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Short Communication

Types and Health Hazards of Fibrous Materials Used as Asbestos Substitutes

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ABSTRACT

Asbestos has been banned in many countries but many countries, including developing countries, are still using asbestos or materials containing asbestos. Substitute materials have been studied and developed over a long period of time because of the hazards of asbestos, and many people have recently shown interest in the hazards of substitute materials. However, comprehensive information about the types of asbestos substitutes, their use and health hazards, and references for the protection for the health of workers is limited. The purpose of this study is to provide people in the related industries with information on the types and health hazards of fibrous materials that can be used as asbestos substitutes. According to the patent resources from the United States and Europe, fibrous materials have been used to develop asbestos-free products since before 1980. Recently, the health hazards of asbestos substitutes have been assessed and many additional researches are required. However, only some of the substitute materials have been assessed for health hazards, and health hazard data has not been sufficient in many cases. Therefore, efforts should be made to minimize workers' exposure to substitute materials that do not contain asbestos.

1. Introduction

The World Health Organization (WHO) estimates that about 125 million people are exposed to asbestos at worksites around the world, and more than 107,000 people die of asbestos-related diseases, including lung cancer, mesothelioma, or asbestosis, due to occupational exposure to asbestos [1]. Substitute materials have been studied and developed over a long period of time because of the hazards of asbestos, and many people have recently shown interest in the hazards related to such substitute materials.

Fibrous materials may be considered as an alternative to asbestos. There are many kinds of fibrous materials, which can be largely classified into synthetic fibers and natural fibers. Synthetic fibers can be classified into organic and inorganic fibers; synthetic organic fibers include polyamide fiber, polyolefins fiber, polyester fiber, polyurethane fiber, and polyvinyl fiber, and synthetic inorganic fibers include glass filaments, glass wool, refractory ceramic fibers, rock wool, and slag wool fiber. Natural fibers include natural organic fibers such as cotton and hemp and natural inorganic fibers such as attapulgite, erionite (*zeolite*), nemalite (fibrous brucite), sepiolite, and wollastonite [2].

According to patent resources in the United States and Europe, asbestos substitutes have constantly been developed since before 1980 [3–31]. An asbestos-free drywall joint compound was developed in 1975 [3], an asbestos-free tape sealant was developed in 1979 [4], and an asbestos-free friction material was developed in 1980 [5]. An asbestos-free gasket was developed in 1982 [7] and a method of manufacturing an asbestos-free glass fiber reinforced product was developed in 1983 [10]. Flexible sheet material suitable for use in the manufacture of asbestos-free gaskets was developed in 1985 [15] and a method of manufacturing aramid-containing friction materials in 1986 [16]. In 1996, a fiber-reinforced building material was developed using sepiolite [26]; in 2002, a press pad composed of an asbestos-free material was developed [29].

The International Social Security Association provides information on asbestos substitute materials through a technical report [32]. The report classifies types of asbestos use into eight categories which are raw asbestos in bulk, asbestos in powder, asbestos in liquid or pastes, asbestos in sheet or board, asbestos in woven or braided goods, asbestos in a resin or plastic matric, asbestos in cement, and asbestos in asphalt or bitumen. According to the report

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of the International Social Security Association, mineral wool and ceramic fibers can be used as an asbestos fiber substitute for insulation or soundproofing, while sheets and boards containing asbestos can be substituted with synthetic vitreous fibers or clay instead of asbestos, and textile containing asbestos can use polyethylene fiber, polypropylene fiber, polyamide fiber, carbon fiber, and glass fiber instead of asbestos. Asbestos cement products can use cellulose, polypropylene fiber, polyvinyl alcohol fiber, aramid, and glass fibers instead of asbestos. Cellulose, polypropylene fiber, polyvinyl alcohol fiber, aramid, and glass fibers can be used as an asbestos fiber substitute for asbestos cement products.

In addition to the development of asbestos substitute materials, a series of studies have also been conducted in regard to the hazards of fibrous materials. Erionite fiber, which is a mineral fiber, causes malignant mesothelioma and has been classified into Group 1 (carcinogenic to humans) by the International Agency for Research on Cancer (IARC) [33]. Also, refractory ceramic fibers are classified into Group 2B (possibly carcinogenic to humans) by the IARC [34] and Group A2 (suspected human carcinogen) by the American Conference of Governmental Industrial Hygienists (ACGIH) as it can cause lung fibrosis [35]. The WHO has assessed the hazards of 14 types of asbestos substitute materials, including para-aramid, attapulgite, and carbon fiber [36]. Also, Harrison et al [37] has discussed the health hazards of para-aramid, polyvinyl alcohol, and cellulose in comparison to chrysotile. According to this literature, the major characteristics related to the health hazards of fiber are its dose, dimensions (especially diameter), and durability. National Institute for Occupational Safety and Health has recently presented a research roadmap for a broad understanding of the health hazards of asbestos fiber and other elongate mineral particles [38]. This roadmap suggests that studies related to the toxic effect, occupational exposure, and development of methods of measurement and analysis of asbestos fibers and elongate mineral particles are required.

This study discusses the types of fibrous materials that can be used as asbestos substitute materials, the development of asbestos-free products, and the health hazards of fibrous materials to provide information for the protection of health of workers in the related industries.

2. Materials and methods

Literature on the types and characteristics of asbestos substitutes, the development status of asbestos-free materials, and the health hazards of asbestos substitutes was reviewed for this study. To examine the types and characteristics of asbestos substitutes, this study referenced literature on chemical and physical properties and morphology [2,3,11,13,26,31,33,34,39–41]. The resources on the development of asbestos substitutes referred to the cases of asbestos substitutes that have been certified internationally based on patent resources from the United States and Europe. According to the United States Geological Survey report on the worldwide asbestos supply and consumption, the United States and Europe imported more than 80% of worldwide asbestos production during 1920∼1960 [42], which caused high levels of asbestos-related disease in the United States and Europe [43,44]. As a result of searches on the patent site (Google patents, https://patents.google.com), there were many patents for asbestos substitutes in the United States and Europe. The development status of building materials, friction materials, gaskets, joint sheets, and fabrics that are free of asbestos was identified by patent resources [3–31]. Literature on the hazard assessment of asbestos substitutes has referenced hazard assessment report of asbestos substitutes prepared by the WHO through an workshop of expert group [36], IARC's carcinogen assessment resources on fibrous materials [33,34,39], and ACGIH's resources on threshold limit values (TLVs) [41]. The participants in the WHO workshop evaluated the health hazards and carcinogenicity of asbestos substitutes based on epidemiological evidence, studies in experimental animals, *in vitro* short-term tests, physicochemical properties, and biopersistence. The workshop decided to group asbestos substitutes roughly into hazard groupings of high, medium, and low. These hazard groups should be considered in relation to each other and did not have reference to formal criteria or definitions, as such. The IARC evaluated the carcinogenicity of some silicates and synthetic vitreous fibers based on studies of cancer in human, studies of cancer in experimental animals, physicochemical properties, persistence and biodegradability, other data relevant to evaluation of carcinogenicity and its mechanism. ACGIH evaluated the carcinogenicity of synthetic vitreous fibers based on studies of cancer in humans, studies of cancer in experimental animals, physicochemical properties, and other data relevant to evaluation of carcinogenicity.

3. Results

3.1. Types and characteristics of fibrous materials

The asbestos substitute materials known so far include synthetic fibers such as man-made vitreous fibers (synthetic vitreous fibers) and para-aramid and natural inorganic fibers such as attapulgite, sepiolite, and wollastonite. Man-made vitreous fibers refer to inorganic fibrous materials made with glass, rocks, minerals, slag, or processed inorganic oxides [34]. Para-aramid, which is a widely known asbestos substitute material, is a type of polyamide fiber similar to nylon fibers. This material is mostly used to improve the strength, durability, and heat resistance of synthetic materials. It is light enough to be used within the aviation and sports industries, and it is also used to reinforce fiber for synthetic materials, thermoplastic materials, tires, and rubber products. It is used as an asbestos substitute material for automotive friction materials and gaskets [39]. Natural inorganic fibers such as attapulgite, sepiolite, and wollastonite have been used as a substitute for asbestos in building materials and friction materials [3,11,13,26,31].

Attapulgite is a hydrated magnesium aluminum silicate mineral [40]. Attapulgite is elongated in structure and similar to the mineral structure of amphibole group. It is known as "palygorskite" in mineralogy, but it is more widely known as "attapulgite" [39]. Attapulgite has been used as an asbestos substitute material for building materials and friction materials as asbestos has been found to be hazardous [3,13].

Sepiolite is a clay mineral composed of hydrated magnesium silicate. Structurally, it is similar to attapulgite, but it has one more SiO_4 tetrahedron when compared to attapulgite. Sepiolite is an elongated and lath-like structure of crystals. The length of fibers varies according to the location of sepiolite sediments [39]. The elongated particles of sepiolite improve its usability as a viscosity improver and sedimentation preventer.

Wollastonite is a calcium silicate mineral that is chemically inert, but it can be decomposed in concentrated hydrochloric acid. With its unique cleavage property, it breaks into thin lath-like shapes or needle-like particles. Wollastonite is mostly used for ceramic, plastic, rubber, asbestos substitute, paint, and coating products, and wollastonite with a high aspect ratio (10: 1 to 20: 1) is used to reinforce plastic and rubber and as a functional filler and an asbestos substitute material [39].

Erionite is a fibrous hydrated aluminosilicate mineral in the zeolite group. Erionite is similar to amphibole in shape, but it has different physicochemical structures. Erionite exists in the form of a

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