g/m^2 (Bornemann and Hildebrandt, 1986). Spurny (1989) reported that the surface of asbestos cement slates corroded due to weather changes at the rate of about 0.01–0.024 mm a year (Spurny, 1989). The findings of existing research, however, were not sufficient to estimate the amount of asbestos discharged naturally from slates using the approximate values acquired from the level of bonding between cement and asbestos and the analysis of soil or rainwater near the slate buildings. There were a number of studies on the hazards of asbestos and the release of asbestos from slates, but no research was found which quantified the amount of asbestos discharged naturally from slates.

In order to quantify the amount of asbestos discharged naturally from slates the researchers carried out field surveys. The researchers visualized the amount of asbestos discharged naturally from slates by district by applying the deduced formula to calculate the amount of asbestos discharged naturally from slates to buildings in Korea. The researchers also deduced the rate of increase to estimate the slate roof area of buildings on the basis of the Korean standards on slates and the regulations on construction of slate roofs. The researchers divided the whole country into 165 administrative districts in accordance with the urban management plan of Korea and estimated the area of slate-roofed buildings on the basis of 6830 thousand building registers which provide a summary listing of the buildings. The researchers created the database regarding the area of slate roofs in each administrative district in Korea by applying the increase rate of the slate roof area to the estimated slate-roofed building areas. Then, the researchers measured the thickness of slate and the age of 193 slate-roofed buildings in three regions which have average weather conditions in Korea. The thickness of slates was measured in micrometers and the ages of the slate roofs were acquired from the building registers. The researchers created a database based on the thickness and ages of the slates and conducted regression analysis with SPSS to deduce the formula to calculate the change of thickness of slate according to age. By applying the specifications of slate (thickness, density, content of asbestos, etc.) to the deduced formula for thickness change, the researchers were able to estimate the amount of asbestos discharged naturally per unit area of slate. Finally, by applying the formula to estimate the amount of asbestos discharged naturally per unit area of slate, to the database on the area of slate roofs of each administrative district in Korea, the researchers deduced the amount of asbestos discharged naturally from slates in the administrative district in Korea and then visualized the results using ArcGIS. This data is deemed to be very useful as a starting point for establishing measures to prevent damage from asbestos and for estimating hazards of cancer caused due to asbestos. The researchers also calculated the amount of asbestos discharged naturally from slates by administrative district of Korea, providing useful data based on which the government can select the priority regions for removing slates. The results of this study will also contribute to developing the methods, which could be used to estimate the amount of asbestos discharged naturally from slates according to different specifications of slates in different countries. Fig. 1 illustrates the flowchart for the procedures in this study.

2. Review and application of theories

The aim of this study was to develop a formula to calculate the amount of asbestos discharged naturally from slates and, thus, deduce the amount of asbestos discharged naturally for each administrative district in Korea. This section provides an overview of the studies which were reviewed in order to arrive at the formula which could be used to estimate the discharge of asbestos from slate roofs within specific building areas based on the specifications of the slate. This section also discusses the applicability of using the building registers to provide the requisite data on the building stock in Korea, and gives the specifications of the micrometer used to measure the thickness of slates during the field survey.

2.1. Overview of slate and building register

The asbestos-containing materials used in typical buildings in Korea include slate (outdoor roof material), tex (indoor ceiling finishing material), bamlite (indoor wall finishing material), gasket (facility joint) and asbestos cloth (fire-fighting sheath) (Bae et al., 2013). The asbestos-containing materials cause no serious problems in terms of asbestos emissions when they are used indoors since they are not exposed to damage caused by wind and rain. The asbestos used in the roofing material covering 1.26 million buildings - which is about 18.09% of all the buildings in Korea (Kim et al., 2011a) – is, however, potentially hazardous as it can be emitted into the atmosphere after prolonged exposure to rain, wind and other inclement weather conditions. In Korea, slates were manufactured by two companies, BYUCKSAN and KCC, in accordance with Korean standards. All slate products used in Korea contained asbestos (Kim et al., 2014). Slates are classified as small-corrugated slates or large-corrugated slates depending on the size of the corrugation. Large-corrugated slates are normally used in industrial