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Airborne Polyvinyl Alcohol (PVA) and Cellulose Fibre Levels in Fibre-Cement Factories in Seven European Countries

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Because of their relatively high diameter, polyvinyl alcohol (PVA) fibres, as used in fibre-cement, are not fibres as defined by WHO (or other) regulations. Nevertheless, as with all particulate raw materials, it can be questioned if and to what extent particles with critical fibrous dimensions might be generated by the handling or machining of this material. In order to investigate any tendency of PVA fibres to release airborne particles with critical fibrous dimensions (WHO fibres), static and/or personal samples were taken in eight fibre-cement factories at locations where potential exposures to PVA fibres were expected to be the highest. The following locations were surveyed: the PVA fibre weighing station, where PVA bales are opened mechanically and the PVA fibres are dispersed and weighed in a dry state; the fibre-cement slate punching machine; the slate 'riven edge' cutting machine or sheet sawing machine, whichever was present in the respective factories. Since cellulose fibres are an important constituent of fibre-cement, the organic fibre concentrations observed at the machining operations include cellulose. At each factory a control sample was taken in open air. Sampling, sample preparation and sample analysis by scanning electron microscopy (SEM) were performed according to standard German procedures. Only very low number concentrations of organic WHO fibres, ranging from below detection limit to 0.006 f/ml, were found. These levels are lower than the typical levels of organic fibres commonly found in the normal personal environment (0.009–0.02 f/ml), stemming from the release of particles by a person's activities and from clothing and other textiles (bed sheets, blankets, pillow,...).

We conclude that the handling of PVA fibres as well as the machining of PVA and cellulose fibre containing cement products in the fibre-cement factories surveyed have a low potential to release fibres with critical fibrous (WHO) dimensions.

Keywords: polyvinyl alcohol; cellulose; fibre-cement factories; WHO-fibres; SEM

INTRODUCTION

The use of asbestos has been banned from the workplace in many countries because of the established adverse health effects of asbestos fibres. Alternatives for asbestos have been found and are now readily available. The main substitutes for chrysotile include the man-made vitreous fibres (MMVF), such as glass fibres, rock and slag wool, but also man-made organic fibres, such as polyvinyl alcohol (PVA) fibres and other synthetic materials, as well as natural organic fibres (Hodgson, 1993). As synthetic organic fibres, PVA fibres lack the microfibrillar structure, fire resistance, high thermal and chemical stability of asbestos. Nevertheless, most West-European fibre-cement manufacturers now use PVA and cellulose as the main organic fibrous constituents in fibre-cement, because of these materials' high tensile strength and adhesion with cement (Harrison *et al*., 1999).

Apart from an epidemiological study by Morigana *et al*. (1999), little or no information is available in the scientific literature regarding the health risks associated with occupational exposures to PVA fibres.

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Two important aspects must be considered when assessing the risk of a chemical agent. The first aspect is the evaluation of the hazard of the chemical, i.e. its toxic properties and dose–response relationships, and the second consists in evaluating the potential and extent of exposure.

Although the parent material (PVA) has been used extensively, the published toxicological information on PVA-fibres is relatively sparse. PVA was first produced in the 1930s and commercial production started in 1950. In the USA, the use of PVA is allowed by the Food and Drug Administration for food packaging purposes. Other major consumers of PVA are the textile and paper sizing industries. Furthermore, PVA has been used for medical purposes in surgical drapes, towels, and gauze sponges; protective gloves; cosmetic formulations; topical ophthalmic preparations; plastic sponge implants for reconstructive surgery; and intravaginal contraceptive foam and film (NTP, 1998). As a chemical substance PVA was evaluated by IARC in 1979 and classified in Group 3, i.e. non classifiable (IARC, 1979). In an in vitro test using Chinese hamster lung cells, PVA fibres showed neither cytotoxicity, nor induction of chromosomal aberrations (Hatano Research Institute, 1999). Like the other available organic fibres, but unlike several mineral fibres, PVA fibres are classified neither as a carcinogen, nor as a suspected carcinogen (ACGIH, 2000; HSE, 1999; MAK Kommission, 2000; IARC, 1979).

The definition of ‘fibres’ in most, if not all, health-related regulations is restricted to the WHO definition, whereby fibres are particles with a length >5 μm, a diameter <3 μm and a length to diameter ratio of more than 3. Experts of the World Health Organization regarded such fibrous particles as ‘critical fibres’, here called ‘WHO-fibres’ (WHO, 1986). As pointed out by Harrison *et al*. (1999), fibre levels observed in industrial applications such as asbestos-free fibre-cement production are reported to be very low but, so far, little of this has been published and most of the measurements were by optical microscopy. Those optical microscopy results, however, still might include mineral fibres and, moreover, the proportion of organic fibres cannot be determined. For this reason, it is not known whether and to what extent organic fibres with critical (WHO) dimensions are generated in the fibre-cement industry during the handling of PVA fibres as a raw material, as well as in subsequent finishing of the final products. These subsequent stages also involve exposure to cellulose fibres.

To provide answers to this important question, the present paper reports on organic fibre exposure data obtained from SEM-based measurements made in eight fibre-cement factories in seven European countries.

MATERIALS AND METHODS

Sampling

Between the middle of 1998 and early 1999, WHO fibre concentrations were measured in eight fibre-cement factories in seven European countries: two factories in France (Rennes, Vitry) and one factory in each of the following countries: Austria (Vöcklabruck), Belgium (Kapelle-op-den-Bos), Germany (Leimen), the Netherlands (Goor), Switzerland (Niederurnen) and the United Kingdom (Meldreth). In all these factories the use of asbestos had ceased in previous years. The measurements (sampling, analysis, reporting) were performed by the Gesellschaft für Schadstofmessung und Auftraganalytik GmbH laboratory (GSA, Neuss-Norf, Germany). At each factory, 3–4 samples were taken, of which at least one sample was taken at or in the fibre weighing station. One or two samples were taken at the stations where PVA and cellulose fibre containing cement products are machined (collectively referred to hereafter as ‘machining stations’). These machining operations consisted of the fibre-cement slate punching machine (where the large fibre-cement sheets are punched to slates), the corrugated sheet sawing machine, the corrugated sheet demoulding machine or the slate ‘riven edge’ cutting machine, whichever was present. All sampling at the workplaces was performed according to a standardized German procedure (ZH/120.46b, 1991), with a sampled volume of at least 40 l. per cm^2 filter surface, and a sampling duration of about 2 h. Both static and personal samples were obtained. The static samples were taken at 1 m distance from the above mentioned installations at the side at which the operators were located. The personal samples were collected in the worker’s breathing zone. During the measurements, care was taken that at all workplaces normal quantities of raw materials or final product were handled.

In each factory, a control sample was taken in open air away from the workplaces, but still within the premises of the factory. Such samplings in open air were performed according to the German VDI-guideline 3492, Part 2 (VDI, 1994), with a sampled volume of >1 m^3/cm^2 filter surface and a sampling duration ranging from 4 to 8 h. All samplings were carried out using gold-precoated Nucleopore filters with a pore size of 0.8 μm and a diameter of 25 mm.

Analysis

The filters were analyzed by a scanning electron microscope (SEM), according to VDI-guideline 3492 (VDI, 1994), with the exception that the filters were not ashed after the sampling in order to retain the organic fibres. Operating at a 2000× magnification, at least 100 WHO fibres or a filter surface of at least 1 mm^2 were counted, whichever was achieved first. The fibres were categorized into the following categories: asbestos, calcium sulphate (gypsum), and ‘other inor-

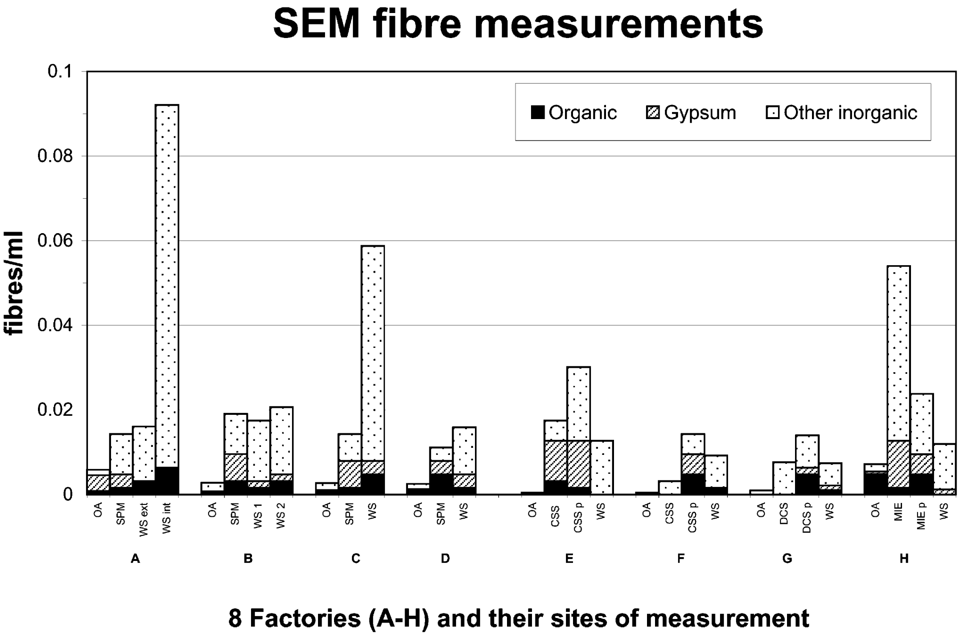

Fig. 1. Abbreviations: OA: open air, SPM: sheet punching machine, WS: weighing station, CSS: corrugated sheet sawing, DCS: demoulding corrugated sheets, MIE: MIE punching machines, p: personal sampling, ext: exterior, int: interior.

ganic' fibres. In addition the class 'organic fibres' was included (Schneider *et al.*, 1996). It should be noted that this category contains PVA fibres, as well as cellulose and other organic fibres, including those originating from clothing, since electron microscopic as well as other available techniques are unable to reliably identify organic fibre types.

Detection limits of these standard measurement methods are between 0.001 and 0.002 f/ml for the workplace measurements and about three times lower for the outdoor measurements.

RESULTS

Figure 1 presents the results of the measurements of WHO fibres taken in the eight different factories in chronological order of measuring. Table 1 presents the median (f/ml) and the range of all fibre types, in the various areas where sampling was carried out, i.e. open air, weighing station and machining stations (with the personal samples being reported separately). In the open air, the concentrations of organic fibres ranged from below the detection limit to 0.0049 f/ml with a median of 0.0007 f/ml. Within the factories, 14 of the 18 static measurements gave concentrations of airborne organic fibres above the detection limit ranging from 0.0011 to 0.0064 f/ml, with overall median values of 0.0016 f/ml for the weighing, as well as for the machining stations. There were no consistent differences between levels measured at the weighing stations and those measured at the machining operations. Values obtained from personal sampling had a median of 0.0048 f/ml, as compared with the measurements obtained by static sampling in the

Table 1. Median and range of all fibre types

Fibre types/Sampling points	Organic (fibres/ml)	Gypsum (fibres/ml)	Other inorganic (fibres/ml)
Open air (8 measurements)			
Median	0.0007	0.0002	0.0013
Range	0–0.0049	0–0.0038	0.0001–0.0021
Weighing stations (10 measurements)			
Median	0.0016	0.0011	0.0128
Range	0–0.0064	0–0.0032	0.0053–0.0858
Machining stations — static (8 measurements)			
Median	0.0016	0.0048	0.0070
Range	0–0.0048	0–0.0111	0.0032–0.0413
Machining stations — personal (4 measurements)			
Median	0.0048	0.0048	0.0110
Range	0.0016–0.0048	0.0016–0.0111	0.0048–0.0175

corresponding jobs with a median of 0.0008 f/ml. No asbestos fibres were detected in the measured samples. The detection limit together with the fact that these factories are not located in urban environments, explains why no asbestos fibres were observed. Gypsum fibres were found in most samples (ranging from below the detection limit to 0.0111 f/ml) and these were less numerous in the open air (median of 0.0002 f/ml), than inside the factories, where levels were generally higher in the air at the machining stations (median of 0.0048 f/ml), than at the weighing stations (median of 0.0011 f/ml). Other inorganic fibres were found in all samples, with airborne concentrations being lowest in the open air (median of 0.0013 f/ml) and higher inside the factories, where levels were highly variable and with no significant differences between weighing (median of 0.0128 f/ml) and machining stations (median of 0.0070 f/ml). For both gypsum and other inorganic fibres, the quantities found in personal samples were comparable to those found in samples collected statically from corresponding areas.

DISCUSSION

Worldwide, reference methods and regulatory exposure limits regarding workplace fibre levels consistently refer to fibres with critical dimensions as defined by WHO (1986). In the present study, we report on the extent to which such WHO-fibres are generated during the handling of PVA fibres, as well as the machining of products containing PVA and cellulose fibres, as used in the modern fibre-cement production process.

All the measurements (sampling, analysis, reporting) were performed by the Gesellschaft für Schadstofmessung und Auftraganalytik GmbH laboratory (GSA, Neuss-Norf, Germany). GSA is an independent organisation and was one of the participating laboratories in the recent European multicentre study on ubiquitous fibre exposure (Schneider *et al*., 1996). The use of the same laboratory and the application of the same standardized measuring methods should increase the comparability of the present results with those obtained in the Schneider et al. study.

In each factory, a control sample was taken in the open air away from the workplaces, but still within the premises of the factory. These control samples ranged from below the detection limit to 0.00485 f/ml with a median of 0.0007 f/ml. It should be mentioned that the conditions in the outside air are different from those within the factory: the humidity of the floor and the surfaces within the factory was generally lower than in the open air. Also, given the human and mechanical activities within the factory, the resuspension of deposited fibres of either industrial origin or from textile clothing may be higher than outside. Therefore, these outdoor background levels will be lower than indoor background levels and hence they can probably be considered safely as reflecting natural background data. Even so, the SEM measurements of organic fibres at the workplaces did not reveal markedly higher levels than these background levels: in our study the concentrations of organic fibres measured at the workplaces were in the range of 0.0011 to 0.0064 f/ml, with 4 out of the 22 samples falling below the detection limit.

From these 22 measurements, at least one sample in each factory (10 measurements in total) was taken at the fibre weighing station, where the PVA bales are opened and the fibres mechanically dispersed on a grill prior to dosing into the cement mixture. During this mechanical dispersion the fibres are still in a dry and free state and therefore, in terms of airborne PVA fibre generation, this was expected to be the location with the highest potential for airborne fibre release, in line with the previous experience with asbestos (Browne, 1994) or cotton (Takam and Nemery, 1988; Castellan, 1996). This was only the case at the weighing stations in two factories (A and D), where measurements showed the highest concentration of total fibres (0.0921 and 0.0587 f/ml, respectively) of which 0.0064 and 0.0048 f/ml, respectively, were identified as organic fibres. In factory A with the highest number of fibres, the measurement had taken place within the closed cabinet of the weighing station. Workers do not normally operate within this cabinet, except for maintenance work. In the other factories, the fibre weighing station measurements were taken at the place where the workers operate, i.e. immediately next to the weighing station at its orificium. Nevertheless, the organic fibre levels at these fibre weighing stations were still in the same order of magnitude as at the other work stations. That these levels were much lower than would be expected with asbestos fibres can be explained by the fact that PVA fibres are produced as filaments with a homogeneously large diameter and have no microfibrillar structure. They, therefore, lack the tendency of asbestos and other fibres to split lengthwise to form respirable fibres.

Once the fibres have passed the weighing station, they are mixed with water and cement slurry. In this wet state as well as in the final product, where the fibres are bonded with cement, the potential of airborne fibre release is less pronounced, except for operations where dry fibre-cement product is subjected to mechanical aggression, such as at the finishing machines. Therefore, among the locations selected for the other 12 air samples, the corrugated sheet sawing machine, the corrugated sheet demoulding machine and the slate cutting and edge riving machine seemed the most relevant. An additional reason for selecting these sites, was that workers work quite closely to these particular machines. Besides the personal samples ($N = 4$), the present study, however, used static air samples for the remaining measurements ($N = 8$) for machines, where workers come close for only a small proportion of their working time and static samplers can be placed much closer to the potential dust source at the respective machines. However, contrary to expectation, the personal measurements resulted, in three out of the four cases, in a higher concentration of organic fibres. This could be due to the fact that personal sampling considerably increases the probability and proportion of collecting organic fibres other than PVA stemming from the personal dust cloud of the workers. Recent studies have shown that a clothed person is surrounded by a personal dust cloud due to a combination of the resuspension of dust particles caused by the person's activities, convective air flow caused by the body warmth, and an air pumping action caused by the body's surface (Clayton *et al*., 1993; Ehrler and Liebert, 1998). As the scanning electron microscope (as well as the other available techniques) is unable to reliably identify or distinguish PVA fibres from other organic fibres, it is impossible to know the contribution of other organic fibres from the general environment (or possibly even the personal environment) to the results found here. A recent study showed that normal organic fibre levels (24 h-TWA) in the personal environment range from 0.007 to 0.025 f/ml, depending on the type of person and activity investigated, e.g. suburban schoolchildren, rural retired persons, office workers or taxi drivers (Schneider *et al*., 1996). The same study showed organic fibre levels in the general outdoor environment, as measured by SEM, ranging from 0.0005 to about 0.0037 f/ml. Draeger cites studies in which an average organic fibre level of 4000 f/m^3 (0.004 f/ml) to 'a few ten thousands of fibres per cubic meter' were found. According to the same source, typical background levels of asbestos fibres, gypsum fibres and other inorganic fibres are 100, 3000 and 2000 f/m^3, respectively (Draeger, 1998).

So far, no SEM-based scientific publications on PVA levels at the workplaces seem to exist. Of some importance are the levels mentioned by Morigana *et al*. (1999). However, these measurements concerned a PVA fibre production plant and fibre number concentrations were measured quantitatively by optical methods while SEM was used only for some qualitative investigations (Van Cleemput, 2000). Nevertheless, the levels mentioned in the Morigana study are low, notwithstanding the fact that in these phase contrast optical microscopy results all fibre types have been lumped together.

Polyvinyl alcohol fibres, as used in the fibre-cement production, are produced by an extrusion process (wet spinning) with nominal geometric diameters of 13.8 μm and above. The extrusion production process explains the highly constant diameter. Based on single fibre quality control measurements on thousands of representative samples, corresponding to all grades of PVA fibres used in the fibre-cement industry, the lowest observed diameter was 10.4 μm, and the highest 16.7 μm (unpublished data, Polyfibre S.A., Lausanne, Switzerland). Furthermore, in a recent study of Saito *et al*. (1999), in which different fibre types were tested for their tendency to fibrillate with a Niagara beater, PVA fibre types as used for fibre-cement showed damage in the forms of nodes but no fibrillation, while cellulose, acrylic and p-aramid fibres, as well as special purpose PVA fibres as used for rubber reinforcement, did show fibrillation after beating. Similarly, in a dry state fibrillation test with a ball mill, PVA fibres showed zero or only minimal fibrillation in contrast with p-aramid (Asada, 1999) and comparable results were found in a dry state stirring and abrasion test (Japan Spinners Inspection Foundation, 1999).

Recent outbreaks of interstitial lung disease (the 'nylon flock worker's lung') in nylon flock processing plants should render us aware that even supposedly innocuous materials can represent significant respiratory hazards if such agents are inhaled in substantial quantities (Kern *et al*., 1998; Eschenbacher *et al*., 1999). It appears that the nylon flock hazard originated from the mill, where fibres are dried and mechanically separated and from handling procedures in which respirable fibres or shreds of fibres were produced by rotary cutting as opposed to guillotine cutting (Kern *et al*., 2000; Burkhart *et al*., 1999). PVA fibres cannot be compared with nylon flock fibres with respect to their chemistry, physical dimensions or production process. In addition, in the fibre-cement industry, organic dust levels are orders of magnitude lower than with nylon flock processing. In the fibre-cement industry, PVA fibres are neither cut nor milled, but they are injected into the water–cement mix without mechanical alteration. A potential for mechanical alteration or damage of PVA fibres does exist when fibre-cement end-products are machined. However, the fact that measured organic fibre levels remained very low even where fibre-cement corrugated sheets are sawed, suggests that the potential of PVA to release particles with fibrous dimensions is low to very low.

We conclude from the present field study that PVA fibres have a low potential to release fibres with critical fibrous (WHO) dimensions. Their use in fibre-cement factories does not significantly increase the magnitude of the cumulative (personal and environmental) exposure of the workers to airborne organic (WHO) fibres.

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