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General Research Paper

The Mineral Fibre: Asbestos - Its Manufacture, Properties, Toxic Effects and Substitutes

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ABSTRACT

The primary useful properties of asbestos fibre are its outstanding thermal stability and very high tensile strength. Moreover, because of its abundance and performance quality, it is used in the manufacture of more than 3000 products including textiles, building materials, insulation and brake linings. Ironically, its one of the main strengths of asbestos, but it's fibrous nature is also its greatest weakness. Asbestos fibres are subdivided into fibrils and since they never rot, are very harmful if breathed into the lungs. All forms of asbestos fibres are scientifically proven to be carcinogenic. Though there is no single and better substitute for asbestos fibres, alternative materials are being used due to the health hazards involved in asbestos manufacture and use.

INTRODUCTION

Asbestos is the name given to a group of mineral fibres that are formed in rocks and has been known since ancient times, though originally more as an object of wonder and curiosity than as a useful item of commerce. The name asbestos comes from the Greek word meaning, "will not burn", "indestructible" or "unquenchable" in reference to its resistance to fire and heat. The Greeks called asbestos the 'magic mineral'. However, asbestos has been known by many other names including "mountain leather", "incombustible linen", and "rock floss" (Bowles 1946).

ASBESTOS USAGE IN ANCIENT AND MEDIEVAL AND MODERN TIMES

Asbestos was a well known substance to the ancient Greeks and Romans. Anecdotes about its use have been reported by many, namely Pliny the Elder (The Roman Historian/Naturalist around 79 BC.) and Marco Polo (around AD 1250). However, early evidence of its use to strengthen clay pottery as long as 2005 BC has been found in Finland. The geographer in the first century identified what has believed to be the first asbestos quarry on the Greek island of Evvoia (Gross & Braun 1984, Selikoff & Lee 1978, Bowles 1946).

The Greeks are known to have woven the asbestos fibre into lamp wicks for their temples as early as the 5th century BC. According to Pliny, shrouds of asbestos were made for wrapping royal bodies, to prevent their ashes mingling with those of wood or other combustible materials commonly used in funeral pyres. Hence, asbestos became known as the funeral dress of kings.

In medieval times asbestos was used extensively in suits of armour. Unscrupulous merchants made crosses from the mineral and sold them as pieces of Christ's Cross.

Though the indestructible and fireproof qualities of asbestos were well appreciated, it was not until the 1800s that asbestos found place as a useful item of commerce. Asbestos was a natural choice because of its abundance and performance quality namely flameproof, durability and excellent insulating properties.

Towards the end of the 19th century, the use of asbestos became even more widespread as a result of the industrial revolution. Asbestos was used in the manufacture of more than 3000 products including textiles, building materials, insulation and brake linings.

CHEMICAL COMPOSITION AND TYPES

Asbestos is a generic term, refers usually to six kinds of naturally occurring fibrous materials. It is composed primarily of silica, magnesium and water. Depending upon physical properties and structure, its types are classified into two distinct mineral groups: (i) the amphiboles and (ii) the serpentines.

The amphibole: Amphibole asbestos form crystalline fibres, those are more brittle than serpentine asbestos and are more limited in being fabricated. Amosite (The word amosite was coined from 'Asbestos mine of South Africa', from the

'Amosa Mine'), Crocidolite, Anthophyllite, Tremolite and Actinolite are all members of the amphibole group. For the amphibole class of asbestos, the polymeric structure consists of a linear double chain. These chains crystallize into long, thin, straight fibres, which are the characteristic structure of this type of asbestos group.

The amphibole structure is formed by Si-O-Si chains. The chains are connected by other elements like Na, Mg, Ca, and Fe. These fibres have a diamond-shaped cross-section. They are less flexible than serpentine fibres and they tend to split into small, very sharp splinters.

Amphibole fibres generally are more variable in width and less symmetrical than chrysotile (serpentine) fibrils. Franco et al. (1977) examined samples of crocidolite whose fibre width range from 50 to 150 nm, although widths of up to 350 nm also have been reported for other samples. Lengths of fibre bundles up to 8 cm for crocidolite and 30 cm for amosite have been reported (Virta 2006, Selikoff & Lee 1978).

The serpentine: Serpentine asbestos process relatively long and flexible crystalline fibres that is capable of being woven. For the serpentine class, the polymeric form is an extended sheet. This extended sheet tends to wrap around itself forming a tubular fibre structure. These fibres are usually curved "serpentine", in contrast to the straight morphometry of the amphibole. Chrysotile is the only member of serpentine group of minerals. The name chrysotile is derived from the Greek words "Chrysos" (gold) and "tilos" (fibre) or "gold fibre". This mineral fibre has a layered structure, made up of SiO_4 tetrahedral and $Mg(OH)_2$ layers. The mismatch between the two types of layer is responsible for a curvature in the structure and forms a tubular fibre structure. The connections between the layers are weak, giving the chrysotile asbestos fibres a great flexibility.

Chrysotile fibres can be extremely thin, the unit fibre having an average diameter of approximately 25 nm. Commercial grades of chrysotile fibres are aggregates of these unit fibres; their lengths range from a fraction of a millimetre to several centimetres, though most of the chrysotile fibres used are shorter than 1 cm (Roberta 2004, Virta 2006, Bowles 1946, Selikoff & Lee 1978).

The different kinds of asbestos, though all contain long chains of silicone and oxygen, vary in physical and chemical properties, depending on the other components of the rock, such as calcium, magnesium or iron. Unlike most fibres that break in half the long way, all asbestos fibres split down the middle like a hair splitting.

It should be noted that most asbestos minerals also occur in non-fibrous or non-asbestiform forms with identical chemical compositions. These non-fibrous minerals, which are not asbestos are much more common and wide spread than the asbestiform varieties and both the forms of mineral may occur in the same deposits. The reason being very likely that the temperature and pressure might be sufficient to metamorphose completely some but not all of the igneous rock into the asbestos form. In the case of anthophyllite, actinolite and tremolite, the word "asbestos" is added after the mineral name to distinguish it from the non-asbestos form. Chrysotile, crocidolite and amosite do not require "asbestos" to be added because the non-asbestos forms have different names. OSHA (The Occupational Safety and Health Administration) defines an asbestos fibre for counting purposes as a particle with a length >5 μm and a length:width

Table 1: Basic chemical and physical data.

	Serpentine	Amphibole				
	Chrysotile	Crocidolite	Amosite	Anthophyllite	Tremolite	Actinolite
Empirical Formula	$Mg_3Si_2O_5(OH)_4$ $Si_8O_{22}(OH)_2$	$Na_2Fe_2(Fe,Mg)_3$ $O_{22}(OH)_2$	$(Fe,Mg)_7Si_8$	$Mg_7Si_8O_{22}(OH)_2$ $(OH)_2$	$Ca_2Mg_5Si_8O_{22}$ $O_{22}(OH)_2$	$Ca_2(Mg,Fe)_5Si_8$
Relative Molecular Mass	277.13g	1,008.82g	1,171.83g	780.88g	812.42g	1,091.67g
Density	2.2-2.6 g/cm^3	2.8-3.6 g/cm^3	2.9-3.3 g/cm^3	2.8-3.2 g/cm^3	2.9-3.2 g/cm^3	3.0-3.21 g/cm^3
Melting Point	1,500^{0}C	1,200^{0}C	1,400^{0}C	1,450^{0}C	1,315^{0}C	1,400^{0}C

Sources: Volume III: Compendium of environmental standards, Documentation on monitoring and evaluating environmental impacts, German Federal Ministry for Economic Cooperation and Development, Germany.

Colours of Different Types of Asbestos					
Chrysotile	Crocidolite	Amosite	Anthophyllite	Tremolite	Actinolite
White, gray green yellowish	Lavender, blue, green	Brown, grey greenish	Gray, white brown-grey, green	White* to pale green	Green*

* Tremolite and actinolite form a continuous mineral series in which Mg and Fe(II) can freely substitute with each other. With increasing iron content, the colour of tremolite, typically creamy white, takes on a greenish cast.

ratio (aspect ratio) > 3:1. It should be noted that other agencies use different definition of asbestos fibres for counting purposes. For example, EPA (Environmental Protection Agency) defines a fibre as any particle with aspect ratio >5:1 when analysing bulk samples for fibre content.

Asbestos is widely distributed, but the largest deposits are found in former Soviet Union, Canada, South Africa and Australia. Now-a days, chrysotile is the only asbestos mined for its commercial value. Production worldwide has decreased greatly since 1975 and most developed countries have now outright bans on the use of asbestos because of concern regarding health effects.

Chrysotile occurs in large quantities, and its commercial deposits are more widely distributed than those of amosite, anthophyllite asbestos, crocidolite, and tremolite asbestos. Chrysotile usually has soft fibres that are less harsh than the amphibole varieties of asbestos and also has other properties that make it well suited for most asbestos applications. Chrysotile accounted for about 96% of world asbestos production and consumption between 1900 and 2003. Crocidolite accounted for 2.2%, amosite for 1.6%, and anthophyllite and tremolite asbestos varieties for less than 1% of production and consumption (Virta 2006, Roberta 2004).

PROPERTIES AND USE OF ASBESTOS FIBRE

Asbestos fibre are basically chemically inert, or nearly so. They do not evaporate, dissolve, burn or undergo significant reactions with most chemicals. In acid and neutral aqueous media, magnesium is lost from the outer brucite layer of chrysotile. Amphibole fibres are more resistant to attack by alkalis (WHO 2006).

The primary useful physical properties of asbestos are its outstanding thermal stability and very high tensile strength. It can melt, but only at 1450°-1500°C (2580°-2670°F), the temperature of lava in a volcano (Humphires 1996). Its tensile strength surpasses that of steel. It is flameproof, rustproof, and has low electrical and thermal conductivity. Because of these superior properties, asbestos has been widely used in construction and insulation materials. Asbestos can be broken into very fine fibres, which can be spun and made into textile fabrics that are used in making fire-fighting suits and fire-resistant fabrics, and in fire-proofing materials of many types, namely, theatre curtains, draperies, shingles, tiles, auto brake lining and partitions. It is spun around copper wire and wrapped around pipes and joints of high-pressure steam engines. Inferior grades are used for soundproofing (Corbman 1998).

EXTRACTION OF FIBRES

Asbestos deposits are found underground, and the ore is brought to the surface for processing using conventional mining practices. The two most common amphiboles-amosite (often referred as "brown" asbestos) and crocidolite (often called 'blue' asbestos) are mined underground. Chrysotile (often referred as "white" asbestos) usually found near the surface and can be mined from open pits.

After the rock is removed from the pits, it is crushed and dried before being transported to a mill. The rock is dried by exposure to the air and sun or by using furnaces. It is then fractured mechanically in a mill and the fibre is separated from the rock on a series of screens after which it is graded, tested and bagged.

Domestically, in US, the asbestos fibres are classified into seven quality categories on grades. Grades 1, 2, and 3 include longer, maximum strength fibres and generally used in the production of textiles, electrical insulation, and pharmaceutical, and beverage filters. Grades 4, 5, and 6 are medium length fibres used in the production of asbestos-cement pipes and sheets, clutch facings, brake linings, asbestos paper, packaging, gaskets, and pipe coverings. Grade 7 includes short fibres generally used as reinforces in plastics, floor tiles, coating and compounds, some papers and roofing felts (OSHA 1986).

MANUFACTURING PROCESS OF ASBESTOS TEXTILES

For the manufacture of asbestos textiles, the longest chrysotile fibres are used and undergo the standard textile production technique such as carding, combing, and spinning of the fibres.

There are two basic processes involved in asbestos textile manufacturing: [1] the conventional process, used to manufacture most asbestos textile and [2] wet processes.

Conventional Process to Manufacture Asbestos Textile

Fiberizing and blending: The fibre is first debagged, followed by fiberizing and blending. Depending on the type of fibre being processed and the type of cloth desired, as well as the specific manufacturing operation itself, different methods will be used to fiberize (open and soften) asbestos strands before they can be further processed. Fiberizing can be achieved through the use of a machine (for example, Kollergang) that utilizes a wet or dry method to crush and spread asbestos fibres before they move on to additional fiberizing machines such as a Willow or Creighton opener, both of which rely on a variety of mechanical processes designed to further spread asbestos fibres for optimal volume and softness. Once fiberized, the asbestos strands can be blended with a variety of the fibres as desired.

Blending can be done by the following methods: 1. floor blending, 2. rotary mixer, 3. hopper feed blending, and automatic blending. Floor blending is a traditional method of producing blends of various types and grades of fibre by placing layers of the blend components uniformly one above the other. Material is withdrawn from the pile by taking vertical slices. Every slice removed contains the correct amount of each material. Belt blending is a variation of this method where after opening the fibre grades and types are placed on a conveyer belt. When the correct number of layers is deposited on the belt, the belt is started to feed the hopper for the card. Both these blending methods are extremely dusty and workers must wear protective clothing (disposable or washable overalls) and personal HEPA respirators at all times and also, before leaving the mixing room, the fibre adhering to clothing and shoes must be removed by vacuum equipment. Dust control with the above methods or their modifications is extremely difficult. Hence, they are often replaced by automated mechanical devices, such as blending drums or single and multi-hopper blending units.

Carding: Subsequent to fiberizing and blending, the fibre is fed to a carding machine, which utilizes a series of rollers and blades to further separate asbestos fibres while aligning them in parallel rows, to produce a uniform sheet or lap. In the process, impurities and dust are removed. The carding process includes the three basic functions: working, stripping and brushing. The working action is the chief means by which the asbestos blend is opened and turned into a uniform web. The entire sequence of action is a complicated process involving many parts of the card.

Roving: During carding, the fibre is continuously refined through the removal of impurities such as rock fragments, soil, dust, etc. before the material is formed into web shaped sheets or laps. From these sheets ribbon-like strips are cut and then bundled into fibrous strands that are known as roving. Cotton, rayon or other material may be added at this stage to strengthen the roving.

Spinning: The purpose of the spinning process is to impart a greater twist to the roving. Roving which has been mechanically twisted and spun to give it greater tensile strength, forms a single yarn. The spinning process is typically facilitated by either a ring frame or flyer frame spinning machine, both of which serve to provide the roving with a specified diameter and tensile strength in a finished yarn suitable for weaving into cloth. In the doubler process, two or more yarns and possibly wire are combined and twisted into stronger yarn.

In preparation for weaving, the weft is prepared by re-spooling for the shuttle on the loom. The warp is prepared in a variety of ways. Equipment used in the wool industry is most suitable for this particular purpose.

Weaving: Asbestos yarn is eventually woven into a wide variety of textile products through the use of equipment that is much the same as the machinery used to weave cotton and wool. Two types of weaving, namely creel weaving and beam weaving, are used in the asbestos industry. The former obviates the re-spooling of the weft and warp because weaving can be done directly from the spinning bobbins. A variety of looms can be used to weave a broad spectrum of textile products.

Finishing: Subsequent to weaving, the asbestos-containing fabric is ready for washing, colour dyeing, pre-shrinking, decorative design imprinting, special finish coating applications, etc. The asbestos textile product will next be cut into a variety of standard sizes before being spooled or flat stacked for shipment to numerous finished product manufacturers, wholesalers, retailers, and end users (www.asbestosinstitute.ca).

Wet Process to Manufacture Asbestos Textile

In wet process single filament fibres are produced by extrusion. The process comprises of making a gelatinous mixture of fine asbestos fibres in water with a volatile dispersant. The mass is then extruded through small dies to form asbestos thread. The extruded thread is spun to form yarn which is fabricated into various products as in the conventional process.

HEALTH RISKS OF ASBESTOS

The fibres subdivide to fibrils and, since they never rot, are very harmful if breathed into lungs (Humphries 1996). All forms of asbestos fibres are scientifically proven to be carcinogenic. They can cause 'asbestosis' (serious scarring of the lung), lung cancer, pleural and peritoned mesothelioma (tumors of the membranes lining the chest, abdominal cavities and surrounding internal organs), and other cancers. The primary routes of potential human exposure to asbestos are inhalation and ingestion. Dermal absorption of asbestos is minimal, but dermal contact may lead to secondary ingestion or inhalation of dust. The most significant asbestos exposure is in the workplace. People who work in asbestos mining and industry are more susceptible to exposure to asbestos fibres and therefore to develop asbestos-related diseases. Clinical reports show that asbestos induced diseases can take as long as 20-40 years to develop.

According to a study by the late pioneer researcher, Dr. Irving Selikoff, it is estimated there have been nearly a half million deaths to date since epidemiological studies began in the early 1900's. Currently, there are approximately 10,000 asbestos related deaths per year, worldwide. The volume is projected to remain at that level until the year 2015 (Onderick 2010, LaDou 2010).

The health hazards posed by asbestos led France to ban all forms of asbestos in a decree of 24Dec. 1996. The decree bans the production, transformation, sale, import and marketing of asbestos and asbestos made products, with certain exceptions for applications for which safer substitute do not yet exit.

EU ban on asbestos: On 26 July 1999, the legislative adjustment of Annex 1, directive 76/769/EEC on hazardous substances and preparations banned the marketing and use of chrysotile (white) asbestos, among the member states of the EU. The other five types of asbestos had already been banned earlier in 1991. The amended directive specifically imposed a complete ban on the introduction and use of chrysotile asbestos in cement materials, friction products, seals and gaskets across the 25 member EU, which was fully implemented across Europe by 1st Jan 2005. The only exception to the ban is the use of chrysotile in diaphragms which are used for electrolysis in certain chlorine plants. In this case, a substitution would be hazardous as it would increase the risk of explosion. This derogation was to be reviewed in 2003 and 2008 in the light of scientific progress. The EU directive said "No threshold level of exposure has yet been identified below which chrysotile asbestos does not pose carcinogenic risks-an effective way of protecting human health is to prohibit the use of chrysotile asbestos fibres and products containing them".

On June 22, 2009, the European Commission adopted a regulation that amends Annex XVII, of the REACH (Registration, Evaluation, Authorization and Restriction of Chemicals substances). One provision concerns asbestos. The commission maintains the possibility of using diaphragms containing asbestos in existing electrolysis installations.

The revised Annex XVII also contains a new provision that authorizes the placing on the market of articles containing asbestos under rules that could vary from one country to the next. The only condition laid down is that such articles must have been "installed and/or in service before 1st January 2005 under specific conditions ensuring a high level of protection of human health (www.europarl.europa.eu).

Impact of EU ban on third-world countries: The EU ban on asbestos saw a shift of the commercial activities of asbestos to third-world countries. Though the use of asbestos decreased significantly in the developed countries, it has escalated in developing countries despite of the clear scientific and clinical evidence on the health dangers of asbestos fibres. According to the British Geological Society, the sales of asbestos to Asia rose from 661,000 metric tons in 1970 to 1,137,000 metric tons in 1995. Its popularity may be due to the cost-saving production of unprocessed asbestos that yields high profits for the asbestos mining companies and multinational companies that create a global market for asbestos products, beliefs International Federation of Building and Wood Workers. Laurie Kazan-Allen said, "Multinational asbestos corporations present a deplorable history of international exploitation". These firms have opened large and profitable internal and export markets in Brazil and elsewhere in South America, and in India, Thailand, Nigeria, Angola, Uruguay, Mexico, and Argentina. Considering that most of the world production of asbestos, is used within third world countries, the European Trade Union Confederation (EUTC) calls for an international ban on asbestos and condemns the export of asbestos waste to countries outside EU.

The Collegium Ramazzini, an International Academic Society that examines critical issues in occupational and environmental medicine, reported that Asbestos is banned in 52 countries (Collegium Ramazzini; IBAS 2010), including all EU member countries, and safer products have replaced many that were once made with asbestos. Unfortunately, a much larger number WHO member countries still use, import, and export asbestos and asbestos-containing products. These are mostly developing countries, and over 70 percent of the world production of asbestos is used today in Asia and Eastern Europe, in countries desperate for industrial growth and often naive to the health effects of occupational and environmental exposures to asbestos (WHO 2006, Collegium Ramazzini, IBAS 2010).

ASBESTOS SCENARIO IN INDIA

In fact, it was in view of the adverse effects of asbestos mining on the health of the workers that the central government directed the state government in 1986 not to grant any new mining lease for asbestos (including chrysotile variety) in the country. In June 1993, the central government stopped the renewal of existing mining leases of asbestos. The ban was imposed in phases in 1986 and 1993 but not on its use, manufacture, export and import. Vast development in Asia is largely responsible for maintaining the chrysotile asbestos market. In particular, India's asbestos industry is burgeoning (Burki 2010).

Despite of the EU Ban, India continues to use white asbestos due to a number of reasons. In a developing country like India, manufacturing of asbestos products create jobs. Moreover, asbestos cement sheets lend themselves to rapid construction and particularly useful for light weight housing and industrial buildings. The use of asbestos cement sheets in pipes and sheets does not require a large, highly-trained labour force, the equipment required for their manufacture is very simple and often locally available and withstand surges unlike plastic pipes, particularly in case of intermittent water supply. Other major factor for the use of asbestos and asbestos-made products for a developing country like India is that, it is not commercially viable to go in for expensive substitutes and there is also very little public knowledge about the dangers posed to the human health by asbestos.

In India, alarmed at the continuing usage of asbestos and asbestos made products, Ban Asbestos Network of India (BANI) has been launched to raise public awareness about the dangerous consequences of asbestos (Down to Earth 2005).

ASBESTOS SUBSTITUTES

No better substitute material has been found or manufactured, that is as versatile as asbestos and combines all the qualities and technical performances of asbestos. However, as a consequence of the prevalence of use, exposure and the health hazards involved in it, asbestos fibres are being replaced by various substitute fibres, both natural and man-made. The following are few asbestos substitute materials used by many manufacturers worldwide.

Polyurethane foams: Spray polyurethane foams can be used in any type of structure and these products are extremely safe in that they emit no harmful gases. Its composition can be adjusted depending on the preferred uses which facilitate multi-tasking. One form of this material, known as flexible polyurethane foam, is used more frequently in consumer products namely furniture, bedding, carpet, cushion, packaging and automotive parts.

Amorphous silica fabrics: These fabrics are highly heat resistant materials, and do not rot or mildew and used for a wide range of insulation and protection applications in industries such as ship building, aerospace, electrical, metallurgy and automotive services.

Cellulose fibre: Cellulose fibre contains adhesive characteristics and is often made to be water-soluble. It is one of the most popular alternatives to asbestos cement. Cellulose fibre is often made from cotton, wood pulp, linen or shredded paper products. Chemically treated to increase fire resistance and reduce mold, cellulose fibre is generally made of 85 percent recycled content, making it another viable green option.

Thermoset plastic flour: Thermoset plastics can be filled with wood flour and other low-priced fillers to reduce cost and provide a balance of good insulation and strength. It provides similar benefits to asbestos without putting the user at risk, making its use widespread in construction.

Flour fillers: Flour fillers that are made of natural materials such as rice flour, pecan shell, wheat flour etc. can be used to fill in the cracks and crevices in a structure that aid in insulation and may be used as an alternative to asbestos filler. Being entirely natural, they are ecological and pose no hazards to those who are exposed to them (www.asbestos.com).

CONCLUSION

Notwithstanding its ill effect, the Indian asbestos market has grown, primarily because it serves the poor. In India, asbestos products carry no health warnings, lacks official attention and also the trade unions have no mandate to prevent asbestos-related diseases at workplaces. With continued use of asbestos, this problem will likely to worsen over time, until proper regulations or bans on asbestos containing materials come into place and protect asbestos-exposed individuals. Safer substitutes for asbestos products are often more expensive than asbestos. However, this additional cost must be considered in the light of the enormous cost of asbestos related diseases in the world.

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